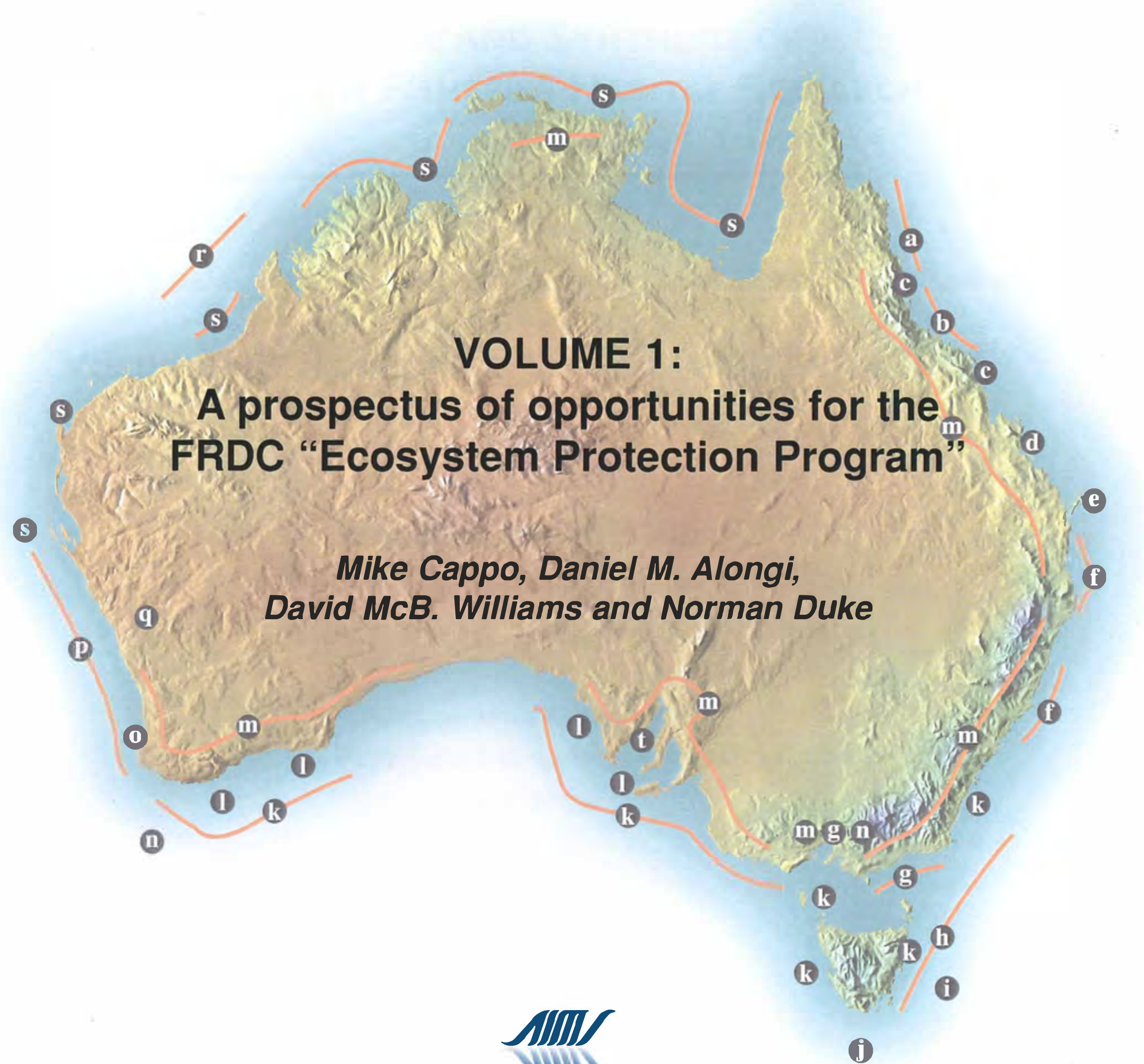
A Review and Synthesis of Australian Fisheries Habitat Research

Major threats, issues and gaps in knowledge of marine and coastal fisheries habitats



VOLUME 1:
A prospectus of opportunities for the FRDC "Ecosystem Protection Program"

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Australian Institute of Marine Science

Fisheries Research & Development Corporation

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A REVIEW AND SYNTHESIS OF AUSTRALIAN FISHERIES HABITAT RESEARCH

MAJOR THREATS, ISSUES AND GAPS IN KNOWLEDGE OF COASTAL AND MARINE FISHERIES HABITATS -

VOLUME 1: A PROSPECTUS OF OPPORTUNITIES FOR THE FRDC "ECOSYSTEM PROTECTION PROGRAM"

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95/055 A Review and Synthesis of Australian Fisheries Habitat Research

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Objectives

1. *To review and synthesise the available knowledge on Australian fisheries habitat research, in order to:*
2. *describe and evaluate the suitability and coverage of the areas of research priority identified at a scientific workshop convened by the FRDC in March 1994, and*
3. *prepare a prospectus of opportunities for the FRDC Ecosystem Protection Program.*

Non Technical Summary

This project was commissioned by FRDC. The task was to review and synthesise the available knowledge on Australian fisheries habitat research and on this basis:

- *describe and evaluate the suitability and coverage of the areas of research priority identified at a scientific workshop convened by the FRDC in March 1994, and*
- *prepare a prospectus of opportunities for the FRDC Ecosystem Protection Program.*

The priority issues and impacts reviewed were:

1. *natural dynamics in fisheries habitats and environmental variability*
2. *changes to drainage and habitat alteration*
3. *nutrient and contaminant inputs*
4. *effects of harvesting on ecosystems and biodiversity*
5. *introduced and translocated pests and diseases.*

To obtain this information we conducted a formal literature search and interviews with informants from key organisations in all States and Territories in 1995-96.

The results have been prepared as a detailed scoping review (Volume 2) describing the issues, knowledge gaps and impacts, and proposing more than 60 R&D opportunities. These R&D themes, issues have been summarised as a prospectus here in Volume 1. Sources of citations are provided in Volume 3, and the full bibliography will be linked (HTML) with the scoping review for access on the Internet.

There are five strategic questions common to all issues and impacts:

1. *What are the major habitats of the coastal fringe and Exclusive Economic Zone and where are they located?*
2. *What is the role of these habitats in providing and maintaining fisheries production?*
3. *What is the role of these habitats in maintaining ecosystem integrity and biodiversity as a basis for long-term ecosystem health, and what are suitable indicators and monitors of this health?*
4. *What are the natural dynamics of the major marine habitats, and how are they affected by the fishing and aquaculture industries and other human activities?*
5. *What linked mitigation, monitoring, scientific assessment, and management strategies will provide the habitat protection necessary to achieve ecologically sustainable development of fisheries and aquaculture?*

In pursuing a ranking of R&D priorities for the given issues and impacts we found that:

- *natural dynamics in fisheries and habitats and environmental variability underpin all the other human impacts in fisheries habitat research. Without better understanding of this issue, there are uncertainties in identifying human-induced effects to help develop appropriate management strategies*
- *the major threats and disturbances are clearly specific to region and habitat type, and must not be considered in isolation - they are linked and interact with one another in coastal zones to aggravate habitat degradation*
- *there are generally high risks perceived for the anthropogenic disturbances, but the effects and impacts, or hazards, are often poorly documented – specially for introduced pests and diseases*
- *ultimate causes of many disturbances in the coastal zone are outside the direct sphere of influence of the FRDC and its stakeholders - but there is much common interest with many other agencies in addressing them*

- *the FRDC will have the lead role in providing R&D for the various effects of aquaculture and harvesting on fisheries habitats - these are not limited to the widely publicised bycatch and benthos damage in some trawl fisheries.*

The major anthropogenic disturbances to fisheries habitats are clearly from urbanisation, land and freshwater use, and introduced pests and diseases in the coastal zone and from fishing in shelf and slope waters. Many of these disturbances are relatively localised and often amenable to mitigation or rehabilitation. Introduced pests and diseases, however, pose wider long-term threats because eradication is unlikely and spread can be wide and rapid.

The causes and impacts on fisheries habitats of several types of disturbance are relatively well understood in some locations. These include some downstream effects of land use and effluent disposal that are beyond the immediate responsibility of the FRDC and its stakeholders, including:

- *effects of nutrients from effluents and runoff on some temperate seagrass and estuarine ecosystems*
- *effects of barriers on fish migration in coastal rivers and of floodgates on water quality and access by fish and tides in NSW.*

There is evidence that habitats recover and fisheries production is improved after the sources of such stress are removed or reduced. In such cases, the challenge lies in providing R&D that can achieve better outcomes for fisheries by:

- *extending the results of fisheries R&D into the local planning and management of development and wastewater disposal*
- *developing, implementing and monitoring the success of rehabilitation and restoration of key degraded habitats.*

Resolution of these problems requires multi-disciplinary R&D and extension outside the suite of ecological expertise usually invested in by the FRDC to translate research into action. We believe that this will be best achieved in close coalition with the R&D Corporations and Cooperative Research Centres who supply R&D to the users of land and water resources.

All forms of commercial and recreational fishing and aquaculture have some risk of affecting surrounding habitats, often including those that sustain them. The FRDC "Effects of Trawling" sub-program is addressing some of the major concerns, but the FRDC will also provide the lead role in identifying, assessing and minimising the effects of all other forms of harvesting *and aquaculture. These include a poorly acknowledged role of industry in the introduction and spread of pests and diseases.*

Key uncertainties exist concerning both the relative values of fisheries habitats and the effects of human disturbances at both regional and local scales. Strategic R&D is needed to overcome the poor ability to predict and; manage such impacts, including:

- *collection, integration, interrogation and extension of new and existing fisheries and habitat data at scales useful to management - what habitats and links should be conserved and rehabilitated, where they are located, and what are the key threats on a regional scale?*
- *proactive incorporation of this information in plans for regional development*
- *comprehensive research on life histories of important aquatic plants, benthic communities and fished species*
- *identifying the effects of fisheries of key pests and diseases, and developing vigilance to avoid new introductions*
- *strategic linkages of the FRDC research with major landscape-scale environmental studies to add fisheries value to multi-disciplinary research on processes determining structure, function and variability in key habitats*
- *helping develop question-driven monitoring of estuaries and coasts to distinguish the effects of past or unavoidable habitats changes and disturbances on fisheries values at long time scales - an emphasis on monitors that help identify sources of stress is needed.*

The impacts that are well known, tactical R&D is required to mitigate and manage the effects, including:

- *development and maintenance of inventories of key threatening structures and processes to determine priorities for action and educate other coastal resource users*
- *application of adaptive research and management of rehabilitation techniques and approaches*
- *monitoring and publicising fisheries performance of management interventions and rehabilitation*
- *development of surveillance and management techniques for pests (eg. dinoflagellate blooms), diseases and contaminants that assure quality of harvests*
- *development of "environmentally friendly" fishing gear and practices, including programs aimed at reducing spread of pests and diseases.*

To extend the FRDC sphere of influence beyond fisheries stakeholders there is a strategic need for the FRDC Ecosystem Protection program to strengthen existing links with the habitat research and protection activities of Environment Australia, the Land and Water Resources R&D Corporation, the Diary, Sugar and Grazing R&D Corporations, and the Australian Quarantine Inspection Service. There is also a need to align R&D priorities with those of the various networks that advise on regional research priorities, such as the Fisheries and Environment Health Committee and the Centre of Research on Introduced Marine Pests.

Because of the inter-connected nature of fisheries habitats, the need to take a regional and ecosystem- or landscape-based approach to fisheries habitat research is critical. Environment Australia's "Interim Marine and Coastal Regionalisation for Australia" (IMCRA) provides a good starting point for integrating information on the relevant boundaries of coastal fisheries ecosystems, fisheries production and key anthropogenic disturbances.

Marine parks, reserves and spatially-based management plans in general, provide both a challenge and an opportunity for fisheries R&D. If the appropriate knowledge of fisheries habitats and dynamics is available and is part of the planning process, protected areas could potentially provide a strong basis for fisheries habitat protection. If the data to optimise the fisheries value of marine protected areas and Multiple Use Management plans in cases where there is conflict with the goals of other users.

Keywords

Ecosystem Protection Program, environmental impacts, fisheries habitats

Glossary

Our use and definition of the jargon used in the review, and listed below, is derived primarily from Harden-Jones (1994).

aquaculture and mariculture - land-based or sea-based pond, cage, rack, and rope culture and rearing of hatchery-reared or wild stocks of freshwater or saltwater ("mariculture") fishes, crustaceans, molluscs and algae

biodiversity - refers to the variety of life on earth. Three levels of biological organisation, genetic, species and ecosystem, are reflected in a widely used hierarchical three-tiered description of biological diversity.

bycatch, byproduct and discards - species taken in fishery targeted on other species, or on a different size range of the same species. The part of the bycatch which has no commercial value ("byproduct") is discarded ("discards") and returned to the sea, usually dead or dying.

coastal zone - "the landward boundary is the line beyond which events have only an insignificant or trivial effect on the resources and amenities of the coastal zone which extends seaward to the line beyond which the resources and amenities are insignificantly or trivially affected by events along the coastline" (Harden-Jones 1994).

conservation - the planning and management of resources so as to secure their wise use and continuity of supply while maintaining and enhancing their quality, value and diversity.

contaminant - a substance or energy introduced directly or indirectly into the environment by human activities

ecologically sustainable development (ESD) - using, conserving and enhancing the community's resources so that the ecological processes on which life depends, are maintained, and the total quality of life, now and in the future, can be increased.

ecosystem - systems of plants, animals and micro-organisms together with the non-living components of their environment. No ecosystem is a closed system and the precise meaning of the term varies according to the context.

environment - the conditions under which an organism lives, thus including all living or non-living factors and the activities of humans

fisheries - used here to include all commercial and recreational fisheries and aquaculture, elsewhere as "the business of catching fish, or of taking other products of the sea or rivers from waters often specialised"

fisheries habitat - natural and artificial habitats that support directly or indirectly the production, capture or culture of species of interest to fisheries.

habitats - the sum total of the environment of a species. May be referred to in the review as being dominated by particular plants (eg. seagrass habitats), or occurring in particular locations (eg. shelf habitats).
hazard - used here as the nature and degree of loss, harm, injury, effect, and impact of an anthropogenic disturbance.
indicator and biomonitor - that which points out, or directs attention to, something. Anything used in a scientific experiment (or survey) to indicate the presence of a substance or quality, change in a body (or habitat). "Biomonitors" refer in our review to indicators that interrogate living organisms to infer the nature, proximity and source of stressors.
landscape - a cluster of interacting ecosystems.
large marine ecosystems (LMEs) - regions with unique hydrographic regimes, submarine topography and trophically-linked populations.
marine protected area (MPAs) - intertidal or subtidal terrain, together with its overlying water and associated flora, fauna, historical and cultural features, which has been reserved by law or other effective means to protect part or all of the enclosed environment.
mitigation - alleviate, reduce severity of disturbance.
risk - used here as the degree of probability of loss or exposure to hazards associated with anthropogenic disturbances.
stakeholder - one who has an interest in an outcome rather than in passively holding the stakes.
tactical and strategic - used here as R&D that is undertaken to answer a specific question so that a management decision can be taken ("tactical"). "Strategic "R&D provides the foundation for tactical research and addresses fundamental uncertainties. It combines scientific freedom and flexibility with relevance to long-term goals.
threat - used here as the subjective total of "risk" plus "hazard".

Introduction

Background and Need -- The FRDC Ecosystem Protection Program

The goal of the FRDC Ecosystem Protection Program is to protect the Australian ecosystems upon which fisheries and aquaculture depend, through investing in the following key areas:

- *Ecosystems Status – R&D that will increase knowledge for the protection of ecosystems, including: interrelationships between fish and their environments; impacts of fishing, aquaculture and other marine and land use; biodiversity; fish health; and impacts of exotic organisms.*
- *Ecosystems Maintenance and Improvement – R&D that will maintain and improve ecosystems, including: protecting, restoring and enhancing habitat; reducing bycatch and impacts on other non-target flora and fauna; and enhancing wild fish resources.*
- *Ecosystems Management Improvement – R&D that will help to develop and evaluate ecosystems management, including: developing systematic approaches to ESD; determining impacts on ecosystems; and regulating access to ecosystems.*

A scientific workshop was held by the FRDC in March 1994 to clearly identify and prioritise major research needs across these three key areas for coastal marine habitats and their relationship with fisheries resources (see Williams and Newton 1994).

The impacts and issues were ranked by Williams and Newton (1994) in descending order of priority for R&D as:

1. *Natural dynamics*
2. *Modification of nearshore, estuarine and wetland habitats*
3. *Effects of fishing*
4. *Change in drainage*
5. *Introduction of marine pests*
6. *Nutrient inputs.*

The workshop consensus was that research is needed in order to reduce uncertainty concerning questions where a reduction of uncertainty is both possible and helpful:

- *to improve our scientific understanding of the values of coastal habitats for target species, and how changes in habitats might affect dependent species,*
- *to improve the application of existing and new knowledge to the decision making processes of managers.*

Objectives

These key areas and general statements of research needs immediately posed the following more specific questions for the FRDC:

- *what are the various risks and hazards that combine to form the threat of these impacts?*
- *what relevant scientific research has been done or commenced in Australia?*
- *what specific R&D approaches and projects could be considered as opportunities for FRDC investment to address these issues and impacts?*

In 1995 we were commissioned by the FRDC to address these questions by assembling, reviewing and synthesising Australian literature and knowledge on fisheries habitat research, in order to :

- *describe and evaluate the suitability and coverage of the areas of research priority identified by Williams and Newton (1994), and*
- *prepare a prospectus of opportunities for the FRDC Ecosystem Protection Program.*

We interpreted this brief by structuring our scoping review directly around the major issues and impacts, and expanding on them to provide detailed Australian perspectives from various scientific, regional and fishery-specific viewpoints. We chose to take the broadest view possible of issues relevant to fisheries ecosystems but, because of the location of most human activity, the review is focussed on coastal habitats from freshwaters in lower catchments to the mainland continental shelf. Our use of the term "fisheries" applies to commercial and recreational fisheries and all forms of aquaculture, and our definition of "habitat" encompasses the physical, biological and ecological relationships supporting fisheries.

This is an ambitious goal, but we believed there was most benefit in describing for the FRDC the wide range of impacts and R&D issues relevant to the Ecosystem Protection Program – in any case the lack of Australian literature and information for most of the issues and impacts prevented us from producing definitive treatises on any one subject. We also sought to cast *our scoping review of the impacts in the context of an appropriate description of the Australian coastal environment and its major forcings and processes.*

Methods

Using key words and their derivatives from the six issues and impacts identified by Williams and Newton (1994), we searched for Australian literature by:

- *on-line searches of the contents of the major research databases until September 1996 – Aquatic Sciences and Fisheries Abstracts (ASFA), the Australian Bibliography of Agriculture (ABOA), the Australian Rural Research in Progress database (ARRIP) and "Streamline"*
- *consulting FRDC project reports and proposals*
- *searching the back issues of major journals dealing with marine habitats and fisheries biology*
- *searching freshwater, marine and coastal Internet pages through the links provided by the Environmental Resources Information Network (ERIN)*
- *requesting copies of manuscripts in progress, reprints and reference lists from informants contacted in the interview phase (see below)*
- *writing to the Australian university departments and libraries of the State institutions most active in marine research to seek lists of relevant theses, reports and publications.*

The results of these searches were downloaded electronically or entered manually into an annotated bibliographic database ("Procite" version 3.1). A bibliography of more than 2000 records was short-listed and edited with key words from about 7000 records retrieved in searches. Reprints and hard-copies of over 600 of these publications and reports are indexed and housed at AIMS, the entire bibliography has been prepared for mounting on the Internet, and the citations of the bibliography appearing in Volume 2 have been listed in Volume 3 of this report.

To capture unpublished initiatives, manuscripts and reports, all States were visited in late 1995 and relevant conferences were attended in 1995 and 1996. A list of informants for the review was drawn up from the authors listed in search results, and by consulting the Fish Habitat sub-committee of the Australian Society for Fish Biology and the Fisheries Environment and Health Committee (FEHC) advising the Commonwealth Standing Committee on Fisheries and Aquaculture.

These interviews and conferences produced information from 220 researchers and managers from all States and Territories, covering 62 research and environmental management organisations. Notes from these verbal communications were assembled on an annotated electronic database ("Procite" version 3.1). These staff are summarised by organisation and subject in Appendix 7 in Volume 3 of this report.

Finally, the FRDC Executive (February 1997) and FRDC Board of Directors (June 1997) reviewed drafts of our results to align our review of R&D gaps and opportunities with the "core business" of the FRDC, and six external reviewers provided critical input to the final draft of the entire scoping review.

Results

Our review found that the priorities derived from the FRDC scientific workshop on fisheries habitat issues and impacts were comprehensive and useful. Like Williams and Newton (1994) we conclude that diverse gaps in knowledge of natural dynamics in both fisheries habitats and fished stocks creates much uncertainty in distinguishing and predicting the effects of anthropogenic disturbances. The issue of natural dynamics in fisheries habitats and environmental variability therefore appears first in our scoping review and underpins interpretation of the human impacts.

We found that some of the impacts identified by Williams and Newton (1994) could be amalgamated for more efficient review here by considering together "changes to drainage and alteration to habitat" and "nutrients and contaminants". This is because these impacts:

- *often occur together – eg. urban sewage always contains contaminants as well as nutrients*
- *can aggravate one another and act together – eg. "changes to drainage" almost invariably modifies coastal habitats, and the culmination of various disturbances in some habitats is the firm establishment of introduced pests and diseases.*

Most importantly we found that the threats posed by the various anthropogenic disturbances are clearly specific to region and habitat type in Australia, so generic statements about the relative impact of separate classes of disturbance are not warranted. Furthermore, the threats themselves are poorly known – whilst the risks of impacts on fisheries and habitats are generally perceived to be high, the actual effects, or hazards, are often poorly documented or cannot be predicted with any certainty. Therefore, any simple ranking of R&D priorities became subjective and problematic.

Instead, we chose an order of review to reflect the underlying importance of natural dynamics, and the logical connections and synergies amongst human impacts. This culminated in our scoping review chapters as:

1. *natural dynamics in fisheries habitats and environmental variability*
2. *changes to drainage and habitat alteration*
3. *nutrient and contaminant inputs*
4. *effects of harvesting on ecosystems and biodiversity*
5. *introduced and translocated pests and diseases.*

Using this review

To make the results as accessible as possible we have structured this report at two levels of synthesis below the executive summary. At the most detailed level we have assembled, reviewed and synthesised the scientific information in the scoping review (Volume 2) to produce summaries of over 60 specific R&D gaps – as opportunities for action by the FRDC and the scientific community. These numerous specific opportunities have then been drawn together and summarised here in Volume 1 as a more general prospectus for consideration by policy makers and industry. They range from broad disciplines and common R&D themes that we identified across issues and impacts, to quite specific R&D projects relevant to single impacts.

To complement the scoping review – which is strictly based on the five issues and impacts — we have based further summaries of R&D issues in three different permutations here in Volume 1:

- *by following the State of the Environment Reporting framework (SOER 1996)*
- *by broad geographic location on "hazard maps"*
- *by broad habitat types.*

However, these are not meant to be fully comprehensive or self-explanatory – the five chapters in the scoping review fulfil these needs by adhering to a specific structure for each issue and impact that give:

- *an overview describing the causes, symptoms and key uncertainties*
- *a short classification and summary of key literature to define themes of past research*
- *a tabulation of specific R&D gaps and opportunities for action by FRDC with habitats and fisheries affected, key references and related initiatives*
- *detailed review and synthesis of the scientific literature and information on causes, symptoms, key uncertainties and R&D opportunities.*

Throughout the scoping review we refer to personal communications from the informants, to FRDC projects and final reports and to tabulations of scientific literature. These are fully referenced in the bibliography and information sources (Volume 3) and in appendices at the end of the scoping review (Volume 2).

All three volumes can be downloaded as portable document format (.PDF) files from an Internet site on the AIMS home page at http://www.aims.gov.au/pages/research/AFHR/AFHR-00.html

The scoping review and bibliography (Volumes 2 and 3) are also being prepared for cross-referencing (HTML) on the Internet and will be accessible through both the AIMS site and the FRDC home page at http://www.frdc.com.au/home.html

A Prospectus of Opportunities for the "Ecosystem Protection" Program - R&D Gaps, Threats to Habitats and Responses; Priorities, Approaches and Outcomes

Since the FRDC Ecosystem Protection Program concerns national environmental issues, we have chosen to broadly adopt the "Pressure-State-Response" model used in Australia's State of the Environment Report (SOER 1996) as the first framework for summarising our findings in Tables 2, 3 and 4.

In this framework, "State" is defined as the "state or condition of the environment", "Pressures" are human activities and impacts, and "Response" refers to institutional and individual responses. In the SOER, Pressures are restricted to human activities and impacts, but – because of the enormous impact of natural and environmental variability in fisheries and habitat dynamics – we chose to also include it as a Pressure in tabulations.

The common themes from more than 60 specific, issues-based recommendations for FRDC action that we have identified in the scoping review (Volume 2) have been drawn together and described in Tables 2, 3 and 4 across broad habitat groupings. Major R&D issues and gaps in knowledge of State of fisheries habitats and threats to these habitats (Pressures) are summarised and described in Tables 2 and 3. General issues related to the Responses needed to address Pressures on fisheries habitats are described in Table 4.

These tabulations are the background for the recommended R&D approaches and outcomes for these problems that we propose in Table 1.

The challenges

As more than one reviewer has commented, although perhaps 90% of Australia's EEZ covers waters more than 20m deep, the emphasis and detail of this review concentrates on coastal fisheries and habitats in waters generally shallower than 20m. This reflects both the issues-based approach of the review, the lack of literature found in our searches and the feedback from our extensive interviews with researchers and managers throughout the country. Put simply, and exemplified by Figures 1- 5, most of the known human impacts occur along the coastal fringe – especially near concentrations of population and freshwater resources.

Australia's offshore habitats are generally poorly known and understood and will bear the brunt of any future expansion in Australia's harvest fisheries. Habitat research in these areas is crucial and requires relatively large sources of funding because of the general remoteness of the habitat and need for ships. The major issue there is one of a general lack of data and systematic observations. Of the issues reviewed by us, understanding natural variability is critical everywhere including offshore waters. Effects of harvesting are also important in many offshore areas and have been highlighted here but the other pressures on fisheries habitats are primarily concentrated in the coastal zone. Our review revealed not only extensive issues in the coastal zone but also issues of considerable urgency.

We conclude – as do the major recent Australian environmental reports (eg. Resource Assessment Commission (RAC 1993), State of the Marine Environment Report (Zann 1996), State of the Environment Report (SOER 1996)) — that integration of information and effort among researchers, managers and industry is of utmost importance. Coastal zone problems are a classic case. The nature of hazards and risks in coastal catchments causes conflict in assigning responsibility for habitat degradation amongst stakeholders in catchment management and greatly dilutes the impact of fisheries R&D. Resolution of these problems requires multi-disciplinary R&D and extension outside the suite of ecological expertise usually invested in by the FRDC. Scoping reviews such as the recent report by Webbnet (1996) for northern NSW floodplains are an essential pre-requisite to targeting R&D in the coastal zone.

In response to these problems there is an urgent, strategic need for the FRDC to link its Ecosystem Protection Program with the habitat research and protection activities of Environment Australia, the Land and Water Resources R&D Corporation and the Dairy, Sugar and Grazing R&D Corporations. There is also a need to align R&D priorities with those of the various networks that advise on regional research priorities such as the Fisheries and Environment Health Committee (FEHC) and the Centre for Research on Introduced Marine Pests (CRIMP) (see Appendices 1 and 2 in Volume 2 for FEHC role and priorities).

The greatest, over-riding challenge facing the FRDC and its stakeholders with all the downstream effects of agriculture and development is to identify and implement better ways to transform scientific expertise and knowledge into information relevant to natural resource management – and to ensure this information produces outcomes that safeguard fisheries values. This strategic need is a common goal amongst all the R&D organisations. In the first instance coalitions should be formed, and the next priority could be to invest in studies of where the FRDC can best channel R&D. That is, are there existing vehicles for action "on the *ground" to achieve outcomes – such as integrated catchment management committees, landscape scale modelling initiatives in bays and estuaries, adaptive environmental assessment and management approaches in catchments?*

In contrast, the FRDC will have the lead role in R&D on the shelf waters and beyond where effects of harvesting – on benthic communities, on food chains by predator and baitfish removal, and on bycatch species (some of them endangered or threatened) – are the prime anthropogenic disturbance. Many of the fished species recruit directly to these deeper habitats, there are high levels of endemism and important resources for conservation of biodiversity, and links to coastal resources and disturbances are weak.

A further challenge still lies with extension of the fisheries and habitat information to allow wider interrogation and use. The present narrow focus of fisheries R&D extension within the industry is not spreading wide enough to be of best use in management of coastal resources. Projects within Environment Australia's programs, such as the National Marine Information System (NatMIS), should be reviewed as potential vehicles for integrating much of the fisheries habitat information at the national scale.

The Priorities for R&D

Opportunities for the FRDC Ecosystem Protection Program include the need for both tactical and strategic R&D. Some problems - various blockages to fish passage in coastal waters for example - are so well known that appropriate responses are clear and tactical R&D is required. Other pressures require strategic R&D to assess threat and response.

Our recommended mix of strategic and tactical R&D ("Approaches") is summarised for each major issue and impact ("Priorities") in Table 1 with examples of outcomes.

In broad strategic terms there are five main questions that are common to all issues and impacts in our review. These could be included in the national strategic directions for the Ecosystem Protection Program as:

1. *What are the major habitats of the coastal fringe and Exclusive Economic Zone and where are they located?*
2. *What is the role of these habitats in providing and maintaining fisheries production?*
3. *What is the role of these habitats in maintaining ecosystem integrity and biodiversity as a basis for long-term ecosystem health, and what are suitable indicators and monitors of this health?*
4. *What are the natural dynamics of the major marine habitats, and how are they affected by the fishing and aquaculture industries and other human activities?*
5. *What linked mitigation, monitoring, scientific assessment, and management strategies will provide the habitat protection necessary to achieve ecologically sustainable development of fisheries and aquaculture?*

Strategic R&D is needed to overcome poor ability to predict impacts of disturbance on fisheries production by, for example :

- *complementing stock assessments with mapping and monitoring of the ecosystems supporting fisheries*
- *mapping the location and severity of human disturbances to fisheries habitats to identify R&D needs and assist planning of coastal resource use*
- *integration and extension of existing fisheries and habitat data at scales useful to management and to investigate and monitor fisheries-habitat links*
- *comprehensive research on life histories of important species – particularly early stages of coastal species when recruitment to habitats is occurring*
- *research on effects and transmission of key introduced pests and diseases that threaten fisheries, and development of technologies, industry best practice, risk assessment and surveillance procedures to prevent further spread and new introductions*
- *strategic linkages of the FRDC research with major landscape-scale environmental studies*
- *helping develop suitable indicators of fishery health and question-driven monitoring of estuaries, coasts and other sub-tidal habitats to detect the effects of habitat changes and measure the success of management interventions.*

The need to take a regional and ecosystem or landscape-based approach to fisheries habitat research is critical. Such an approach is required by the National Strategy for Ecologically Sustainable Development; provides a framework to identify gaps in knowledge and set priorities (Thackway and Cresswell 1996); encompasses all the ecological processes required for Ecosystem Protection and avoids the creeping effects of many separate modifications of habitat.

Environment Australia's "Interim Marine and Coastal Regionalisation for Australia" (IMCRA - see section 1.2.3 of Volume 2) provides the best available starting point for identifying appropriate spatial boundaries to both the location of key fisheries habitats and the nature and severity of pressures on them. This would be a firm basis for planning R&D in the Ecosystem Protection Program.

IMCRA exists primarily to be the regional framework for the proposed National Representative System of Marine Protected Areas (NRSMPA - see section 1.2.3 of Volume 2) - a system due to be implemented by the year 2000. One of the key objectives in establishing NRSMPA is:

"to protect and manage substantial examples of marine and estuarine systems to ensure their long-term ecological viability and to maintain biological biodiversity at all levels" (Thackway and Cresswell 1996).

Marine parks, reserves and spatially-based management plans in general, provide both a challenge and an opportunity for Fisheries R&D. If the appropriate knowledge of fisheries habitats and dynamics is available (eg. inventories of fisheries habitat values and knowledge of "sources" and "sinks" of recruitment) and is part of the planning process, protected areas could potentially provide a strong basis for a national fisheries habitat protection strategy. If the data and relevant research are not available or not included in planning processes, it will be impossible to optimise the fisheries value of marine protected areas and multiple use management plans in cases where there is conflict with the goals of other users.

Some pressures on fisheries habitats – such as the effects of barriers on fish migrations and destruction of benthos by trawlers – have been known for several decades. For them, tactical R&D is required to:

- *develop and maintain inventories of key threatening structures and processes*
- *develop and implement frameworks to determine priorities for action*
- *apply adaptive research and management of rehabilitation techniques and approaches*
- *monitor and publicise fisheries performance of management interventions and rehabilitation*
- *development of surveillance and management techniques for pests (eg. dinoflagellate blooms), diseases and contaminants that assure quality of harvests*
- *develop "environmentally friendly" harvesting gear and practices.*

Tactical R&D must be couched in catchment-scale initiatives for coastal issues, with close focus on outcomes with those industries sharing the costs and benefits of habitat degradation. Whilst habitat rehabilitation through restoration of tidal flow, for example, seems both highly attractive and feasible from a fisheries viewpoint the alterations to hydrology could produce some conflicts with other stakeholders, mosquito control and wildlife conservation.

There are no "magic bullet" approaches to fisheries habitat research. Some of the basic information required is "simply" descriptive – although not necessarily easy or inexpensive – such as mapping habitat inventories and determining early life histories. Overall, however, we suggest that the approaches most likely to provide major insights ask clear questions (erect appropriate hypotheses), are couched in regional perspectives and include one or more of the following approaches:

- *powerful experiments*
- *modelling frameworks*
- *studying effects of unavoidable loss through modification*
- *monitoring the performance of management intervention and rehabilitation.*

THE R&D ISSUES

Key R&D issues and gaps in knowledge of "State" of fisheries habitats and their links are described in Table 2. The key R&D issues and hazards of "Pressures" on fisheries habitats are listed and described in Table 3, and the general "Response" needed to address these pressures through conservation and protection, restoration and rehabilitation is outlined in Table 4.

Here we give a brief overview describing the issues and threats, with reference to "hazard maps" giving a geographic introduction – by no means comprehensive or spatially accurate – to notable examples of "Pressures" on fisheries habitats and production.

A) State

Major issues of "State" include lack of knowledge of :

- *nature and location of fisheries habitats at scales useful for research and management*
- *habitat dynamics and ecosystem processes*
- *links between different habitat types through nutrient and energy flow*
- *fisheries-habitat links*
- *life history information for both fished species and important components of the habitat, such as aquatic vegetation and benthic invertebrates.*

Regional-scale integration of fish and habitat data is critical, but generally (across all habitats) one or both of the data sets is unknown or unpublished – or if available, neither is integrated at the appropriate scale. A general lack of knowledge of life histories is also common across all habitats – mainly for early stages in coastal habitats, but for all stages in deeper shelf waters. Other priority R&D issues of "State" vary considerably across the different habitats (Table 2). In general terms we must know where and what must be conserved for sustainability of fisheries and mariculture, before we determine why and how to do it – the knowledge base is generally inadequate.

Habitat inventories are particularly required for rocky coasts and reefs and the continental shelf and large gulfs - the two habitats supporting the most valuable commercial fisheries. A priority need for better information on life histories of fishery targets and major bycatch species is highlighted - particularly early life histories for estuaries, bays and trawl grounds (habitats supporting major commercial and recreational fisheries) and for the continental shelf. The need for a better understanding of habitat processes and dynamics is highlighted for all major habitat types – testable paradigms about fisheries production exist only for temperate seagrass. Estuaries are defined by the interface between fresh and salt water but there is a surprising lack of knowledge of the role of freshwater in estuarine processes and fisheries production. Relative to their fisheries value, overall gaps in knowledge are particularly outstanding for the continental shelf (and slope), followed by rocky coasts and reefs (Table 2). Perhaps least studied in Australia are the nursery role and biological processes of sandy shores.

The concept of a "critical chain of habitats" with shifts between several habitat types as the fish matures may be most useful for Australian species important to fisheries, yet basic life history information is still lacking for many species. Furthermore, lack of knowledge of the *relative contribution to fisheries of nurseries and spawning grounds throughout many species' ranges hampers better valuation and protection of some regions.*

B) PRESSURES

Australia's ocean and atmospheric climate and geomorphology are dominated by extreme events and gradients that produce major effects of the environment on fisheries habitats and fisheries production. These natural dynamics are poorly understood for most habitats. Major anthropogenic disturbances to fisheries habitats are clearly from land-use and urbanisation in the coastal zone and from the effects of fishing in shelf waters (Table 3). The major coastal zone problems are often amenable to conservation and rehabilitation approaches and are of high priority (R&D Approaches to each Pressure are proposed in Table 1 and general Responses are outlined in Table 4). However, the greatest long-term threat may come from introduced pests and diseases for which the likelihood of spread is high, control or management is very expensive and the chances of eradication are minimal. The knowledge of effects of some of the most visibly abundant, notorious pests is poor, but studies are in progress. Overseas invasions of such pests indicate that vigilance is required to safeguard fisheries and aquaculture.

Changes in drainage, habitat destruction and degradation, nutrient inputs, contaminants and introduced pests and diseases are all diverse and major pressures on coastal and aquaculture environments. They are usually interlinked and effects are often cascading. For example, sewage inputs of nutrients are always accompanied by contaminants, and introduced pests apparently gain firm establishment in disturbed areas. The diversity of pressures is highest close to centres of urbanisation, but even in remote areas a widespread and growing threat to fisheries habitats in estuaries and coastal streams is freshwater diversion and blockages to access by tides and aquatic fauna and flora.

Natural dynamics in fisheries habitats and environmental variability

Climatic cycles, driven by the El Nino-Southern Oscillation (ENSO) or other factors, affect sheltered waters principally via flood and drought and on waters further offshore by modifying current patterns, vertical structuring of water bodies, production cycles and water temperature. Notable coastal habitat types, such as tropical and estuarine seagrasses can change relatively rapidly in extent and community composition within and amongst years due to seasonal and episodic factors such as cyclones and floods.

The fished stocks themselves vary widely in abundance -- variability in recruitment, sometimes correlated with environmental factors, is a feature controlling production of several important fisheries. Natural outbreaks of disease and of populations of herbivores and corallivores (eg. sea urchins and crown-of-thorns starfish) can also modify ecosystems at important scales.

A better understanding of this natural variability is critical to determining whether variations in habitats and fish production is due to anthropogenic or natural factors.

Changes to drainage and alteration of habitat

Freshwater flows define estuarine conditions when they meet the sea – yet the links with estuarine processes and coastal fisheries production are poorly known – the implications of an increasing trend in freshwater diversion and river regulation need further research to safeguard fisheries values. Variability in rainfall requires Australia to impound more than twelve times the amount of freshwater (per capita) as similar latitudes in the United States of America, and the growth in demand for freshwater before it reaches the coastal zone poses a variety of threats to estuarine processes and fish production.

There have been widespread changes to the access of the tide in many estuaries – even those remote from intense catchment use – and disruption of fish life-histories and alienation of estuarine nursery habitats have resulted. In some catchments there have been gains in mangrove cover, sometimes at the expense of saltmarsh or freshwater wetlands, and sometimes in the form of thick stands where once fringes stood. Natural dynamics in estuarine in-filling have been implicated but here have also been instances of changes in tidal prism induced by human activities in dredging channels.

Land-use behind some of these tidal barriers has resulted in exposure and drainage of sulphuric acid, de-oxygenation and other water quality problems when lower catchments are flushed. The modified wetlands are havens for aquatic weeds, invasive pasture grasses and other pests. The alienation of habitat and changes to wetlands disrupt the life cycles of some major finfish species. The broad geographic locations of notable instances and symptoms of some of these disturbances are shown in Figure 1.

Nutrient and contaminant inputs

Nutrient and sediment inputs from sewage and stormwater effluents and agricultural run-off have had major effects on the sources of primary production at large scales in some important estuaries and sheltered waters (see Figure 2). In turn, the nutrient pathways to secondary consumers and fisheries have been fundamentally altered and water quality has declined in these areas. At some stages in this process fisheries production may have been enhanced, but as the cycle progresses towards eutrophication there are invariably negative effects on fisheries of de-oxygenation and loss of habitat. At much smaller scales there is concern that wastes from mariculture must be managed to prevent sea-floor souring and reductions in water quality.

Contaminants invariably accompany nutrients to a greater or lesser extent in sewage inputs, and metals have caused local problems in the vicinity of major refineries or industrial sites through bioaccumulation (see Figure 3). In the case of tributyltin and some metals there have been relatively rapid improvements in tissue levels of sentinel organisms when the sources of pollution are removed or diminished. Closures in some locations to harvesting of contaminated fish and shellfish have resulted, but the wider ecological effects are largely unknown and reviews and monitoring of the overall Australian situation are lacking.

Mosquito larvicides are sprayed onto coastal wetlands and may be a threat to early life history stages of crustaceans and fish, yet lack of knowledge about the relationship between laboratory testing and actual field toxicity of these pesticides typifies much of the uncertainty about the threat posed by organochlorines and hydrocarbons in fisheries habitats.

Despite some major, well-documented changes to water quality and losses of aquatic vegetation known to have high fisheries values, Australian science has frequently found no definitive links with decline in fisheries production. This in part may be due to the nature of the disturbances to date – an intermediate disturbance, such as widespread seagrass dieback into a mosaic of patches, may produce in the short-term of study an increase in abundance and diversity. However, it would not be prudent to presume a linear relationship between habitat loss and fisheries decline.

It is well known that maintenance of water quality is fundamental to mariculture production, yet there may also be a link to prevention of algal blooms that harm entire ecosystems – subtle changes to nutrient regimes and freshwater influence in estuaries may aggravate the blooming of nuisance and toxic dinoflagellates.

Effects of harvesting on ecosystems and biodiversity

The effects of harvesting (demersal trawl damage to megabenthos and the substratum; bycatch of species with special conservation status; bycatch of non-target species; discards and baitfish removals; removal of top-level predators) are the major anthropogenic pressure in shelf environments and are a hazard in various forms in sheltered and reef environments also (see Table 3 and Figure 4).

Assessment of the threats posed directly by harvesting requires a close understanding of:

- *precise spatial extent of effort, method of operation and catches of specific fisheries*
- *demography of target and bycatch species*
- *distribution and dynamics of benthic habitats subject to trawling*
- *potential for recovery of benthic communities from disturbance*
- *"unaccounted for" sources of mortality or injury such as ghost fishing of lost gear, injury of fishes in escaping from hooks and trawl and net meshes.*

Advances in design of trawling gear and practices to reduce bycatch and contact with benthic communities have resulted in some fisheries from the R&D underway in the FRDC Effects of Trawling sub-program. However, the effects of other fisheries – for example angling and pot-fishing for rock lobster in Australia's most valuable fishery– have received little attention. Study of the mortality of fishes and other organisms that come into contact with gears but escape or are released has also been uncommon in Australia, but these may be developed after better documentation of such basic information as composition of the retained catches that is still being pursued for many fisheries.

Other, indirect effects of harvesting on ecosystems include the effects of removal of predators, removal of forage or "baitfish" species and introduction of discards into populations of scavengers. These have been poorly studied in Australia, mainly because they must be based on advanced (and presently unavailable) knowledge of food chains and stocks of fished and unfished species.

Without appropriate knowledge of effects of harvesting it may be difficult to plan for access by fisheries to marine areas protected for other purposes.

Introduced and translocated pests and diseases

There are three main differences in the threat posed by introduced pests and diseases that make them so important for Australian fisheries. Firstly, an introduction of an exotic pest *species is virtually forever – eradication is not yet a practical option, whilst the other impacts reviewed here could generally be corrected, given time and suitable public will and policy. Secondly, as a biological pollutant, the pest species differ from almost all other impacts in that they do not remain localised. Once introduced they have the potential to spread to the full geographical limits of their environmental tolerances. Finally, there are still high risks that a further suite of diseases and invasive marine pests that are causing problems overseas could reach our shores. It is possible that some of them are here already.*

Hull-vectored marine pests such as fanworms, Northern Pacific sea stars and Japanese kelp are very abundant in some sheltered temperate areas in Australia and are visibly altering the appearance of benthic communities – yet their impacts on ecosystem function and fisheries production are unknown (see Figure 5). The weakness may be in the lack of studies, not the impacts on ecosystems. For example, the introduced New Zealand screw shell Maoriculpus rosaceous spread from the Derwent River in Tasmania to the Great Australian Bight and southern Queensland, and is in very high densities on trawl grounds of the south east, yet there is no information on its effects on shelf ecosystems and the fisheries sustained by them.

In contrast, the serious hazards to mariculture of dinoflagellate blooms are well known but not fully predictable and are in need of R&D to aid prevention and management of the symptoms. Introduction of diseases, such as cholera, that affect aquaculture or seafood consumers has very high hazards, but the risks are not well-known because of a lack of study at the source ports where ballast water originates.

Finally, there is evidence that marine and freshwater pests gain establishment in areas affected by other anthropogenic disturbances, such as clearing of riparian vegetation and harbour works -- but fishing and aquaculture industries themselves have had a major role in introducing and translocating some pests and diseases, and must take responsibility to prevent further problems. Vigilance is required.

c) RESPONSES

General opportunities and issues for "Responses" have been divided into "Conservation and Protection" and "Restoration and Rehabilitation" in Table 4. The range of issues highlighted for sheltered waters befits the diverse range of anthropogenic pressures. These pressures can be divided readily into those caused directly by the activities of the fishing and aquaculture industries and those caused by other means.

The FRDC has had a leading role in investing in R&D to document, understand and reduce the various effects of harvesting and aquaculture on the environment. This role has seen major advances in understanding of the threat of trawling to seabed communities, and subsequent development of trawl gear that avoids bycatch and damage to seabed communities. This could be profitably extended further to recognise and address the role of these industries in the spread of pests and diseases, by developing education programs and industry practices and technologies that minimise spread amongst ports and aquaculture facilities. Vigilance is needed to prevent further introductions and make fisheries values better recognised in assessments of imports for the aquarium trade and other industries.

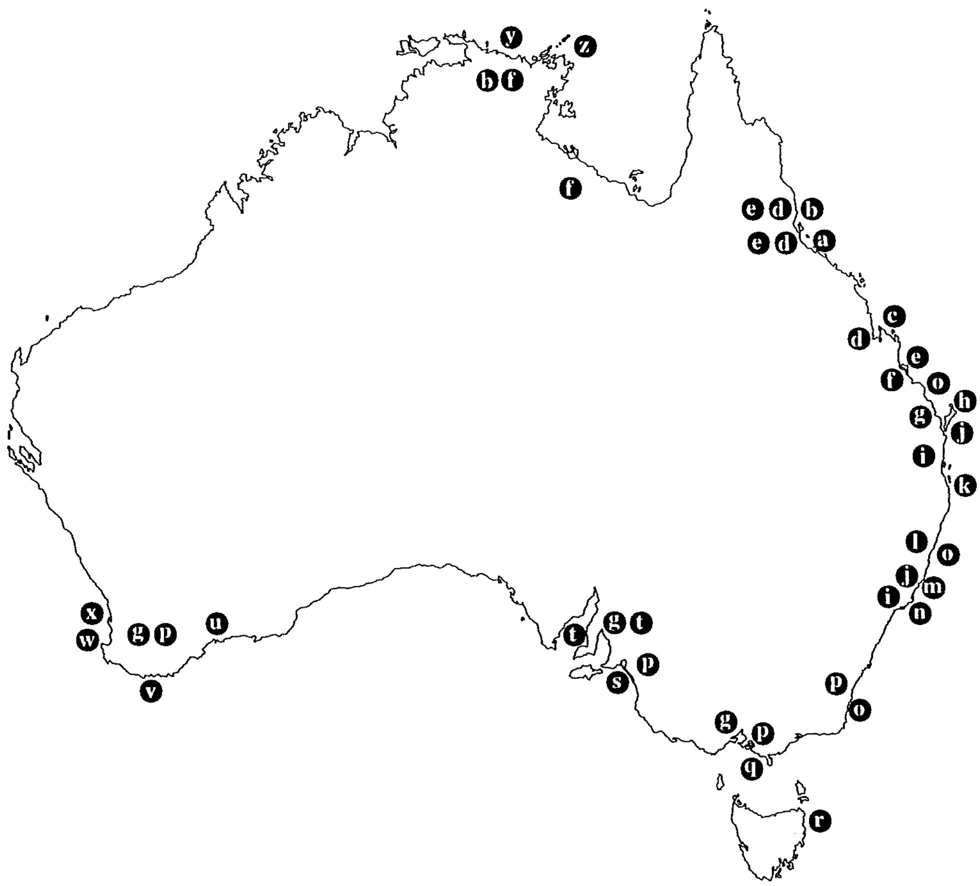
Declarations of marine protected areas such as the proposed National Representative System of Marine Protected Areas (NRSMPA) can be seen both as a challenge and an opportunity to fisheries in all environments. The spatial zoning affords protection from harvesting for some species and some opportunities for research and monitoring of contrasts in fishing effort. It may be possible to manipulate the effort and the zoning to perform powerful experiments and make inferences about the effects of harvesting. However, the opportunities for suitable fisheries habitat protection from marine protected areas depend strongly on having the relevant fisheries-related information.

The second class of pressures on fisheries habitats comes from a diverse assemblage of resource users, ranging from coastal developers with interests in mangrove reclamation, to agricultural developers of floodplains, to freshwater resource users and the producers of wastewater streams. All these point and diffuse sources of impacts are outside of the direct influence of the FRDC.

To help protect and restore fisheries habitat values in these cases (eg. areas disturbed by catchment use and coastal development) it will be imperative to harness economic forces outside of fisheries interests. This could mean financial incentives for on-farm wetland *rehabilitation such as tax incentives and rate relief. Adaptive R&D in rehabilitating habitats can also serve to fill strategic gaps in knowledge of life histories and fisheries-habitat links (Table 4).*

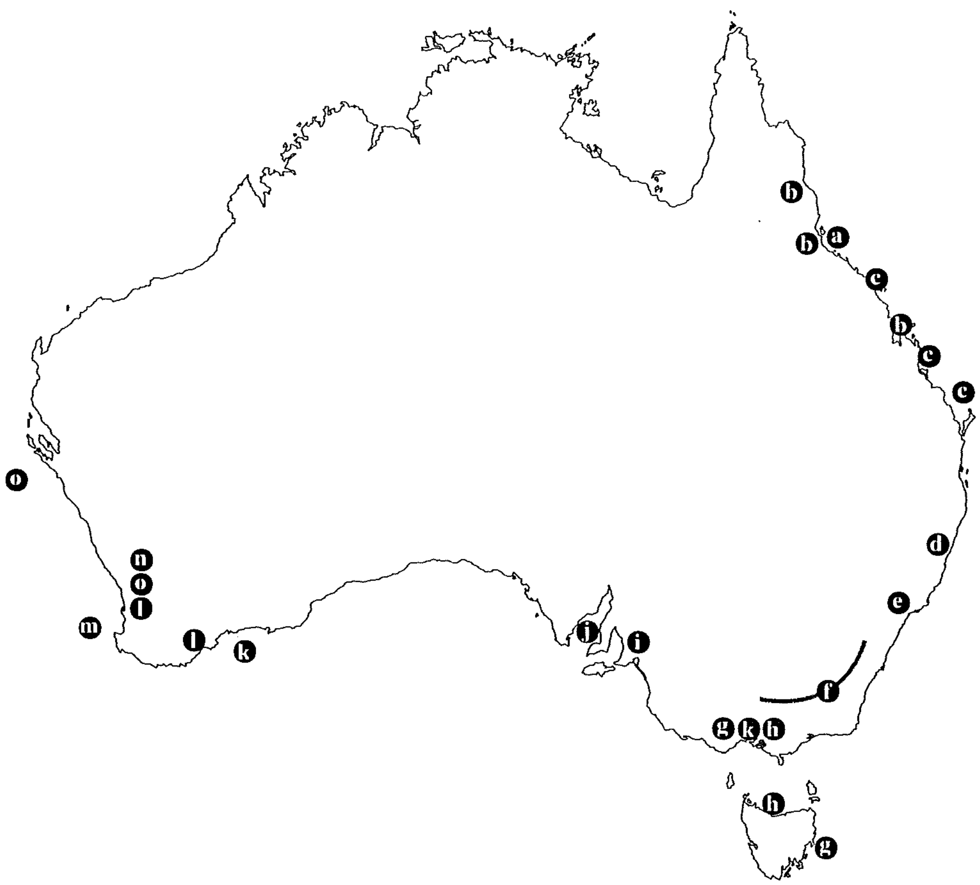
There is an urgent need to develop priorities, techniques and monitoring programs for rehabilitation efforts in lower catchments – such as fishways – to restore some fisheries production in disturbed estuaries and wetlands. The same information is needed to aid the implementation of "no nett habitat loss" policies with positive, measurable outcomes for fisheries production.

To have the best chance of converting R&D in coastal habitats into management outcomes there needs to be a clearer link to vehicles for change. These include integrated catchment management approaches and regional planning exercises. This is essential in the coastal zone mosaic of legislation, jurisdiction, resource use and current trends in population growth, coastal development and demands for water resources.



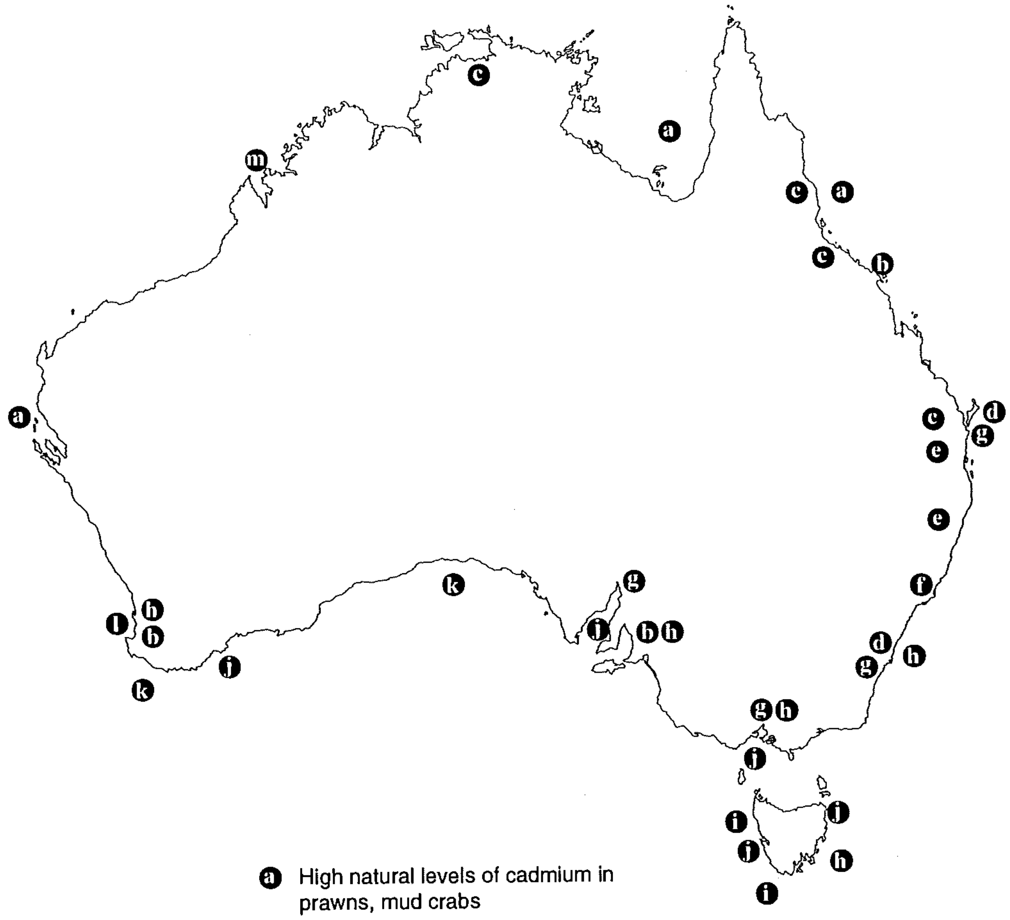
- a Acid sulfate soil disturbance
- b Saline intrusion
- c Sedimentation: seagrass narrow-banding and dieback? Incremental mangrove removal
- d Wetland and lagoon destruction
- e Barriers to tidal access and migration: weirs, floodgates, sand-dams, dams
- f Ponded pastures
- g Saltmarsh "reclamation"
- h Coral sand mining: seagrass loss, rubble destabilisation
- i Runnelling for mosquito control: saltmarsh/mangrove alienation
- j Canal estates and marinas
- k Acid sulfate soil disturbance: acid drainage, epizootic ulcerative syndrome, fish kills
- l Wetland alienation
- m Barriers to tidal access and migration: floodgates, weirs, culverts
- n Training walls and breakwaters: hydrodynamic changes to tidal and wave climate, beach depletion
- o Estuarine seagrass loss: removal,sedimentation. Modified opening regimes for coastal lagoons
- p Freshwater diversion
- q Bay seagrass loss: sedimentation
- r Freshwater diversion
- s Barriers to tidal and fish access: Murray Mouth barrages
- t Seagrass blowouts
- u Catchment salinisation
- v Modified opening regimes for coastal lagoons
- w Shell-sand mining: seagrass loss
- x Seagrass blowouts
- y Saline intrusion
- z Ponded pastures

Figure 1. Examples of major hazards and disturbances caused by changes to drainage and habitat alteration.



- **a** Phase shifts in algal, soft and hard coral dynamics - a role for nutrients and sediments?
- **b** Localised estuarine eutrophication from sewage inputs: mangrove invasions
- **c** Seagrass loss, wasting disease and narrow-banding - a symptom of nutrient and sediment inputs?
- **d** Estuarine eutrophication from sewage inputs: seagrass dieback, blue-green algal blooms. Harmful algal blooms: *Nodularia*
- **e** Disease and pathogens in oysters: QX disease, faecal coliform and hepatitis. Seagrass dieback
- **f** Blue-green algal blooms
- **g** Harmful and toxic algal and dinoflagellate blooms: deoxygenation, fish kills, paralytic shellfish poisoning. Seagrass dieback. Localised seafloor souring
- **h** Seagrass dieback
- **i** Macroalgal and epiphyte blooms: seagrass dieback, mangrove wasting
- **j** Localised seafloor souring
- **k** Epiphyte growth and phytoplankton blooms: seagrass dieback and blowouts. Seabed anoxia
- **l** Estuarine eutrophication
- **m** Epiphyte growth and phytoplankton blooms: seagrass dieback and blowouts. Seabed anoxia
- **n** Estuarine macroalgal blooms: catchment inputs of phosphorus. Fish kills
- **o** Harmful algal blooms: *Nodularia*

Figure 2. Examples of major hazards and disturbances caused by nutrient inputs.

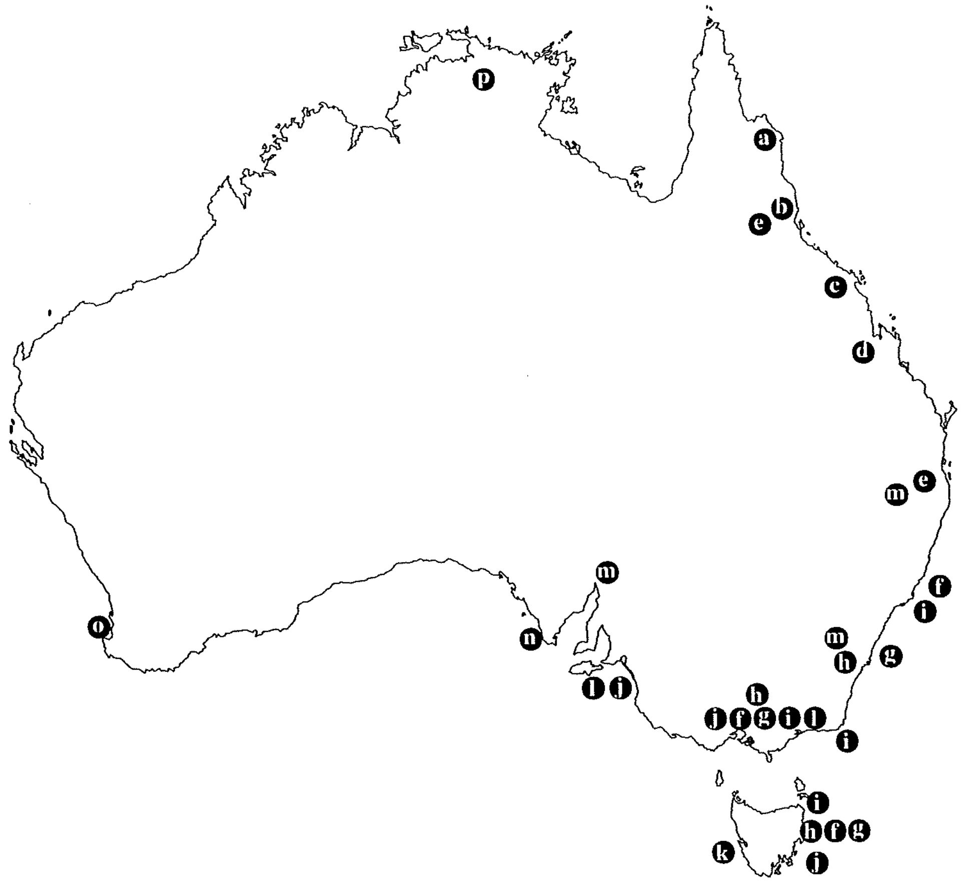


- (a) High natural levels of cadmium in prawns, mud crabs
- (b) Localised heavy-metal hotspots in ports
- (c) Mosquito larvicides
- (d) Hydrocarbons: seafood tainting
- (e) Pesticides, herbicides
- (f) Selenium and other metals in Lake Macquarie
- (g) Chronic oilspills: mangrove dieback
- (h) Ports, industrialised catchments, sewage ocean outfalls: organochlorines, PCBs, hydrocarbons, tributyltin - highest concentrations in sea-surface microlayer and sediments
- (i) Fishing litter
- (j) Heavy-metal pollution: mercury, cadmium, zinc, lead - localised bioaccumulation and closures to fishing
- (k) Fishing litter
- (l) tributyltin : threat to rock lobster puerulus?
- (m) High natural levels of cadmium in prawns
- (n) Mosquito larvicides

Figure 3. Examples of possible hazards caused by contaminants.

- **a** GBR red-spot king prawn trawl: megabenthos destruction, bycatch
- **b** Inshore banana/endeavour prawn trawl: bycatch of juvenile spanish mackerel, *Lutjanus* spp etc
- **c** Foreshore gillnet bycatch: dugongs, queenfish
- **d** Pilchard baitfish removals
- **e** Moreton Bay prawn trawl: turtle bycatch
- **f** Estuarine school prawn trawl and pocket-netting: bycatch of bream, mulloway
- **g** Scallop dredging
- **h** South-east trawl: discarding, bycatch, unknown effects on megabenthos
- **i** Baitfish removals: jack mackerel (Tas.), pilchards, anchovies (Vic.)
- **j** Deep-sea trawling: sea-mount megabenthos destruction. Southern Ocean and Tasman Sea longlining: albatross, shark and other bycatch
- **k** Southern Rock Lobster potting: unknown effects on reef communities
- **l** Pilchard removals
- **m** Shoreline angling, harvesting
- **n** Baitfish removals
- **o** Lower SW king prawn trawl: bycatch of sand whiting, sand crabs
- **p** Western Rock Lobster potting: unknown effects on substratum and benthic communities
- **q** Shoreline angling, harvesting and bait-digging
- **r** NW Shelf finfish trawl
- **s** Prawn and demersal fish trawling : megabenthos destruction, bycatch of "charismatic megafauna" and commercial/recreational species, trophodynamic effects of discards, species shifts
- **t** SA prawn trawl: bycatch

Figure 4. Examples of known or potential hazards and disturbances caused by effects of harvesting.



- **a** Pasture grasses:
  para grass (*Brachiaria mutica*), *Hymenachne*
  Woody weeds: Rubber vine (*Cryptostegia*)
- **b** Aquatic weeds and pasture grasses:
  water hyacinth, *Salvinia molesta*,
  water lettuce (*Pistia amplexicaullus*), para grass
- **c** Noxious fish:
  eg tilapias, mosquito fish
- **d** Translocations:
  eg Australian bass, golden perch,
  silver perch
- **e** Translocations:
  eg barramundi, golden perch,
  redclaw
- **f** Toxic dinoflagellate blooms: (Vic. Tas. NSW)
  Alexandrium catenella,
  Gymnodinium catenatum
- **g** Invasive benthic animals: (Vic., Tas.)
  fanworms *Sabella*,
  Asian mussel *Musculista*,
  screwshell *Maoriculpus*
- **h** Noxious fish:
  eg carp, mosquito fish,
  weather loach, Japanese goby
- **i** Invasive algae and plants:
  Caulerpa scapelliformes (Botany Bay),
  Spartina cordgrass (Vic.),
  Japanese kelp *Undaria* (Tas.)
- **j** Predatory benthic animals: (Tas.)
  Nth Pacific seastar *Asterias*,
  NZ seastar *Astrostole*,
  European shore crab *Carcinus maenas*
- **k** Threat of salmonid diseases: (Tas.)
  Aeromonas, *Myxosoma*
  and *Renibacterium*
- **l** Invasive benthic animals:
  fanworms *Sabella*,
  Asian mussel *Musculista*
- **m** Translocations:
  eg marron, yabbies
- **n** Toxic dinoflagellate blooms:
  Alexandrium minutum
- **o** Invasive benthic animals:
  fanworms *Sabella*
- **p** Aquatic weeds:
  water hyacinth (*Eichornia crassipes*),
  Salvinia molesta
  Woody weeds: Sensitive Bush (*Mimosa pigra*)

Figure 5. Examples of translocations, pest location and industry threatened by potential for disease introduction.

Table 1. Priority issues, and recommended R&D approaches and examples of outcomes.

Priority Issues	R&D Approaches	Examples of R&D Outcomes
Knowledge of "State"		
Need for knowledge of habitat processes/dynamics	• coordinate with LWRRDC and Cooperative Research Centres to supplement "Wetlands" R&D Program and fledgling "Estuarine Health" Program – with a focus overall on the need for "environmental flows" of freshwater in estuaries • FRDC to be pro-active in seeking fisheries R&D input as an add-on to landscape-scale coastal research programs set up to model and address relevant habitat problems (eg. Perth Metropolitan Coastal Waters Study, Port Phillip Bay Environmental Study) • invest in research on the demography and dynamics of recovery of megabenthos on fish and prawn trawl grounds • supplement ongoing seagrass inventories with demographic studies (eg. environmental tolerances, dispersal, longevity, seedbanks and germination requirements)	• fills existing gaps : in coverage of estuaries by LWRRDC ; in coverage of freshwater by FRDC • "value-adding" of major coastal research initiatives is the only way for FRDC to obtain necessary knowledge of ecosystem processes • modelling of key "fisheries-end" uncertainties enables refinement of fisheries R&D • helps in understanding of effects of fishing on biodiversity and opportunities to enhance fisheries by manipulating species-interactions • defines restoration potential and interpretation of changes and declines in seagrass
Need for habitat inventories and monitoring	• coordinate with and supplement mapping of vegetated habitats, wetlands and sub-tidal habitats being done under national and State programs • link with the National Marine Information System (NatMIS) to invest in collation, interpretation and distribution of existing datasets on macrobenthos, seagrass and mangroves to define gaps in knowledge and needs for further inventories • coordinate "Ecosystem Protection" Program with LWRRDC "Wetlands" R&D Program to identify coastal wetlands significant to fisheries • assist with development of estuarine and coastal "indicators" for State of the Environment Reporting - especially monitors of aquatic plant health that assist in identifying sources of stress ("biomonitors")	• identification of key regions, areas and habitats supporting fisheries • extension of FRDC research to supplement national initiatives and avoid duplication of effort • ensures that fisheries values of habitats are measured in national monitoring initiatives • helps distinguish appropriate management responses to changes in habitats, especially dieback of seagrass

Table 1. (continued)

Priority Issues	R&D Approaches	Examples of R&D Outcomes
Need for integration of fisheries and habitat data	• multivariate analysis of existing catch datasets with estuarine and coastal inventories of habitat characteristics • extension of the Interim Marine and Coastal Regionalisation of Australia (IMCRA) to include fisheries production values and activities • refinement of collection and analysis of CPUE data to be useful as monitor for condition and trend in fisheries habitats • make summary CPUE data available to national, regional and local research and management endeavours outside traditional fisheries institutions • develop CPUE collection and vessel monitoring systems at spatial scales useful to habitat management, monitoring and research of links	• knowledge of regional significance of fisheries habitats allows industry to be pro-active in regional planning and integrated catchment management • links with IMCRA will give first true definition of fisheries ecosystems and allow industry to be pro-active in negotiations on zoning for marine and estuarine protected areas • identification of R&D priorities and useful hypotheses to be tested regarding the key links between fisheries production and habitat variables • better spatial resolution of key production areas for conservation, protection and rehabilitation
Need for knowledge of fisheries-habitat links	• shift focus of community studies from single vegetated habitat types to "chain of habitats" and regional sampling of alternative habitats with a suite of gears • development and use of innovative biomarkers (eg. stable isotopes, otolith chemistry) to trace links • tests of the utility of hydrodynamic and biological models at local (site within estuary) and regional (bay within coast) scales to predict recruitment "hotspots" • refine studies within vegetated habitats to ascertain fisheries production role of "fringes" and "stands" • determine fisheries-megabenthos associations in temperate and tropical trawl grounds • test commonly invoked hypotheses concerning fisheries-habitat and species interactions (eg. Edgar and Shaw's 1995c paradigm about seagrass-crustacea-fisheries production)	• ability to predict effects of habitat disturbance on fisheries production and to distinguish anthropogenic effects from natural disturbances • ability to identify major sources of recruits or viable eggs to adult fisheries and define priority nursery areas or habitat types for conservation • refinement of techniques for rehabilitation or creation of fisheries values and design of harvest refugia • better understanding of the effects of fishing on ecosystems
Need for knowledge of life-histories	• refine life history information for important species to understand natural fluctuations and find major nursery areas on regional and local scales • determine critical water regime and physico-chemical requirements for spawning and recruitment of catadromous, anadromous and estuarine species • determine recruitment sites and response of pre-recruits if preferred sites are lacking • determine connectivity of sites, locations and regions by larval supply • develop dietary biomarkers and feeding studies to determine trophic links	• helps distinguish the role of environmental variability from anthropogenic disturbance • enables definition of habitats and links that have priority for conservation, rehabilitation or enhancement • definition of "critical" and "limiting" environmental flows of freshwater and other habitat factors • ensures that "sources" and "sinks" of larval supply are distinguished in spatial management plans of habitat use • enables determination of the roles of coastal currents and zonal winds in causing variability in recruitment • develops understanding of neglected trophic links in major habitat types

Table 1. (continued)

Priority Issues	R&D Approaches	Examples of R&D Outcomes
Inaccessibility of information and dilution of impact of R&D	• coordinate "Ecosystem Protection" Program activities in consultation with other R&D Corporations investing in coastal land-use or aquatic research, with CRIMP and with FEHC • form a coalition of water resource R&D Corporations to best target and extend multi-disciplinary R&D to causes of some downstream effects of agriculture and development • monitor adoption and performance of management interventions and habitat rehabilitation undertaken as a result of fisheries R&D • investigate ways to invest in or ensure funding of "post-disturbance" monitoring of unavoidable habitat alterations and coastal developments, eg. as part of the environmental impact assessment process and legislation • pro-actively assist in supply of up-to-date regional knowledge of fisheries-habitat links demanded by Integrated Catchment Management Committees and regional planning initiatives; NatMIS may be the best conduit	• avoids duplication and ensures extension of fisheries habitat R&D to sources of problems • makes available multi-disciplinary suite of necessary skills for coastal habitat R&D • ensures landscape-scale focus on solutions to degradation of fisheries values in lower catchments • monitoring impacts and interventions enables better predictions of effects of disturbance on fisheries habitats • unavoidable coastal developments offer many R&D opportunities to learn about ecosystem responses to habitat alteration • shifts R&D from reactive to pro-active in identifying fisheries "stake" in coastal development and management
addressing "Pressures"		
Natural dynamics and environmental variability	• develop innovative sampling and monitoring techniques for fisheries habitats and their inhabitants • maintain long-term fisheries dependent and independent datasets on recruitment and key environmental correlates, including zonal winds and currents and "environmental flows" of freshwater • develop palaeo-indicators of ocean climate and hindcasting of recruitment variability from age structures • develop techniques to map and monitor key fisheries habitats or proxies for them, and to collate and analyse the information efficiently (eg. Geographic Information Systems - GIS)	• helps collect or refine knowledge on fisheries-habitat associations that overcome the selectivity of measurement imposed by gear types or depth • better understanding of mechanisms causing recruitment variability • better ability to distinguish anthropogenic disturbances from natural variability in recruitment • flexibility to discern important environmental "events" and focus study on them • better inventories of key habitats helps conserve and protect them

Table 1. (continued)

Priority Issues	R&D Approaches	Examples of R&D Outcomes
Change to drainage and Habitat alteration	• link with agricultural R&D Corporations to coordinate joint industry action on floodplain rehabilitation, riparian zone rehabilitation and pest management • aid with lobbying for rate and tax relief for land-holders to adopt better land-use practices • develop, maintain and update national inventories of degraded habitats and threatening processes and structures – invest in national extension of the results of FRDC project 94/041 • develop national framework for prioritising rehabilitation under the "Area-Catch-Expense" framework tested in FRDC project 94/041 • assemble multi-disciplinary teams to develop, implement and monitor performance of adaptive environmental assessment and management (AAEAM) in rehabilitation techniques for blockages to tidal access and fish movement, and for restoration of profiles and vegetated habitats • study mechanisms of transport of larval and pre-settlement stages into nursery areas • apply R&D to unavoidable coastal developments to test key question concerning generic impacts on habitat • develop "best practice" in translocations and restocking of impoundments and open systems	• incentives for riparian zone rehabilitation, coordinated drainage schemes and reduction in silt loads • priority needs for rehabilitation and fishways identified in an accountable manner amenable to testing of performance • ownership of problems and solutions by ICM stakeholders • restoration of access and environmental flows enhances estuarine fisheries production • better prediction of effects on fisheries of habitat disturbance and engineering works • creation of productive sportfisheries in under-utilised impoundments and diversion of growth in angling pressure from coasts • reduced risk of genetic pollution in stocking of open systems
Nutrient and Contaminant inputs	• develop monitoring and management protocols for "seafloor souring" and biotoxins and faecal coliform bacteria in mariculture • test the major hypotheses invoked to predict fisheries response to macroalgal blooms • test egg and larval chromosomal abnormality methods as indicators of contaminants in sea surface microlayer • develop techniques to assess risks and hazards to fisheries and marketing posed by localised contamination of sediments and water column by metals , tributyl-tin and organochlorines • implement biomonitors and biomarkers for detecting impacts of sewage and sediments in vegetated aquatic habitats • investigate construction of estuarine wetlands to fulfil dual role as "nutrient scrubbers" (eg. from mariculture ponds) and fisheries habitats	• reduces impact of mariculture operations on benthic habitats • reduces impact of poor water quality on mariculture harvests • understanding of the responses of fisheries production to nutrification • procedures for safe harvesting in contaminated waters • identification of reasons for seagrass dieback allows appropriate response in effluent management • enhanced fisheries value of artificial wetlands • successful techniques will lead to demand for rehabilitation

Table 1. (continued)

Priority Issues	R&D Approaches	Examples of R&D Outcomes
Effects of harvesting on biodiversity and ecosystems	• continue to invest in refinement and extension of environmentally-friendly fishing gears, practises and products to avoid interactions with non-target species and destruction of benthic habitats • fill gaps in knowledge of bycatch occurrence and habitat disturbance in all fisheries • assess threats to biodiversity by modelling "sustainability" of bycatch components (eg. using demographic parameters of bycatch species) • investigate techniques to assess the effects of changes to food-webs through introduction of discards and bait and removal of key baitfish • utilise new zoning of marine and estuarine protected areas to construct contrasts for experimental measurement of effects of fishing • develop collection of catch and effort data and vessel monitoring systems at spatial scales useful to habitat management, monitoring and research of links • investigate ways of assessing the unaccounted technical sources of fishing mortality that occur during the capture-escape process (eg. discards, escape, avoidance, net drop-out and ghost fishing mortality)	• reduce threats to biodiversity and increase profits • reduce interaction of fisheries with juveniles of other fisheries and with habitats supporting fisheries • experiments offer powerful, efficient identification of management options • allows informed response to debate about effects of fishing and better negotiation on fisheries access to National Representative System of Marine Protected Areas • density contours of trawl fishing effort could identify better where disturbance to benthos and bycatch is likely to occur, and therefore plan responses in R&D • assessment of needs for reducing unseen effects of recreational and commercial fishing
Introduced and translocated pests and diseases	• coordinate with Centre for Research on Introduced Marine Pests (CRIMP) and other national coordinating bodies to assess priority needs and opportunities for studying effects on fisheries and mariculture and to identify risks and hazards of possible future introductions • determine role of local and international fishing industry as a vector and source of pests, and develop solutions to reduce this role • develop techniques for improved containment of exotic and translocated species used in aquaculture and liaise with overseas industry to ensure R&D is undertaken to reduce risks of introductions from those sources • develop monitoring and management protocols for existing pests and diseases to identify and minimise impacts (eg. protocols for toxic dinoflagellate blooms in national Shellfish Quality Assurance Program) • for new introductions pursued by aquarium trade, and translocations pursued by sportfishing and mariculture industry, encourage and support assessment of impacts on native fisheries, habitats and mariculture, in order to assess the need for and cost-effectiveness of impact minimisation techniques (eg through coalition with Australian Quarantine Inspection Service)	• ensures fisheries issues included in national considerations of pest and disease research and introductions of aquarium species and translocations of sport and mariculture species • prevention of further spread of existing pests and diseases is critical • greater understanding of the risks and hazards of fanworms, seastars, algae and dinoflagellates – much uncertainty exists • satisfaction of Shellfish Quality Assurance guidelines for export and domestic markets • early warning to guard against harmful introductions and ensure fisheries stakeholders are fully considered; preparedness for undesirable introductions and disease outbreaks

Table 2. Key R&D issues and gaps in knowledge of 'STATE" of fisheries habitats.

"STATE"	Sheltered bays, estuaries and coastal freshwater	Exposed rocky and sandy coasts and sub-tidal coral and rocky reefs	Continental shelf and large Gulfs
1. Need for knowledge of habitat processes/dynamics ... information needed to recognise, assess and predict effects of habitat disturbances on fisheries, and to understand fisheries-habitat links	1.1 **Role of freshwater flow** (containing terrigenous inputs) poorly known for major estuarine processes, habitats and species. 1.2 Need for better understanding and **predictive ability for harmful and toxic algal blooms.** 1.3 Productivity of mangroves, seagrass well recognised; **study of other plant sources** (eg. freshwater macrophytes, algae) neglected. 1.4 Long-term (temperate) and short-term (tropical) **dynamics of seagrass demography** poorly known; reasons for "dieback" not always known.	1.1 Inadequate knowledge of **major factors limiting algal and macro-algal production and demography** on sub-tidal reefs. 1.2 Inadequate knowledge of major pathways of energy transfer **(food-webs) to rock lobster fisheries.** 1.3 Few studies of **food webs, habitat use and fisheries production from soft intertidal substrata** (beaches, mudflats).	1.1 Very poor knowledge of **demography of and recovery from disturbance of macro-benthic** communities on trawl grounds. 1.2 Poor knowledge of **shelf benthic processes** supporting trawl fisheries (prawns, fin-fish). 1.3 Patchy knowledge of **shelf pelagic productivity** and food-webs.
Regional-scale knowledge of **fisheries habitats....** which habitats should be conserved and where are they? **2.1 Existing information** **2.2 Missing information** ..... integrations needed to produce useful hypotheses and understanding of patterns of fisheries production and their associations with habitat	2.1 Existing **habitat inventories and catch and effort datasets are not being drawn together** at all scales. 2.2 **Lack of inventory of degraded habitats** and threatening structures and processes; lack of maps of major wetlands critical for barramundi and bass replenishment.	2.1 **Lack of integration of catch and effort data with sub-tidal mapping** - eg. in the bio-regionalisations undertaken as part of IMCRA. 2.2 **Lack of knowledge of deeper sub-tidal habitats** supporting rock lobster; need for mapping extent, nature and significance of deep reef habitat on the Great Barrier Reef; general lack of knowledge of sub-tidal habitats on hard substrata in sub-tropical and temperate latitudes.	2.1 **Large amounts of unpublished information** on benthos, sediments and demersal fisheries fauna of NW Shelf, Arafura, Timor Seas, Gulf of Carpentaria below 20m. 2.2 Great lack of basic information on **bathymetry, topography, benthic habitats** in South East, GAB trawl grounds and below 20m in Great Barrier Reef matrix.

Table 2. (continued)

"STATE"	Sheltered bays, estuaries and coastal freshwater	Exposed rocky and sandy coasts and sub-tidal coral and rocky reefs	Continental shelf and large Gulfs
3. Knowledge of fisheries - habitat links .... critical to determine what habitats and links must be studied, conserved, rehabilitated or enhanced	3.1 Focus of research and management on individual habitat types not well-balanced w.r.t. the "chain of habitats" requirements of most species. Uncertain if **alternative habitats** are selected as settlement sites after loss of certain components (eg. estuarine seagrass). 3.2 **Hydrodynamic influences on recruitment** at all spatial scales well-recognised but not sufficiently documented to map variations in significance of different sites, locations or regions. 3.3 **Temporal movements and trophic links** between intertidal and sub-tidal habitats poorly known. 3.4 Lack of knowledge of **fisheries value of "stands" versus "fringes" and "patches"** in mangrove and seagrass habitats.	3.1 **Species interactions, herbivory and post-recruitment processes** invoked at small scales to explain fisheries-habitat links -- but unknown roles at larger scales. 3.2 Post-recruitment processes, habitat requirements and interactions of major tropical and temperate reef crustaceans and molluscs unknown; especially below limits of SCUBA. 3.3 Poor knowledge of **demography, distribution and ecology of major "rock-fishing" species** and most temperate reef fin-fish. 3.4 **Habitat role of sandy beaches poorly studied.**	3.1 **Fisheries-megabenthos associations** inferred from NW Shelf work, but specific type of associations unknown ; relationships for other demersal fisheries very poorly known (eg. SE Trawl), or different (Arafura Sea). 3.2 **Climate cycles** cause variability in pelagic habitats, and productivity shifts may transfer to demersal habitats ; palaeo-indicators of climate needed to assess extent of variability.
4. Life History information needed .... essential to enable prediction of the effects of disturbance and determine what habitats and links must be conserved, rehabilitated or enhanced	4.1 **Requirements of pre-settlement and early life-history stages** either in need of further refinement (eg. bream, barramundi), limited (eg. mulloway) or absent (eg. garfish). 4.2 Need for **determination of sources of spawners and recruits** at regional, catchment or finer scales (eg. amongst habitat types) to identify critical areas. 4.3 Role of coastal **surface currents in life-histories** poorly known for most species. 4.4 **Critical spawning and recruitment requirements** (water regime) of catadromous and anadromous species poorly known.	4.1 **Connectivity of sites** (eg. abalone), reefs (eg. coral trout) and regions (eg. sthn rock lobster) by larval supply must be determined to protect sources and sinks. 4.2 Abalone demography and some post-recruitment processes for reef-fish require research to **plan for harvest refugia at appropriate spatial and temporal scales.** 4.3 Poor knowledge for most temperate-reef fish species; **inadequate knowledge of recruitment sites and nurseries** for many important tropical species.	4.1 Most **fin-fish life-cycles have not yet been determined;** early life history requirements generally unknown. 4.2 **Zonal winds and surface currents** affect recruitment of some species, but phenomenon/effects not fully documented and mechanisms poorly known.

Table 3. Key R&D issues in "PRESSURES" on fisheries habitats - examples of major threats.

"PRESSURES"	Sheltered bays, estuaries and coastal freshwater	Exposed rocky and sandy coasts and sub-tidal coral and rocky reefs	Continental shelf and large Gulfs
1. Natural dynamics and environmental variability	1.1 **Flood , drought, storm and temperature extremes - eg.** coastal seagrass is destroyed by silt smothering, wave damage or scorching; lower catchments can be vastly altered from drying to flood; disease *(Labyrinthula)* outbreaks can destroy seagrass. 1.2 **Estuarine infilling is a natural geological process** – eg. mangroves can invade intertidal in large "stands.	1.1 **Climate cycles, cyclones, storms and species outbreaks** - eg. widespread loss of *Macrocystis* in Tasmania and coral bleaching may be due to sea temperature rise; catastrophic storm damage alters habitats; predator (COT starfish, *Drupella* snails) outbreaks destroy coral; urchins create "urchin barrens".	1.1 **Climate cycles, ENSO events and zonal winds** - eg. storms re-work sediments in shallower waters; zonal winds and coastal current shifts affect larval transport, recruitment and productivity. Promising studies in south-eastern waters, but poorly known elsewhere.
2. Change in drainage	2.1 **Freshwater Regime** - eg. diversion causes loss of wetland nursery habitat and loss of access routes (barramundi and bass); loss of spawning cues and larval habitat (black bream); suppression of fisheries production (school prawns, mulloway). Altered flood regime and sediment loads can cause rapid change in habitat (eg. mangrove cover, seagrass smothering). 2.2 **Tidal Regime and Wave Climate** - can be rapidly modified by engineering of estuary mouths/channels. Can cause profound, cascading changes to inter-tidal and freshwater habitats but generally not documented. Can isolate fishery habitats from one another, eg. runnelling for mosquito control in NSW, Qld. 2.3 **Blockages to access** - caused by 2.1, 2.2 and structures (eg. floodgates). Suppresses fisheries production, degrades upstream habitats, aggravates water quality problems, harbours introduced pests, producing chemical barriers to migration. A national problem, fully documented only in NSW.	2.1 **Tidal Regime and Wave Climate** - see 3.1 below.	

Table 3. (continued)

"PRESSURES"	Sheltered bays, estuaries and coastal freshwater	Exposed rocky and sandy coasts and sub-tidal coral and rocky reefs	Continental shelf and large Gulfs
	2.4 **Acid Drainage** - product of changes to water table in pyritic soils and aggravated by 2.1-2.3. Can kill entire estuarine communities and interacts with a fungus to cause fish kills and epizootic ulcerative syndrome (EUS) . EUS prevents spawning and growth in survivors and renders them un-marketable. Major issue in northern NSW; emerging in Qld and NT. Acid sulfate soils widespread on entire east coast.		
3. Alteration of habitats	3.1 **Degradation of lower catchments,** floodplains and estuaries by - 2.1-2.4 above, increased sediment loads and land-uses. 3.2 **Direct removal** of mangroves, seagrass and inter-tidal flats -- eg. by replacement with structures (eg. canal estates, housing developments, seawalls, marinas) or by changes to tidal regime (see 2.2) and shell-sand or coral-sand dredging.	3.1 **Seawalls, breakwaters, sand-mining** affect hydrodynamics via tidal regime and wave climate. Implications for macro-algal reefs poorly known; beach changes are dramatic, but effects on fisheries are unknown. 3.2 **Dieback** of *Macrocystis* **kelp** from unknown causes - perhaps sea temperature rise is a potential threat to Tas. abalone/rock lobster fisheries.	
4. Nutrient inputs	4.1 **Sea grass dieback** - caused by shading by epiphyte growth, water-column chlorophyll shading and sediment smothering and raising of banks (see 2.1). A major issue in most bays and sheltered waterways near population centres. Can cause loss of production and recruitment sites for fish, loss of other ecological services (eg. seabed and beach stabilisation). 4.2 **Nuisance and toxic algal blooms** - eg. phytoplankton and macro-algae threaten mariculture and cause changes to fisheries production cycles and benthic processes and habitats. 4.3 **Threats to denitrification cycles** and fish-kills due to de-oxygenation are caused by nutrient overloading; requires ecosystem level research and modelling (eg. Port Philip Bay Environmental Study).	4.1 **Local macro-algal changes** from brown macro-algae to greens (eg. *Ulva*) documented at small scales (<=100m) near point sources; larger scale effects of increased loadings requires ecosystem level research and modelling (eg. Perth Coastal Waters Study).	

Table 3. (continued)

"PRESSURES"	Sheltered bays, estuaries and coastal freshwater	Exposed rocky and sandy coasts and sub-tidal coral and rocky reefs	Continental shelf and large Gulfs
5. Contaminants	5.1 **Sediment metals and organochlorines** - can cause localised prevention of all harvesting; wider effects on industry through bad public perceptions (eg Selenium "scare" in Lake Macquarie finfish). 5.2 **Faecal coliform bacteria and pathogens**-- threat to mollusc mariculture through threats to human health and marketing (eg. hepatitis in Wallis Lake oysters). 5.3 **Water column hydrocarbons, organochlorines and tributyl tin** – may be high risk for early life history near some industrial centres, but effects generally poorly known and need for study of egg and larval mortality and abnormalities - especially in sea-surface microlayer.	5.1 **Tributyltin** -- widespread evidence of imposex in gastropods ; unknown threat to WA rock lobster puerulus in southern zone near Fremantle.	5.1 **Sewage plumes** from ocean outfalls contain suite of contaminants and are areas of aggregation of larvae; larval abnormalities have been reported from plume fronts; assessing impact very difficult; no knowledge of threat to larvae and later fisheries production. 5.2 **Metal refinery wastes and Mine tailings** – eg. cadmium in northern prawns at levels sufficient to raise public awareness; some concern in Gulf of Carpentaria and Torres Straits that metals pose a threat to marketing of product.
6. Effects of harvesting	6.1 **Estuarine prawn trawling and pocket-netting** - bycatch of juveniles of economically important species (mulloway, yellowfin bream) is important in NSW ; knowledge of flood events, timing and location of fishing critical to understand problem and solutions. 6.2 **Angling** - eg. widespread retention of "undersize" fish, bycatch and discarding during fishing and bait collection (castnets, baitnets), chronic littering at popular localities; habitat degradation by boat, foot and vehicular traffic ; lack of ownership of problems by recreational sector; anglers implicated in spread of carp and tilapia pests. Problems are nationwide and extend to remote localities.	6.1 **Pot damage and species removals** on reefs sometimes perceived to be serious -- but no study (rock lobster) or research just underway (coral trout). Some problems amenable to research by experiment at various scales (eg. abalone/urchin interactions). 6.2 **Shoreline harvesting** of invertebrates and algae for food/bait demonstrated to cause community shifts in molluscs.	6.1 **Demersal trawl damage to megabenthos and substratum** - the single major threat to shelf fisheries habitats. Assessment of threat in each fishery is not yet possible due to lack of seabed mapping, lack of knowledge of demography and recovery rates of benthos and lack of knowledge of fisheries-megabenthos links. Species shifts in fished and bycatch communities can occur, but role of megabenthos loss can be confounded with fishing mortality. 6.2 **Bycatch of threatened or endangered species** - catch of charismatic megafauna in trawls (eg. turtles) and on long-lines (eg. albatross) has low public tolerance and R&D needed to avoid them.

Table 3. (continued)

"PRESSURES"	Sheltered bays, estuaries and coastal freshwater	Exposed rocky and sandy coasts and sub-tidal coral and rocky reefs	Continental shelf and large Gulfs
6. Effects of harvesting	6.3 **Gill-netting** - bycatch of endangered or threatened "charismatic megafauna" – perhaps aggravated by seagrass loss in the case of dugong-gillnet interactions; discards of sportfish (eg. queenfish); public tolerance of bycatch lowered by bad publicity; issue mainly in Qld, NT.	6.3 **Gill-netting**- on Tasmanian reefs; unknown threat to habitat and biodiversity through species removals; may act to spread pest *Undaria* algae among reefs.	6.3 **Bycatch of non-target species** - conflicts with other sectors in regional catch of juveniles of some species (eg. sthn calamari squid, Spanish mackerel); threat to taxa with low natural mortality and low reproductive rate (eg. saw-sharks, rays). Demographic information is needed to model the "sustainability" of bycatch. 6.4 **Discards** - of economically important species is wasteful (eg. redfish); discards of "trash" causes unknown (sharks) or poorly-known (sea-birds) shifts in food-webs and populations through scavenging. New techniques needed to study these intuitive but poorly known effects. 6.5 **Baitfish Removals** - eg. pilchard and anchovy are known to be prime forage species and fluctuations known to cause predator mortality (penguins) yet no studies of effects of fishing them -- and other baitfish removals -- on dependent predators. 6.6 **Other Fishing Mortality** – unaccounted for in stock and bycatch assessments eg. hooking mortality in angling, survival of escapees that have passed through trawl and net meshes, survival of embolised fish released at the surface. A neglected field of study in Australia.

Table 3. (continued)

"PRESSURES"	Sheltered bays, estuaries and coastal freshwater	Exposed rocky and sandy coasts and sub-tidal coral and rocky reefs	Continental shelf and large Gulfs
7. Introduced pests and diseases	7.1 **Alteration of benthic habitats** - high risk but poorly known hazard eg. *Sabella* fanworms, *Musculista* mussels and Pacific oysters visibly alter some seagrass, soft-bottom and inter-tidal habitats; fanworms threaten crucial denitrification cycles in Port Philip Bay; threats to fisheries and ecosystem function poorly known. 7.2 **Competition and predation** – poorly known threat, but suspected that fanworms (inedible to fish) compete for phytoplankton food with scallops. North Pacific sea-star, European shore crab and others could eat cultured molluscs. Known that *Corbula* bivalves are now a major pathway in Port Phillip Bay food-webs. However, general effects of exotics on production inadequately known. 7.3 **Fishing industry may aggravate spread** – eg. of hull-vectored pests and diseases and spread of diseases and escapees in translocations amongst mariculture enterprises. 7.4 **Potential introductions** – no comprehensive safeguards available yet. Candidates for future hull-vectored introductions may include salmonid diseases, cholera and algae such as *Caulerpa* and *Sargassum*. These pose serious threats; need for more industry focus on overseas organisms and diseases of potential threat to fisheries.	7.1 **Competition and predation** - Japanese kelp *(Undaria)* recruits to bare space and poses many threats via competition for light and space ; introduced molluscs compete with natives; sea-stars and shore crabs are potential predators ; threats to fisheries poorly known.	7.1 **New Zealand Screw shell** *(Maoriculpus)* - occurs in such enormous abundance form Tas. to sthn Qld that localised sedimentary changes from soft to hard (shell) substrata have occurred. Unknown effects and unknown role now in shelf food-webs.

Table 4. General issues in "RESPONSE" needed to address "Pressures" on fisheries habitats.

"RESPONSE"	Sheltered bays, estuaries and coastal freshwater	Exposed rocky and sandy coasts and sub-tidal coral and rocky reefs	Continental shelf and large Gulfs
1. Conservation and Protection	1.1 **Coastal habitats and fisheries managed separately** – whilst some States cover mangrove and seagrass in fisheries legislation there are generally problems in safeguarding fisheries values in fragmented coastal management. 1.2 **Need for vigilance and industry best practices to prevent pest and disease spread** -- eg. through live trade, net sea cage or hull fouling, escape from aquaculture and perhaps bait and feed imports. 1.3 **Legislation fails to protect some habitats** from diffuse sources of sediments, nutrients and contamin-ants (eg. downstream effects of agriculture and development on seagrass and mangroves). Regional Planning and Integrated Catchment Management needed to reduce these impacts (and see 1.4). 1.4 **Need for rate relief, tax incentives or other financial incentives** for land-owners to fence riparian zones, use "fish-friendly" drainage schemes and maintain fisheries habitats in coastal catchments. 1.5 **Lack of extension of research results** -- scattering of coastal research amongst disciplines and institutions; poor links between fisheries R&D and agricultural R&D; inaccessibility of key research to local and regional management initiatives. 1.6 **Lack of pre-determined management response options in monitoring programs** - links between research and management response not always established; eg. seagrass loss documented without clear definition of, or plans for, appropriate response -- not always because cause of loss is unknown.	1.1 **National Representative System of Marine Protected Areas** -- for implementation by 2000; planning under-way with biodiversity conservation a major goal - - fisheries will be affected and must be pro-active to optimise fisheries values and avoid conflict. Inventories of fisheries habitat values and landings are a basic requirement. 1.2 **Marine Harvest Refugia** - zoning of multiple-use areas, marine protected areas and harvest refugia needs research on connectivity and post-recruitment processes ; designs should incorporate a component by which powerful contrasts can be made later to assess the effects of fishing, and to assess the performance of the refugia. 1.3 **Need for vigilance and fishing industry best practices needed to prevent pest and disease spread**	1.1 **Strategies to avoid and reduce bycatch and damage to seabed communities** - knowledge of effects of fishing on megabenthos and bycatch is incomplete to develop appropriate technology and avoidance strategies for all fisheries. **Trawl-Efficiency-Devices (TEDs) and Bycatch-Reduction-Devices (BRDs)** R&D has been very successful in reducing bycatch in trawl (eg. TEDs for turtles) and pelagic longline fisheries (eg. "Tori Poles" for albatross). 1.2 Conventions of the United Nations Council for **Law of the Sea** (UNCLOS) **and spatially-based management** imply that resources must be adequately investigated and used to ensure exclusive access to EEZ. Mapping, basic resource inventories of shelf habitats and knowledge of ecology and demography of fished and bycatch species are an essential basic step. 1.3 **Marine Harvest Refugia** - spatially-based management of fishing effort needs research on connectivity and post-recruitment processes ; designs should incorporate a component by which powerful contrasts can be made later to assess the effects of fishing and performance of the refugia. 1.4 **Performance monitoring** of management interventions and changed fishing practises should be undertaken to allow adaptive environmental assessment and management of fisheries on shelves.

Table 4. (continued)

"RESPONSES"	Sheltered bays, estuaries and coastal freshwater	Exposed rocky and sandy coasts and sub-tidal coral and rocky reefs	Continental shelf and large Gulfs
	1.7 **Lack of monitoring of performance of habitat management plans** - zoning of reserves, marine protected areas and harvest refugia without further monitoring of habitat or fisheries condition and trend. 1.8 **Need for monitors** of aquatic plant health (eg. seagrass, phytoplankton) that aid in *identifying* sources of stress as well as *indicating* changes. Some monitoring fails to detect cause of observed habitat change (eg aerial photography of seagrass decline).		
2. Restoration and Rehabilitation	2.1 **Restoration of access** to habitat- eg. Fishways, removal of floodgates and barriers, removal of chemical barriers (water temp., acidity, salinity etc); **restoration of environmental flows** - timing, quantity, quality of freshwater flows in lower catchments. 2.2 **Restoration of profiles** -- provision of shallows as essential nursery habitat, provision of appropriate sedimentary profile and gradient to allow colonisation by propagules of marine plants 2.3 "**No nett habitat loss**" policies require knowledge of fisheries value of habitats traded or created when developments cause loss. Need for techniques to measure performance of these policies. 2.4 **Restocking** - impoundments could support more and better sportfisheries; stocking of open systems needs caution and R&D for "best-practise" to avoid genetic pollution of local stocks and translocation of disease.	2.1 **See spatially-base management** detailed above 2.2 **Artificial reefs** - unknown function as "source" or "sink" of production; unknown suite of recruits to settle on deeper deployments; unknown interaction with nearby habitats; lack of R&D on best type of substrata to use - rubber tyres may be a poor surface for epibenthic communities.	2.1 See **spatially-base management** detailed above -- eg. untrawled corridors of megabenthos may act to enhance neighbouring trawl grounds as well as conserve benthic communities.

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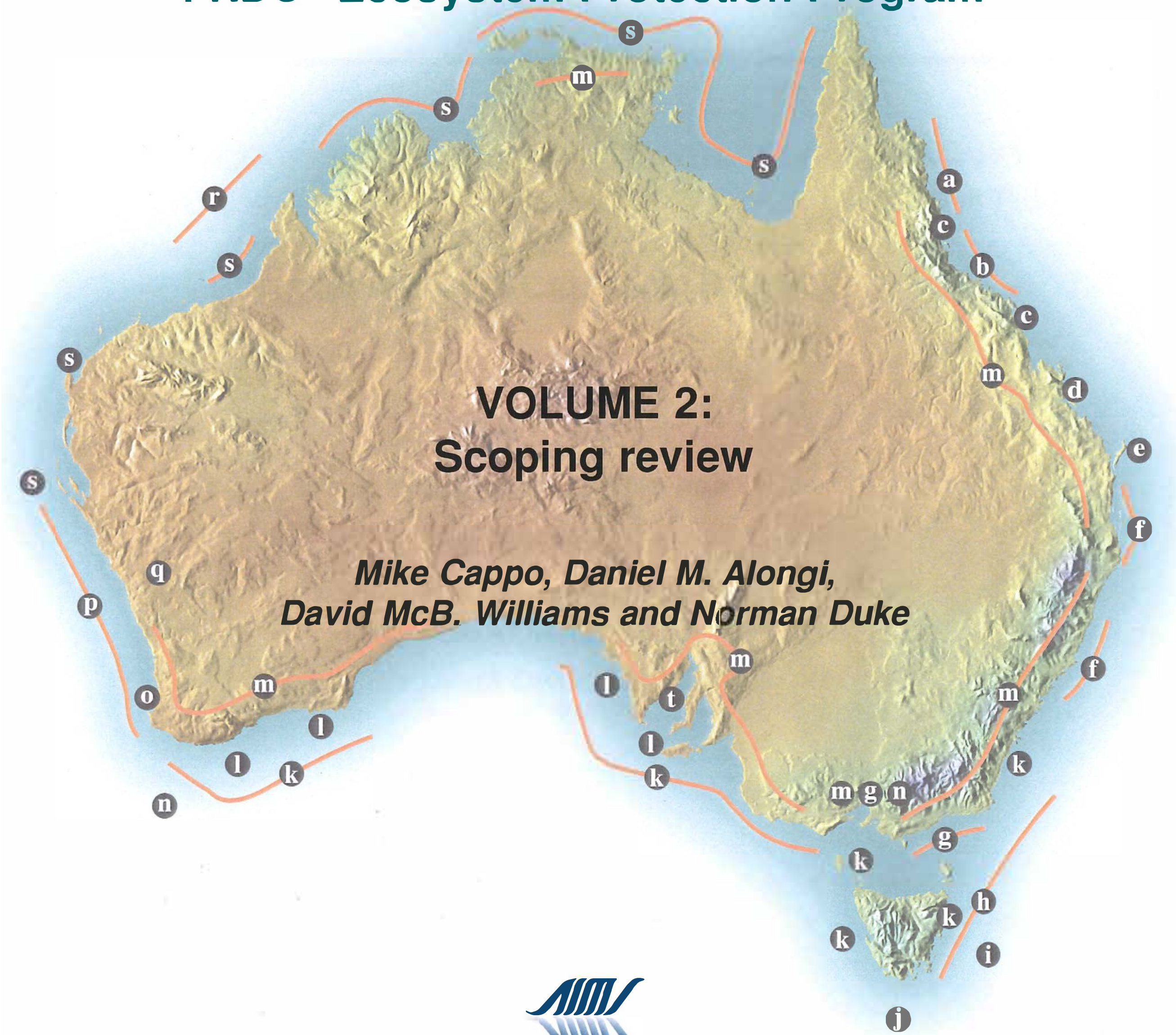
A Review and Synthesis of Australian Fisheries Habitat Research

Major threats, issues and gaps in knowledge of marine and coastal fisheries habitats - a prospectus of opportunities for the FRDC "Ecosystem Protection Program"



VOLUME 2:
Scoping review

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David McB. Williams and Norman Duke

AUSTRALIAN INSTITUTE OF MARINE SCIENCE

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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).

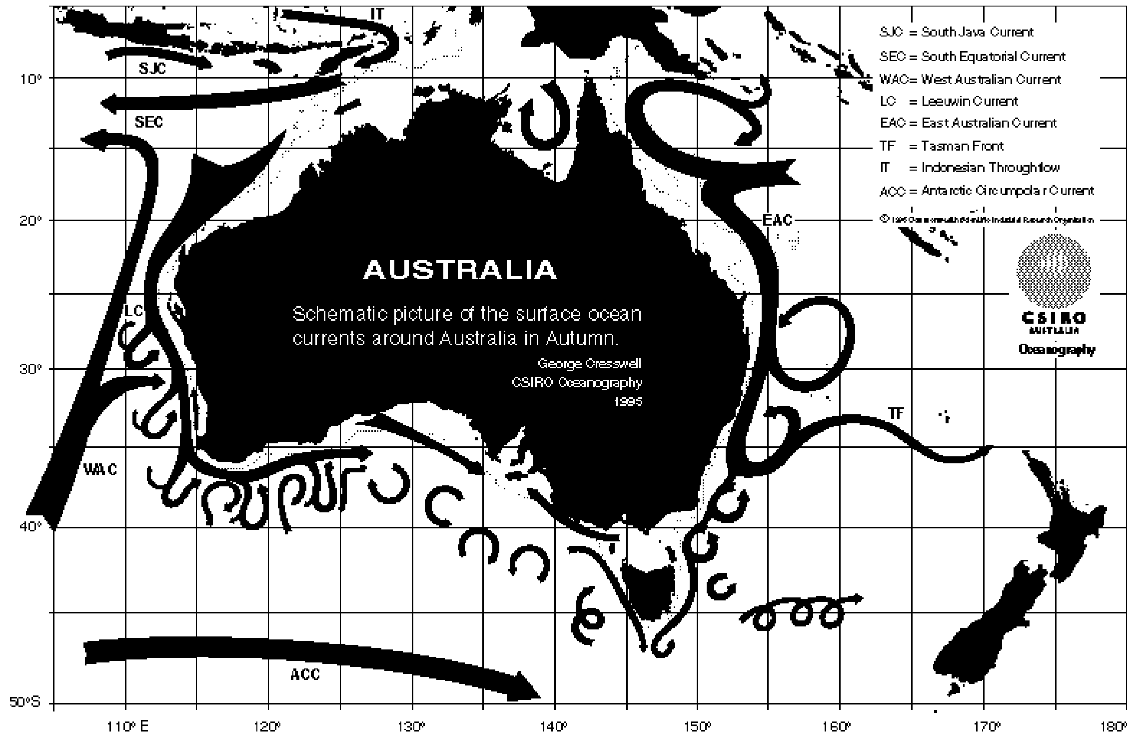

Figure 1.2.1. Schematic diagram of the surface currents of Australia

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.*

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

Code	Map ref.	Region Name	Full Description
SC	1	Shoalwater Coast	Inshore coastal region comprising large bays with very large tidal range, large coastal islands, mostly sandy substrates, little terrestrial input due to relatively low rainfall. Less extensive and complex mangrove forests, less diverse littoral fauna than regions to the north.
PS	2	Pompey-Swains	Offshore region comprised mostly of very complex and extensive planar and lagoonal reef systems, sandy sediments of carbonate origin. Fauna otherwise poorly known. A few isolated sand cays.
MC	3	Mackay-Capricorn	Offshore region comprising the central portion of the very broad continental shelf, characterised by mostly mud and sandy-mud substrates associated with an extensive drowned river valley, fauna very poorly known deep water forms, few reefs or islands except Capricorn-Bunker group in the south, extensive submerged reefs and shoals.
LMC	4	Lucinda-Mackay Coast	Inshore coastal region including complex high-island groups (Whitsundays and Cumberlands), sandy-mud substrates, less complex and diverse mangrove communities and lower littoral faunal diversity than regions to the north. large tidal range, especially in the south.
CR	5	Central Reef	Offshore region including the mid- and outer- continental shelf characterised by mostly sandy sediments of carbonate origin with some mud content in midshelf areas. Reefs in earlier stages of development, poorly developed at the shelf margin.
WTC	6	Wet Tropic Coast	Inshore coastal region dominated by very complex and extensive mangrove forests and very high littoral faunal diversity. Sediments very muddy, of terrestrial origin, from very high but seasonal rainfall. Poorly developed inner shelf reefs.
RBN	7	Ribbons	Offshore region extending to the edge of the continental shelf, eastern margin comprised of ribbon reefs and detached reef complexes, with small, poorly developed reefs behind. Sandy sediments of carbonate origin.
ECY	8	East Cape York	Relatively dry inshore coastal region characterised by lower littoral faunal diversity than adjacent regions, muddy-sand substrates and extensive shoals, planar and lagoonal reefs, low wooded cays.
TS	9	Torres Strait	A complex shallow region with extensive shoals, banks and reefs, extensive seagrass beds. Biology poorly known except commercial fisheries. A mixing zone for waters from the coral sea and Indonesia; major sediment and nutrient inputs from Papua New Guinea rivers. Extremely strong currents and complex tidal regime. Low cyclone incidence.
WCY	10	West Cape York	Inshore coastal region characterised by significant freshwater input from coastal wetlands, dual tidal cycle and distinctive mangrove and salt marsh assemblages and fauna. Generally sandy substrates subtidally, except at river mouths. Low cyclone incidence.
WK	11	Wellesley-Karumba	Inshore-coastal region characterised by relatively low diversity mangrove forests, extensive saltpans (seasonally inundated), a single tidal cycle and sandy substrates in subtidal areas. Major coral assemblages. Monsoonal influence.
CAR	12	Carpentaria	Extensive fairly shallow (<70m) offshore region of the Gulf of Carpentaria. Generally poorly known except from the point of view of commercial fisheries. Mostly muddy substrate, less so towards the east. High cyclone incidence.
PEL	13	Pellew (was S-W Gulf of Carpentaria)	Coastline of alluvial plains, composed of clays and muds in varying proportions. On these shores mangroves can be regarded as continuous, extending up to 1 km inshore in parts. Coral reefs entirely absent. Tidal range increases to a maximum of 3m.
GRO	14	Groote (was N-W Gulf of Carpentaria)	Rocky dominated shoreline. Coastline mainly of large parabolic dune systems formed by predominant south-easterly winds. Mangroves restricted to narrow strips along creeks and lagoons, apart from Blue Mud Bay which is sheltered and supports extensive mangroves and

Code	Map ref.	Region Name	Full Description
			mudflats. Coral reefs absent except for parts of Groote Eylandt, particularly north-western region. Tidal range microtidal with a maximum range of 2m.
AW	15	Arnhem - Wessel	Complex coastline encompassing a variety of bays, inlets, rivers and islands. Tidal range generally increases eastwards from 3m to 5m at Arnhem Bay. Coasts with northerly or easterly exposures generally consist of bare rock or sand barriers and mangrove is absent or restricted between and behind sand ridges. Deeper bays are sufficiently sheltered for greater mangrove development. Alluvial and estuarine plains present, some supporting sparse saltmarsh. Coral reefs generally absent except for fringing reefs off the Wessel and English Company Islands.
TI	16	Tiwi (was Tiwi - Coburg)	Northern coasts consisting of numerous, deeply indented bays and inlets. Extensive areas of mangrove in sheltered inlets and creeks. Intermittent fringing reefs occur off prominent headlands.
BVD	17	Beagle - Van Diemen	A complicated region comprising the majority of the Beagle Gulf and Van Diemen Gulf. Coastline can be broadly categorised into four types: 1) drowned river valley systems in the southwest near Darwin; 2) low, flat, alluvial, deltaic estuarine floodplains, particularly southeast; 3) intermittent smooth, beach ridge shores blended with narrow strips of mangroves (such as the southern coasts of Melville and Bathurst Islands), and 4) intermittent fringing reefs behind which are usually well developed mangroves. Surrounding waters always turbid due to large (4- 6m) tidal range and sediments debouched from large tidally-influenced rivers.
ANB	18	Anson-Beagle (was SE Bonaparte)	Exposed, north-west facing coastline consisting of numerous beach-lined coves and bays flanked by prominent headlands. Sand ridges, in the form of chenier dunes, dominate the backshore landscape intermittently throughout the coastline. From Pearce Point to Cape Ford the coast can be described as moderately hilly or cliffed lacking mangroves. Mangroves are concentrated mainly north of Cape Ford as thin strips along Anson Bay and Fog Bay where sediments are debouched from the Daly and Finniss Rivers respectively.
BON	19	Bonaparte Gulf	***
ARA	20	Arafura	***
CAB	21	Cambridge - Bonaparte	Comprises the headwaters of Joseph Bonaparte Gulf, a broad, open marine gulf straddling the WA/NT border. At its head are two major seasonal estuarine systems - Cambridge Gulf (Ord, Pentecost and Durack Rivers) on the WA side, and a complex of three estuaries (Keep, Victoria and Fitzmaurice Rivers) on the NT side. They are separated by a stretch of low-profile shore backed by saline flats.
KIM	22	Kimberley	This is a remote and little-studied section of the coast, characterised by rocky shore, mud flat, mangal and land-locked marine and estuarine habitats. A broad area of the inner shelf is included within the WA Territorial Sea because the base line is located seaward of the many nearshore islands. Buccaneer Archipelago is included in this region.
KS	23	King Sound	*** This wide, open gulf encompasses the Fitzroy Estuary and Stokes Bay.
CAN	24	Canning	*** The northern part of the Canning Basin shore. (Southern part comprises Eighty Mile Beach)
EMB	25	Eighty Mile Beach	***
PIN	26	Pilbara (nearshore)	*** Inside the 10 m bathymetric contour.

Code	Map ref.	Region Name	Full Description
PIO	27	*Pilbara (offshore)*	*Beyond the 10 m bathymetric contour in the West Pilbara; the ocean water is less turbid than that of the inshore area and there are significant differences in marine ecosystems.*
NWS	28	*North West Shelf*	*The outer part of the North West Shelf comprises an oceanic province (sometimes divided into the Sahul Shelf and Rowley Shelf). There is a series of coral atolls along the shelf-edge (Seringapatam, Scott, Mermaid, Clerke, Imperieuse) and a number of outer-shelf islands and platform reefs (Hibernia, Ashmore, Cartier, Browse, Adele, Lynher). Some of these atolls and islands are within State waters.*
NIN	29	*Ningaloo*	***
ZUY	30	*Zuytdorp*	*(1) mainland coast north of Carnarvon, (2) western sides of the outer Shark Bay islands and Edel Land Peninsula, and (3) Kalbarri cliffs.*
SB	31	*Shark Bay*	***
ABR	32	*Abrolhos*	*This is an off-shore, shelf-edge unit comprising a series of three dissected limestone platforms and islands.*
CWC	33	*Central West Coast*	***
LN	34	*Leeuwin-Naturaliste*	***
DO	35	*Donnelly*	***
WSC	36	*WA South Coast*	***
EUC	37	*Eucla*	*Shallow offshore gradient. Microtidal ~ 0.8 to 1.2 metre range. Open, moderate energy, west facing coastline. Nullarbor tertiary limestone cliffs, Pleistocene dune rock headlands and reefs, Holocene beaches and dune barriers. Warm temperate water. Leeuwin current.*
MUR	38	*Murat*	*Shallow offshore gradient. Moderate to low energy coastline. Microtidal ~ 0.8 to 1.2 metre range. Crenulate bays due to Precambrian crystalline rock headlands usually with a dune rock capping. Pleistocene dune rock cliffs, reefs and headlands. Holocene beaches, dunes and estuarine deposits including intertidal and supratidal flats. Offshore islands and seamounts. Warm temperate waters. Leeuwin current.*
EYR	39	*Eyre*	*Shallow to moderate offshore gradients. Moderate to high energy coastline. Pleistocene dune rock cliffs, headlands and shore platforms. Microtidal ~ 0.8 to 1.2 metre range. Holocene dune barriers, beaches and lagoon deposits. Precambrian metasediment cliffs. Cainozoic colluvial and fluvial sediments. Warm temperate water subject to nutrient rich upwellings.*
NSG	40	*North Spencer Gulf*	*Confined, inverse estuary with minimal land water input. Shallow offshore gradients. Low energy shorelines. Micro to mesotidal ~ 1.8 to 3.6 metre range. Precambrian metasediment shore platforms. Holocene sandflats, beach ridges, recurved spits, and extensive intertidal and supratidal flats. Warm temperate waters with a subtropical biotic element.*
SG	41	*Spencer Gulf*	*Semi confined. Shallow offshore gradients. Low to moderate energy shorelines. Microtidal ~ 1.8 metre range. Precambrian crystalline rock headlands forming embayments. Cainozoic outwash sediments forming low cliffs. Holocene beaches, dunes and estuarine deposits. Cool temperate waters.*
SVG	42	*St Vincent Gulf*	*Confine inverse estuary. Shallow offshore gradients. Low to moderate energy coastline. Micro to mesotidal ~ 1.2 to 3.3 metre range.*

Code	Map ref.	Region Name	Full Description
			Precambrian metasediment and Tertiary cliffs. Holocene beaches, sandflats, dunes, beach ridges, estuarine deposits, extensive intertidal and supratidal flats. Cool temperate waters.
COR	43	Coorong	Offshore gradient decreases from steep to flat resulting in a gradational coastline change from high to low energy. Microtidal ~ 0.8 to 1.2 metre range. Precambrian crystalline rock and metasediment headlands and cliffs. Pleistocene dune rock cliffs, headlands, shore platforms and reefs. Holocene pocket beaches and an extensive beach-dune barrier lagoon complex. Cool temperate waters.
OTW	44	Otway	(SA) Steeply sloping offshore gradient. High energy coastline. Microtidal ~ 0.8 to 1.2 metre range. Pliocene - Pleistocene volcanic outcrops forming headlands. Pleistocene dune rock cliffs, shore platforms and reefs. Holocene beaches and dunes. Cold temperate waters subject to nutrient rich upwellings. (VIC) (1) SA border to Cape Otway. Steeply sloping offshore gradients, dominated by Quaternary dunes and associated sandy shorelines. Dominantly southwest facing coastline. Currents generally slow. Sea-surface temperatures representative of Bass Strait waters. High wave energy (2) Cape Otway transition zone Very steep offshore gradients, dominated by cliffed shorelines Mean annual sea-surface temperature is representative of Bass Strait waters. High wave energy.
BGS	45	Boags	Sheltered open coastline with long sandy beaches broken by rocky headlands that extend under sand in relatively shallow depths (normally < 20m). High tidal range ≈ 3m.
DAV	46	Davey	Very exposed coastline with extensive rocky headlands separated by short sandy beaches. Low tidal range ≈ 1m. Biotically depauperate. Cold water.
BRU	47	Bruny	Highly-dissected coastline with extensive embayments protected from submaximal swell by islands and peninsulas. Low tidal range ≈ 1m. Endemic plants and animals.
FRT	48	Freycinet	Submaximally exposed coastline with approximately equal areas of rocky headlands and sandy beaches, and numerous coastal lagoons. Moderate tidal range ≈ 1.5m. Cool water, sub-tropical convergence.
FLI	49	Flinders	(Wilson's Promontory Transition Zone) Rapid changes in offshore gradient. Granitic coastline exposed to submaximal swells on east-facing shores of Flinders Island and moderate to low swells elsewhere. Sandy beaches of moderate length with seagrass beds prevalent in shallow water. High tidal range ≈ 3m and strong tidal currents. Sea-surface temperature is representative of Bass Strait waters. Waves highly variable.
CV	50	Central Victoria	Very steep to steep offshore gradients dominated by cliffed shorelines. Sea-surface temperature is representative of Bass Strait waters. Moderate wave energy.
CBS	51	Central Bass Strait	The region is about 60,000 sq. km in size and lies in the central area of Bass Strait. The sea floor is shaped like an irregular saucer with water depth varying from about 80m at its centre to 50m around the margins. The substrate of central area is mainly mud. Tidal velocities vary from <0.05 ms^{-1} in the central area to as high as 0.5 ms^{-1} at the margins where the islands and promontories form the western and eastern entrances to Bass Strait. Water mass characteristics are complex and vary seasonally representing the mixing of the different water masses present on western and eastern side of the Strait.
TWO	52	Twofold Shelf	Submaximally exposed coastline with long sandy beaches broken by rocky headlands, and numerous coastal lagoons. Moderate tidal

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

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

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

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

Region Code	Attribute	Data
	Geology/ Geomorphology:	Dominated by cliffed shorelines in Quaternary and Tertiary sediments. Orientation changes from facing south west to south east.
	Tides, sea-levels and currents:	Amplitudes and phases increasing eastward, except for the M_2 phase which decreases. Relative importance of the semi-diurnal constituents increases rapidly eastwards. Rapid eastward increases in diurnal and semi-diurnal currents, with velocities in the order of 0.1 -0.5 ms^{-1}.
	Sea-surface temperatures:	Mean annual sea-surface temperature is approximately 15.5° C, representative of Bass Strait waters.
	Waves:	High wave energy (46 kW/m), though decreases rapidly in an easterly direction as the coastline changes from facing to parallel with the prevailing swell direction.
	(TAS)	
	Sea temperature:	Influenced during winter months by a warm-water extension of the Leeuwin Current, making this region warmer than other Tasmanian waters at that time. Summer water temperatures are cooler than elsewhere in the Bassian province.
	Biota:	Fish and plant species richness both moderate. This is the only recorded area within Tasmanian waters where several species more typically associated with South Australia occur (eg. the queen morwong Nemadactylus valenciennesi).
COR	43	Coorong
	Climate:	Cool temperate, meso-thermal climate with cool, wet winters and warm, dry summers.
	Oceanography:	Offshore gradient decreases from steep to flat resulting in a gradational coastline, from high deepwater wave energies at Cape Jaffa to low energies near the Murray Mouth. Waters are cool temperate.
	Mean sea surface temps:	Varying from 14°C in winter to 18°C in summer.
	Tidal range:	Microtidal ~ 0.8 to 1.2 metre range.
	Coastal Geomorphology & Landforms:	Large barrier coast dominated by a gradational nearshore-offshore gradient. Offshore gradient traversed by the extensive Murray Canyons which extend offshore from the Murray River.
	Coastal geology:	Comprises headlands and cliffs of Precambrian crystalline rock and metasediments and also, Pleistocene dune rock cliffs, headlands, shore platforms and reefs, interspersed with Holocene pocket beaches. Southern coast dominated by a large beach-dune barrier lagoon complex comprising the extensive Coorong lagoon.
	Biology:	Marine flora and fauna typically cool temperate waters (ie. Flindersian Province). Intertidal and sublittoral fringe dominated by the brown alga, Cystophora intermedia. On rocky limestone shores, subtidal macro-algal communities are dominated by red algae assemblages (particularly Osmundaria and species of Plocamium), species of Caulerpa (particularly C.flexilis) and Cystophora (such as C.subfarcinata, C.monoliformis and C.platylobium) and Ecklonia radiata. Granite boulder coasts are dominated by Scytothalia dorycarpa, Acrocarpia paniculata, Carpoglossum confluens, and Ecklonia radiata on exposed coasts and species of Cystophora in areas of moderate wave energies. Extensive seagrass meadows occur at Kingston (Lacepede Bay). Seagrass meadows dominated by Posidonia australis in shallow areas, P.sinuosa,

1.3 Fisheries-habitat links

1.3.1 Key issues

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

For examples:

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

This situation has arisen at the regional scale because of:

- *a widespread emphasis in life-history R&D on factors presumed useful to species-specific stock assessment -- coarse stock delineation, spawning seasonality and age and growth of adult stages - with a lack of study of post-larval, juvenile stages of many major species;*
- *a lack of regional, fishery-independent inventories of nursery habitats and of major areas of fisheries production;*

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

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

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

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

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

Recent R&D has shown that there are recruitment "hotspots" determined by local hydrodynamic processes in transport of larval stages (eg. Carrick 1997b, Jenkins and Black

1994, Steffe and Westoby 1992). This implies that important recruitment sites can be predicted and mapped in some cases, and also that broad generalisations regarding incremental habitat destruction cannot be weighed simply against indices of remaining habitat availability. There are also obvious opportunities for further R&D to test the utility of such predictions.

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

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

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

Contrasts in latitudinal and longitudinal patterns of fisheries production

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

*Table 1.3.2.3. Comparison of commercial and recreational catch (t yr^{-1}) and production (kg Ha^{-1} yr^{-1}) from Victorian, NSW and WA bays, inlets and estuaries. Adapted from Gwyther (1990). *scallops.*

	Area (km^2)	Avg comm. catch	Avg recr. catch	Avg shellfish catch	comm. fish prodn	recr. fish prodn	shellfish prodn	TOTAL prodn
Port Phillip Bay	1950	1196	1048	4680	6.1	5.4	24	35.5
Western Port	680	238	50	2	3.5	<1	<1	4.3
Corner Inlet	500	348	110	n.a.	7.0	2.2	n.a.	9.16
Gippsland Lakes	400	524	351	2	13.0	8.8	<1	22
Lake Tyers	25	20	15	3	8	6	1	15
Tamboon Inlet	7	29-48	n.a.	n.a.	42-68	n.a.	n.a.	n.a.
Mallacoota Inlet	25	84	27	n.a.	33	10.8	<1	44
Sydney Estuary	50	40-108	164	38	8-21.5	33	7.5	48-62.5
Jervis Bay	100.5	61	78	400	6.1	7.8	40	54
Botany Bay	42	183	59	n.a.	43.5	14	n.a.	57.5
Tuggerah Lakes	79	n.a.	67	n.a.	34	8.4	n.a.	42.4
Cockburn Sound	103	344	210	474 +250*	76	20	46-70	142-166
Peel Harvey Estuary	131	n.a.	n.a.	66	26	n.a.	5	31

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

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

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

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

Table 1.3.2.4. Differences in area of habitat and estimated total (commercial + recreational) finfish production (tonnes) from the Clarence and Richmond Rivers. Data adapted from West's (1993) Table 5.2 and Fig 2.3, and West and Gordon (1994) Table 6. * 1986 commercial catch only

km^2	open water	mangrove	seagrass	saltmarsh	Y'fin bream	dusky flathead	sand whiting	luderick	mulloway	tailor	sea mullet*
Clarence	103	5.2	0.9	1.9	64-73	28-34	14-16	19-22	<3-5	<2-3	402
Richmond	14	4.9	0.9	0.1	13-20	7-12	4-7	13-16	<3-3	<2-6	107
difference	7.46	1.06	1	19	4.9-3.6	4-2.8	3.5-2.3	1.5-1.4	1-1.7	1-0.5	3.7

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

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

- West (1993) noted that more bream, sand whiting, tailor and mulloway were caught in the northern NSW rivers than in previous studies done in the Hawkesbury and Botany Bay with the same gear;
- mulloway juveniles are in outstanding abundance in relatively few estuaries in NSW (eg. Hawkesbury, Clarence) and these may contribute most to the adult fishery in the entire State;
- episodic recruitment is a feature of NSW commercial fish in estuaries, even at estuary level – recruitment can be very good across families or within species in one estuary and low in others (eg. Pollard 1992);
- there are consistent north-south differences in age structures of NSW estuarine fish in several families (p.c. #460 C. Gray).

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

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

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

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

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

Specific studies of the status and change in fisheries production of estuaries and bays are rare over the period in which major habitat disturbances have occurred. Commercial fisheries production figures are traditionally used for such comparisons (eg. Kearney 1996), but these are now known to have several sources of bias that must be addressed:

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

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

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

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

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

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

- ***spatial resolution of logbooks, confidentiality and "nil" returns***

  The primary goal of many logbook programs was for use in management, not research, and the resolution of reports are often not informative. For example, in Queensland there is a suite of resolution in the logbook system – at the level of 30-60 mile grids in the gillnet fishery on east coast, but by riverine system in the Gulf of Carpentaria. This makes it hard to tie catches to particular habitats, or even river systems - but there is great promise in this regard in the use of satellite vessel monitoring systems (VMS) for trawlers. These will enable construction of density contours of trawling effort, and will possibly be adopted by major prawn fisheries by 1999. There are widespread efforts at improving the collection of production information to aid R&D (eg. researchers at NSW FRI are now endeavouring to apply logbooks with daily records and gear discrimination).

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

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

BOX 1.3.3.1 USE OF PRODUCTION FIGURES IN NSW ESTUARIES

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

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

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

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

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

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

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

(p.c. #540 R. West)

BOX 1.3.3.2 SEAGRASS DIEBACK AND FISHERIES PRODUCTION IN VICTORIAN BAYS

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

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

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

(p.c. #1060 M. McDonald)

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

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

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

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

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

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

In this regard it is important to note that:

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

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

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

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

The situation has not rapidly improved since then for these taxa, with reviews by West (1993) and Kerby and Brown (1994) outlining both the vintage (many pre-war) and scarcity of definitive literature for major estuarine species. For example, in a review of studies of estuarine fish biology in New South Wales, West (1993) found no published papers for flathead, mulloway, tailor and luderick, sea mullet had no research attention since the 1950's, there *had been no publications on bream for 45 years, and only a single publication on sand whiting since 1947.*

Importance of nearshore resources

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

For example:

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

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

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

Regional variation in life-histories

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

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

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

It is often difficult to tell from the literature how much of such regional life-history differences are due to a lack of sampling of the entire suite of possible recruitment sites in different studies. In Table 1.3.4.1 we have given some examples of the striking differences within *genera, and amongst regions within species, which demonstrate the need for sampling of alternative habitats in life-history studies.*

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

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

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

		Hormosira			

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

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

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

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

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

BOX 1.3.4.3 KNOWLEDGE OF FISHERY-HABITAT ASSOCIATIONS - JUVENILE SNAPPER

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

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

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

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

Similar juvenile flexibility is seen in SA:

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

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

Box 1.3.4.4 Knowledge of Fishery-Habitat Associations -- Prawns

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

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

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

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

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

Sediment type may also be a limiting factor for *P.merguiensis* - mangrove species type does not explain much variance. Rainfall has complex influence on emigration to fishing grounds.
In contrast there is no knowledge of habitat requirements for the Red-leg Bananas (*P. indicus*).

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

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

Blue-Leg Kings (*Penaeus latisulcatus***)** are found around river mouths as juveniles in the north. They prefer a hard-silica sand substratum. Nurseries are largely unknown in the north, but well known in the south and west:
The western kings in SA live 3-4 yrs and aggregate in NE parts of the Gulfs to spawn Oct-March

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

Metapenaeus - inshore endeavours, school, and greasyback prawns

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

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

1.3.5 The concepts of "estuarine dependence", "estuarine opportunism" and "critical habitats"

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

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

Key attributes of suitable nursery habitats in the tropics are

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

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

There are not necessarily the same suite of attributes in temperate Australia, because there is a wholly different fish fauna that is biologically less diverse, and there is a vastly different balance of biological and physical forces. One of the major differences concerns the influence of lower temperatures on osmoregulatory performance. Maintenance of a narrow salinity/temperature balance is not so critical in the tropics, whereas salinity change in *temperate estuaries has far greater effects because of the limiting physiology of osmoregulation at lower temperatures (p.c.# 280 S.Blaber).*

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

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

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

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

The focus in the literature to date has been classification of fish species as "estuarine", "estuarine opportunists", "marine stragglers" and "marine" based on their occurrence in *estuaries and adjacent habitats (eg. Blaber et al. 1989, Lenanton and Potter 1987, Potter et al. 1990, West and King 1996).*

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

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

*Table 1.3.5.1. Classification of Western Australian commercial catch by life-history category - *top 8 groups selected from Table 2 in Lenanton and Potter (1987). β% of total fish catch.*

Estuarine	Semi-anadromous	Predominantly estuarine (M-E)	*Estuarine and inshore marine (M-E &IM)	*Marine (M)
Acanthopagrus butcheri	Nematalosa vlaminghi	Mugil cephalus	Arripis truttaceus	Thunnus maccoyi
			A. georgianus	Sardinops neopilchardus
			Aldrichetta forsteri	Sardinella lemuru
			Cnidoglanis macrocephalus	Furgaleus and Mustelus sharks
			Pagrus auratus	Carcharhinus sharks
			Hyperlophus vittatus	Glaucosoma hebraicum
			Sillago schomburgkii	Mustelus antarcticus
			Sillaginodes punctatus	Seriola hippos
β 0.3	1.5	3.9	36.4	57.9

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

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

The weight of estuarine dependent fish species represents 20.3% of the total commercial fish catch – mainly due to large catches of species which make use of both estuaries and inshore *marine environments. This is much lower than the estimates of Pollard (1981) for NSW, due mainly to the very large catches of rock lobster, tuna and pilchards. When tuna catches were very low, the weight of estuarine-dependent fish species represented 64.8% of the total finfish catch.*

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

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

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

Blaber et al. (1989) demonstrated that, even if one excludes the truly estuarine gobies, gudgeons and other small taxa, at least one-third of the Embley River species are estuarine-dependent– including the economically attractive mullets, barramundi, queenfish and whiting.

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

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

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

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

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

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

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

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

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

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

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

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

1.4.1 Coastal freshwater

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

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

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

These areas quickly run dry however, so most freshwater and estuarine fauna either rely greatly on the presence of coastal fringes of mangroves in this dry coastal region, migrate, or die-off. In the humid tropics, such as in north Queensland, summer wet season precipitation is greater and somewhat more predictable, resulting in larger expanses and persistence of coastal freshwater habitats – wet season blooms of macrophytes and other algae are common *(see Pajimans et al. 1985 for review). In these rivers, fish assemblages appear to be more species-rich than other tropical Australian rivers of equal size, attributable to greater habitat diversity and more constant and predictable freshwater flow (Pusey et al. 1995a,b).*

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

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

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

Rivers with intense land use (mainly grazing, forestry, canelands) in their catchments discharge nearly four times more material than rivers associated with no or weak land use. The types of materials discharged include fertiliser and natural soil nutrients, pesticide residues, heavy metals, remobilised freshwater sediments, and eroded soil. Approximately 80,000 tonnes of fertiliser nitrogen and 17,000 tonnes of fertiliser P are discharged into the GBR, mainly via soil erosion during the summer wet season. Terrestrial runoff is the largest source of sediment and nutrients from the continent to the coastal zone.

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

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

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

It such be pointed out that not all river plumes result in enhanced biological activity. For instance, phosphate levels are several times greater (50-100 Molar) off the Fitzroy and Brisbane Rivers, but turbidity suppresses algal blooms and, presumably, other biological activity. It is likely that the impact of freshwater flow into most coastal zone areas of Australia (including mangroves and salt marshes) is much more subtle than the dramatic impacts observed at river plume fronts in influencing rates of plant growth, altering seasonal community composition of both plants and animals, and producing biogeochemical gradients and fluxes across the land-sea boundary. Needless to say, such subtle impacts have rarely been clearly demonstrated in Australia's coastal zones.

1.4.1.1 Fishery-habitat links

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

Submerged and emergent aquatic macrophytes are known to provide shelter and presumably the basis for food chains in coastal freshwaters, but there are very few publications outlining their role in coastal supporting fisheries. This neglect is surprising, given their abundance and the popular scientific view that carp (Cyprinus carpio) are destroying them (eg. in the Gippsland Lakes). Their role in the freshwater and "gradient" zones of estuaries is locally important as West (1993) found significant beds of Vallisneria gigantea (about 17km^2) in the Clarence River Broadwater to be an important nursery for yellowfin bream. The introduced "Elodea" or "Grafton weed" Egeria densa was also found to shelter new recruits of yellowfin bream and Australian Bass (also see Gehrke and Harris 1996).

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

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

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

Box 1.4.1.1 A Case Study of the Complexities -- Barramundi Life-History

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

Key attributes of habitat links are:

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

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

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

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

1.4.2 Saltmarsh (and saltpan)

Like other intertidal habitats bordering both land and sea, salt marshes exchange biota, nutrients, and other dissolved and particulate materials and gases with adjacent ecosystems. The extent to which salt marshes interact with bordering habitats depends upon many factors, any combination of which can result in ecologically distinct marshes even within the same climatic region. Australian salt marshes have a reciprocal distribution to mangroves, occurring most extensively > 30^0 S latitude. However, this statement is only true if saltpans associated with marshes are excluded. Otherwise, Bucher and Saenger (1991, 1994) have shown that saltmarshes actually have more area than mangroves in northern Australia, and that most saltmarsh is in Qld, the NT and northern WA. Only the plant species richness increases in marshes in the south (Adam 1990).

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

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

Salt marsh connections to the adjacent coastal ocean have been examined within the context of "outwelling", that is, the export of nutrients or organic detritus from fertile estuarine areas to support productivity of offshore waters. Recent reviews indicate that while most salt marshes export some material, many others do not – no data are available on outwelling from Australian marshes, despite their proximity to major nurseries. This is unfortunate because outwelling and other exchanges of material and biota with adjacent coastal systems is a key ecological process that is both a reflection of, and a cause for, high estuarine productivity, including fish. The amount of material exchanged is influenced not only by rate of primary and *secondary production, but also by physical characteristics, to the extent that each system is unique. These characteristics include:*

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

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

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

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

In short, marshes are sites of high faunal richness and productivity because of their proximity to land and shallow seas where tidal energy is maximal. Marsh fauna and flora are closely dependent upon freshwater and land-derived nutrients and trace elements such as iron, manganese, and phosphorus as well as tidal water from which they take up dissolved nitrogen and carbon – exposure to air maximises rates of nitrogen fixation, the use of atmospheric N_2 by microbes to synthesise cellular (organic) nitrogen. Salt marshes are also somewhat dependent upon nitrate derived from precipitation.

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

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

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

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

We found interesting speculation about the role of wind-blown (aeolian) transport of nutrients offshore from extensive saltpans in supporting the benthic production and tiger prawn fishery of Exmouth Gulf (p.c. G. Brunskill AIMS). This is supported in principle by the work of Paling and McComb (1994).

1.4.3 Mangroves

Description

Mangroves comprise a unique and diverse forest and shrub ecosystem of the intertidal zone, bordering coastal margins and offshore islands of the tropical and warm temperate zones of Australia. Mangroves occur in most estuaries although their presence is more limited along the southern coastline and they are absent from Tasmania. The area of mangroves in Australia is around 8,200 km^2, and is the third largest in the world. Most are found in tropical parts, notably in Queensland and the NT (Table 1.4.3.1).

Estimated area (km^2) of mangrove habitat in Australian states:

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

Source: Saenger (1996)

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

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

Mangrove biodiversity

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

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

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

Structural diversity in mangrove habitat

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

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

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

Dispersal and colonising ability

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

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

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

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

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

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

Notes:

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

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

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

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

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

Processes and connectivity

The connections of mangrove forests to other habitats is better understood than for salt marshes, despite the fact that there are slightly more salt marshes in Australia (13, 595 km^2) than mangroves (11,500 km^2). Essentially, the same suite of factors that determine the extent of exchange between marshes and adjacent ecosystems also operate for mangroves, with the prime exception of the role of leaf-burying mangrove crabs in processing and exporting carbon (see Alongi 1989, 1990a,b,c, Alongi et al. 1989, Alongi and Christoffersen 1992, Alongi 1997, Daniel and Robertson 1990, Robertson 1986).

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

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

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

The role of climate and water circulation on the extent of exchange between mangroves and coastal waters is best seen in the nitrogen budget constructed for the mangrove ecosystem of

Missionary Bay, on the northern end of Hinchinbrook Island in north Queensland. More than 80% of nitrogen input into the mangroves comes via tidal exchange, with the rest via microbial nitrogen fixation. Similarly, nearly 99% of the nitrogen output occurs by way of tidal exchange – the remaining losses escape to the atmosphere via bacterial denitrification.

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

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

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

There have been some comparative studies of adjacent fish communities in mangroves and adjacent seagrass (eg. Robertson and Duke 1987, Laegdsgaard and Johnson 1995, Blaber et al. 1995b), but the extent of material links between mangroves and adjacent seagrass beds and saltmarshes is unknown in Australia. Without this information it is not possible to predict the effects of habitat disturbances such as runnelling for mosquito control (see section 2.2)

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

The Gazi Bay ecosystem in southern Kenya is another good example of a tropical ecosystem that shows a broad interdependence among seagrass beds, marshes, mangroves and adjacent coral reefs (Hemminga et al. 1994, Kitheka 1996). Gazi Bay is a semi-enclosed shallow embayment 10 km^2 in area. Mangrove forests, an additional 5 km^2 in area, line the bay. Stable isotope analyses indicate that mangrove-derived particulate organic matter is exported to the adjacent subtidal seabed. The signature of this material decreases rapidly with distance from the shore, indicating that the seagrass beds most proximate to the mangroves receive the most material. Moreover, changes in the isotope composition of seagrass parallel the inputs of mangrove material suggesting that the mangrove carbon is assimilated by the seagrass.

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

Such a linkage between mangroves and adjacent systems likely occurs along some coastal areas in tropical Australia, but comprehensive information does not exist. However, a promising start has been made in the northern prawn fishery (eg. Loneragan et al. in press). How, or to what extent, organisms of commercial importance rely on such proximate habitats for sustenance and growth is not known, but is of crucial importance.

1.4.3.1 Fishery-habitat links

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

A synthesis of those studies features:

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

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

Key uncertainties concern:

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

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

- *refine maps of mangrove areas — Australia-wide and systematic;*
- *develop maps of past (original?) areas of mangroves, using aerial photographs, etc.;*
- *re-assess extent of mangrove areas in regions of greatest change;*
- *monitor success of previous restoration projects — improve future projects;*
- *methods to restore exposed mangrove areas in the tropics;*

- *detailed characterisation of mangrove topography and intertidal profiles — links to mean sea level (MSL) and astronomical high tide (AHT);*
- *growth history of mangrove trees — possible silviculture and use with aquaculture;*
- *role and function of mangroves in nutrient uptake — use in sewage & effluent treatment.*

1.4.4 Seagrasses

Description of Seagrass habitats

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

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

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

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

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

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

Seagrass biodiversity and distribution

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

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

Structural diversity of seagrass beds

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

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

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

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

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

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

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

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

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

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

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

Seagrass Species		Tidal Posn	Dispersal of Fruit/seed	Fruiting Season	Rhizome	Leaves	Colonising Ability and Tolerance to disturbance	Standing Crop (g dry wt.m^{-2})/ Leaf Area Index (LAI)
Halophila ovalis	N	Inter-tidal. Reef flats.	In sediment. High num. Fast spread.	All year	Fast spread. Delicate creeping, white and translucent. Shallow rooted.	Paired oval blades, 1-5cm & 5-20mm wide, on short slender stems.	Good coloniser. Seedlings hold very poorly. No veg. propagation. Tolerates disturbance.	49
Halophila ovata	N	Inter-tidal					Good coloniser. Tolerates disturbance.	
Halophila spinulosa	N		In sediment. High num. Fast spread.	All year	Fast spread.	Frondlike blades on short slender stems.	Good coloniser. Seedlings hold very poorly. No veg. propagation.	
Halophila tricostata	N							
Thalassia hemprichii	N	Inter-tidal						70 LAI=5.1
Posidonia angustifolia	S		Med. num Slow spread	Annual Dec-Jan	Slow spread.		Poor coloniser. Seedlings do hold. No veg. propagation.	
Posidonia australis	S	Sub-tidal	Med. num. Slow spread. Buoyant.	Annual Dec-Jan	Slow spread. Strong 2cm creeping.	30-60cm long & 6-14 mm wide	Poor coloniser. Seedlings do hold. No veg. propagation.	90-440 LAI=4.9
Posidonia antarctica	S							
Posidonia coriacea	S		Med. num Slow spread	Annual Dec-Jan	Slow spread.		Sometime coloniser. Seedlings hold well. No veg. propagation.	
Posidonia denhartogii	S		Med. num Slow spread	Annual Dec-Jan	Slow spread.		Sometime coloniser. Seedlings hold well. No veg. propagation.	
Posidonia kirkmanii	S		Med. num Slow spread	Annual Dec-Jan	Slow spread.		Sometime coloniser. Seedlings hold well. No veg. propagation.	
Posidonia ostenfeldii	S		Med. num Slow spread	Annual Dec-Jan	Slow spread.		Sometime coloniser. Seedlings hold well. No veg. propagation	
Posidonia robertsoniae	S		Med. num Slow spread	Annual Dec-Jan	Slow spread.		Sometime coloniser. Seedlings hold well. No veg. propagation.	
Posidonia sinuosa	S		Med. num Slow spread	Annual Dec-Jan	Slow spread.		Poor coloniser. Seedlings do hold.	360-660

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

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

Seagrass processes and connectivity

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

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

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

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

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

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

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

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

On average, only a small fraction (about 10%) of living seagrass tissue is consumed directly. Important luderick (Girella tricuspidata) and leatherjacket species (see Table 1.4.5.1) are known to directly consume seagrass as well as their epifauna (Bell et al. 1978b,1980). Benthic epifauna prefer either epiphytes or periphyton – epifaunal amphipods, shrimps, gastropods, *isopods, nematodes, and copepods readily graze down complexes of periphyton consisting of diatoms, chlorophytes, encrusting algae, fungi, protozoa, bacteria and sedimentary material lying on leaf blades and colonising understorey surfaces and surface sediments (see Jernakoff et al. 1996 for review).*

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

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

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

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

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

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

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

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

Finally, seagrass blades and fruits contribute very significantly to the beach-wrack of many bays in southern and south-western Australia. This aggregation and decay of this wrack supports fisheries food chains (see Lenanton et al. 1982, Robertson and Lenanton 1984). In the upper gulfs of South Australia the drifting blades of Heterozostera and Posidonia also accumulate amongst Avicennia mangrove pneumatophores and may both enhance shelter and food for fisheries and cause problems with mangrove respiration, but neither aspect has been studied.

1.4.4.1 Fishery-habitat links

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

The importance of seagrass are best known for:

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

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

2) providing critical tiger prawn nurseries -
Post-larval (PL) tiger prawns appear to actively choose amongst intertidal seagrass beds as settlement sites. CSIRO research has shown high recruitment of 1mm carapace length PLs to a range of seagrass types, but numbers had shifted by the time the PL had reached a carapace length of 2 mm. A key uncertainty concerns the reason for the shift – predation or emigration?. Predation rates in Halodule and Syringodium are similar, and Cymodocea provides much better cover. A series of papers has explored the location, type, seasonality and "carrying capacity" of important tiger prawn nurseries (eg. Haywood et al. 1995, Loneragan et al. 1994, O'Brien 1994b, Vance et al. 1994, 1996b; and see Appendix 4).

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

3) providing recruitment sites for juveniles of estuarine and bay fishes in NSW -
A large number of NSW studies in estuaries and bays have established that economically important sparids (eg. tarwhine, yellowfin bream), luderick and blue groper wrasse (Achoerodus viridis) recruit mainly into aquatic vegetation (eg. see Table 1.4.5.1 and Ferrell and Bell 1991, Ferrell et al. 1993, Worthington et al. 1992b).
An extension northward of NSWFRI research interest has produced a series of recent papers documenting the use of different estuarine habitats by commercial species (eg. West and King 1996, Gray et al. 1996). Some of the complexities in life-histories associated with estuarine seagrass are outlined in Box 1.4.4.1. and Box 1.4.5.1.

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

5) providing nursery habitats and food supplies for western rock lobster -
See Edgar (1989, 1990c,d,e), Fitzpatrick et al. 1989, Jernakoff et al. (1993, 1994), Howard (1987, 1988, 1989a,b) for reviews. See also summaries in Appendix 5.

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

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

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

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

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

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

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

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

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

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

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

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

- *will important species utilise alternative habitats?*

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

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

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

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

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

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

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

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

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

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

For example:

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

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

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

1.4.5 Sheltered coasts and estuaries

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

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

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

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

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

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

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

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

Estuaries are highly productive because they:

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

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

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

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

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

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

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

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

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

- *high fertiliser (phosphorus) inputs into the catchments of the Serpentine, Murray and Harvey Rivers*
- *transport of this material into the estuarine waters of the Peel-Harvey*

- *long water residence times in the estuary was a key process in determining whether or not the estuary was in net autotrophy or net heterotrophy.*

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

1.4.5.1 Fishery-habitat links

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

Regional variation - the role of longshore currents and spawning areas

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

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

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

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

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

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

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

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

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

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

Loneragan and Potter (1990) found that location within the estuary was a greater influence than season or year on the faunal composition.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

- *Wet Season – distinct longitudinal gradient (low turbidity at mouth, increasing upstream)*

- *Early Dry Season – decrease in river flow, low level, reversed turbidity gradient with lowest values in the upper reaches*
- *Late Dry Season – negligible river flow and no longitudinal gradient present in turbidity levels.*

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Gear selection and the need for standardisation and innovation

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

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

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

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

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

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

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

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

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

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

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

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

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

1.4.6 Open coasts - sandy shores

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

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

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

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

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

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

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

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

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

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

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

Recent work in WA by CSIRO and Murdoch University has focussed on the interaction between fish life-histories and vegetated and unvegetated habitats on low-energy beaches of varying aspect and levels of exposure (p.c.#1420 G.Hyndes, p.c. # 1460 M. vanderKlift). These locations are open to inundation during winter and early spring with detached macrophytes. The source of material varies with beach aspect and region, and amongst months, with Posidonia in winter and Ecklonia, Sargassum and red algae in spring.

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

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

1.4.6.1 Fishery-habitat links

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

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

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

Temperate

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

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

sub-Tropical

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

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

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

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

Tropical

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

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

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

Surf zones as larval and juvenile habitats

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

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

1.4.7 Open coasts - hard substrata

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

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

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

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

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

1.4.7.1 Fishery-habitat links

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

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

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

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

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

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

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

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

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

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

BOX 1.4.7.1 EFFECTS OF THE ENVIRONMENT ON WESTERN ROCK LOBSTER RECRUITMENT

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

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

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

(p.c.# 1370 N. Caputi)

1.4.8 Coral reefs

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

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

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

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

- *there is a maximum rate of P uptake under highest water flow conditions, but the residence time of the water over the reef is shortest; and*

- *the amount of P removed from the water is only ~5% of the amount that passes over the reef.*

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

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

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

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

1.4.9 Continental shelves

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

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

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

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

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

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

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

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

Whether or not any portion of Australia's continental margin violates any of these generalisations depends upon several factors:
- *presence or absence of large rivers*
- *presence or absence of upwelling*
- *location of ocean boundaries*
- *shelf width.*

All of these factors are influenced by climate.

In regard to the potential for long-term disturbance by trawling on different regions of the Australian shelf, Long et al. (1995) indicated that the relationship between megabenthos abundance and species richness, and geographical location and environmental factors is complex - there may not be a simple link between species richness and latitudinal gradients in the subtidal marine environment. However, the link between substratum type and sessile megabenthos may be a general feature of our shelves, as Long et al. (1995) note that:
- *sponges, alcyonarians and gorgonians were the dominant sessile megabenthos in the coarse sediments of the North West Shelf, but there was little sessile megabenthos in the pelagic carbonate muds on the nearby Scott Reef -Rowley Shoals platform*
- *sponges, ascidians, alcyonarians and hydroids were abundant in the coarse sediments of the deeper (50-70m) waters of the northern GBR, but there were few sessile megabenthos in the muddy inshore areas.*

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

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

1.4.9.1 Fishery-habitat links

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

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

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

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

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

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

Some of the key findings of these studies are that:

- *there are strong cross-shelf patterns in fish community structure that are related to depth and sediment type - eg Blaber et al. (1994b) found six groups in terms of overall fish occurrence and biomass in the Gulf of Carpentaria. They also recognised 15 species groups that fall into four broad categories - widespread, regional, reef-associated and "other" that may not be closely related. Five of these groups were found at only a single station of the 107 sampled. Partial correlation analyses were necessary to examine the relationship between 11 abiotic variables (including turbidity, percentage mud, sand and gravel in sediments and bottom temperature) and community structure patterns. These revealed that only depth was significant but sediment type, turbidity and temperature may be worth further investigation. Long et al. (1995) proposed that substratum type and quality and quantity of food in the water column govern the abundance of sessile megabenthos in the Gulf , with sponges, zoantharians, alcyonarians and ascidians in an eastern-south-eastern grouping, and only few such megabenthos in muddy central and western Gulf areas. Long et al. (1997c) found that seabed current stress was a significant correlate of factors controlling the distribution and abundance of sessile epibenthos in inter-reef areas of Torres Strait, and may provide a powerful surrogate for seabed mapping in the absence of information on sessile benthos*
- *there may not be strong vertical and horizontal patterns associated with hydrodynamic features - eg. Young et al. (1996) found little horizontal and depth-related structuring of the midwater fish community amongst the East Australian Current, Sub-Tropical Convergence and Sub-Antarctic Water . This may be because the lack of strong thermal*

gradients in the study region and the thinness of the overlying EAC water appear to have reduced the horizontal and vertical scale of mixing – limiting secondary circulation and the resultant productivity. This gradient was less than half that found in a South African study of front-induced enhancement of productivity where the thermal gradient was 10°C in 1 degree of latitude.

- *there are important faunistic boundaries associated with bioregions (see section 1.2.3)*
- *there may be important influence of "structure" (hard substrata and megabenthos) on the fish community composition of adjacent fishing grounds - eg. Gray and Otway (1994) found consistent longshore differences in trawl fauna between Long Reef and Port Hacking that may have been due to unmeasured differences in substratum and topography. Many more reef-associated fishes, such as snapper, were caught at the Long Reef.*
- *secondary production of deep-sea orange roughy and oreo dories is driven by capture of sparse, incoming, off-shelf production from the open ocean - eg. Koslow (1997)*
- *storms and climatic shifts can alter patterns of distribution and producti0on at short and long time scales - eg. Gray (1993), Harris et al. (1988, 1992) and see section 1.2.1.*
- *there are significant diurnal changes in the behaviour of demersal species - eg Blaber et al. (1994b) found that night time trawls in were consistently only half as productive in terms of catch rates and biomass per unit area in the Gulf of Carpentaria. There were also big differences in the dominant taxa, with Pomadasys, Upeneus, Pentaprion, and Nemipterus dominating day trawls and Lutjanus malabaricus, Saurida, Priacanthus and Nemipterus dominating night trawls. Fish behaviour in the same families is also widely different between the North West Shelf and the Arafura and Timor seas (p.c.#20 D.Ramm).*

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

ISSUE 2:
Changes to Drainage and Habitat Alteration

2.1 Overview and FRDC role

2.1.1 The issues

Although the greatest risks and hazards from anthropogenic disturbance to aquatic habitats are occurring in freshwater we have focussed our review in lower catchments for the following reasons:

- *The Land and Water R&D Corporation (the LWRRDC) has recently released a definitive "Wetlands R&D Program" Scoping Review, Background Papers and State summaries - none of which focus directly on estuarine issues*
- *there have been several major reviews of riverine issues and processes (eg. Lake 1994), and there is a major R&D effort already in that sphere (eg. CRC for Freshwater Ecology, National River Health Initiative see 2.1.3 below)*
- *we were informed by the FRDC Executive of their interest in commissioning a separate review of freshwater issues.*

The monsoonal, arid zone, Mediterranean and temperate climatic patterns of regions of Australia are major influences on freshwater regimes. Due to the variability in rainfall Australia has to impound much more water than other countries (12 times more, per capita, than most parts of the USA; SOER 1996). The 570 Australian estuaries identified by Bucher and Saenger (1989) are the most variable in the world. The mean annual runoff +- coefficients of variation (CV) for the world's estuaries are 612 cm +- 43% and for Australia 416 cm +- 70%. The variability in runoff increases with catchment size in Australia, and even in the "wet" tropics the rivers have CV about 50% of flow.

There has been an historical push to "drought-proof" Australia, with a very rapid rise in water storage capacity since 1955. There have also been periodic visions of "greening the interior" by turning rivers such as the Clarence back over the coastal ranges.

At the interface with the sea, in estuaries and bays, multiple tidal nodes (micro-tidal <=1 m to macro-tidal >=8 m) around the coast produces complex tidal forcing. Wave climate is dominated by heavy swell on the southern half of the continent. Tides, waves, heat and light regime and geomorphology act in concert with freshwater and sediment input to produce a suite of fisheries habitats of varying susceptibility to anthropogenic disturbances.

This suite of forces has produced shallow, poorly-flushed, semi-enclosed embayments and estuaries in the subtropics that contain ecosystems sensitive to loadings of nutrients, contaminants and sediments (see Chapter 3). There are also important coastal freshwater wetlands that have accessible corridors to the sea only during floods. Altering freshwater inputs to such systems can have profound, but poorly studied, effects on biogeochemical processes and connectivity. Bays and estuaries are also easily disturbed by construction of relatively small training walls or dredged channels in their narrow entrances. The resulting changes in tidal forcing and wave climate have cascading effects on intertidal communities.

The competition for resources in these coastal zones has also led to widespread, incremental, destruction of riparian and aquatic vegetation or "reclamation" of intertidal areas and ephemeral wetlands.

From an interrogation of the available literature and current R&D we have found the following specific threats to fisheries posed by "changes to drainage":

- *diversion and reduction of "environmental flows" of freshwater through catchments and into estuaries and the sea - known to suppress mulloway and black bream production, but a profound lack of knowledge of hazards for all States*
- *structural, chemical, thermal and biological barriers to access of tide and/or juvenile stages of important species - acid drainage and floodgates known to cause disease and fish kills and alienate vast areas of potential fisheries habitat in all States*
- *saline intrusion onto floodplains and salinisation of coastal rivers - in NT , Qld and WA wetland vegetation or estuarine water quality have been irreversibly altered*
- *construction of ponded pastures - in Qld and NT levees trap and kill barramundi, flood saltmarsh and promote pasture grass pests*
- *artificial openings and closures to coastal lagoons - in WA and NSW poorly-timed bar breaching is done for public convenience and fisheries production is severely depressed*
- *runnelling for mosquito control - in Qld and NSW the alienation of saltmarsh from mangrove poses an unknown hazard to nutrient transfer and fish foraging*

- *depletion of coastal aquifers and changes to water table - in north Qld barramundi nurseries are being deoxygenated due to groundwater intrusion after too-rapid drainage of residual floodwaters*

These hazards are inextricably linked to habitat alteration, as either symptoms or causes. Having dealt closely with habitat modifications due to nutrient and contaminant inputs, fishing and introduced pests in Chapters 3,4 and 5 we discuss here the following specific disturbances:

- *mangrove, saltpan and freshwater wetland destruction - incremental loss of key nurseries may occur because there is insufficient documentation of their location*
- *sedimentation, mangrove colonisation and seagrass "narrow-banding" - mangroves are expanding in "stands" as they invade and accrete new sediments, but what is their fisheries significance compared to "fringes" in NSW and Qld? Increased turbidity has lead to seagrass retreat into shallows in Qld and is thought to have contributed to seagrass decline in NSW. Long and Skewes (1997) found that a simple regression model (85% variation explained) based on inverse distance to main sources of terrigenous sediments predicted the percentage cover of seagrass on Torres Strait reefs*
- *tidal and wave climates altered by construction of training walls or by channel dredging - saline intrusion in nth Qld has led to mangrove invasion of freshwater wetlands; vast changes in the intertidal extent have occurred in Wallis Lake with un-documented effect on seagrass*
- *canal estates and their faunas - poorly flushed estates have low diversity; steep-walled estates are predation gauntlets; well-flushed estates have different fish community than estuaries; estates with appropriate sediment profiles have seagrass colonisation*
- *seagrass blowouts and erosion - effects of Posidonia dieback in WA and SA are not scale-independent – erosion exceeds accretion in blowouts; Intertidal Heterozostera dieback in Victoria caused mobilisation of sediment and smothering of sub-tidal beds.*
- *coral-sand and shell-sand mining under seagrass - mining is permitted for cement manufacturers in Moreton Bay and Cockburn Sand*

These issues are all concentrated in the coastal zone and lower catchments where there are multiple, competing uses of resources, a complex maze of legislation, jurisdictions and R&D sectors and a policy vacuum. The major recreational fisheries of this country are based there and their professional counterparts supply most of the fresh fish for domestic consumption.

Historically, estuaries have been the major points of human settlement in Australia, because of the availability of water, arable land, shelter for shipping and fisheries. Following a long history of urbanisation, industrialisation and expansion of intensive agriculture onto floodplains, many estuaries and lower catchments have become severely degraded. This development occurred with very little systematic planning on a regional basis, and estuaries and floodplains have become "problem ecosystems" for managers.

In synthesising all available reviews of the problems, Robertson (in press) identified the following factors at the root of the issues listed above:

- *alterations to land management practices in catchments - destruction of riparian vegetation, overgrazing leading to nutrient, sediment and turbidity loadings downstream*
- *river regulation - major growth in water storage capacity has poorly known effects (but high risks) for estuarine and marine ecosystems; can change geomorphology of lower estuaries*
- *direct habitat loss - "reclamation" of mangroves and saltmarsh for development*
- *urbanisation - direct habitat removal ; increase in point source nutrient and contaminant discharge*
- *over-harvesting - extreme pressure by anglers and conflict with commercial sectors*
- *exotic species - ballast water introductions are costly for mariculture, but have the potential to profoundly alter biodiversity and food webs*

The major issues with changes to drainage and habitat alteration are occurring because of competition amongst users of water resources, floodplain lands, riparian zones and the coastal zone. Whilst direct destruction of mangroves and seagrass are prevented by some States under Fisheries Acts, there are no provisions under this legislation to prevent loss of such downstream and instream habitats from upstream disturbances and wastewater inputs.

Therefore, the greatest challenge facing fisheries stakeholders is to harness economic forces outside of their control to conserve and rehabilitate key features of entire catchments. Our financial system is not attuned to the variability in climate - the fixing of interest rates encourages bad land-use practices in drought times when the environment is most vulnerable, freshwater is under-priced and over-allocated, and there are no tax rebates or rate relief to give incentive for land-holders to actively rehabilitate wetlands.

In this chapter we provide a brief summary of the issues for which the FRDC has a role in conserving and rehabilitating fisheries habitats, in declining order of risk and hazard for fisheries and mariculture.

2.1.2 The literature

The results of our literature searches and interviews could be readily classified by sub-issues in Table 2.1.1. These groupings loosely reflect the risks, hazards and existing responses to sub-issues of changes to drainage and habitat alterations as they are perceived by us for each State, until 1996:

- *New South Wales : mainly riverine, estuarine and floodplain management issues - Acid Sulfate Soils, alienation of habitat, barriers to fish movement, serious loss of seagrass, serious decline in oyster farming; Response : problems now well-known and further R&D is being focussed within restoration and rehabilitation frameworks; NSW has pioneered with Fishways R&D and Total Catchment Management. Coordination and outcomes for the local TCM committees are integrated at State level.*
- *Queensland : mainly estuarine, floodplain and coastal foreshore issues - incremental mangrove and freshwater lagoon loss, canal estates, ponded pastures, biting insect control, seagrass loss, ASS problems now emerging under SIIP drainage; Response : problems of incremental loss of aquatic vegetation being addressed by "no nett loss" policy, but performance of this strategy is unknown; "CHRIS" (FRDC#95/167) aims to integrate habitat and fisheries monitoring; new focus on Fishways - but poor response to freshwater lagoon destruction, only restocking downstream (see Chapter 4). Development of Integrated Catchment Management, and some ICM coordinators in place to implement action.*
- *Western Australia : mainly estuarine and bay issues - seagrass loss in Cockburn Sound and Albany, salinisation of south coast rivers, foregone production due to artificial lagoon openings and closures: Response : unavoidable seagrass loss due to shell-sand mining is being accompanied by R&D on restoration potential and comprehensive study of effects on fisheries; integrated approach to major eutrophication issues very successful (see Chapter 3).*
- *South Australia : mainly Gulf seagrass and Murray Mouth issues - widespread seagrass loss due to variety of causes, foregone fisheries yields from loss/timing of environmental flows of freshwater into Coorong; poor mangrove health in major nursery related to reclamation and nutrient inputs (see Chapter 3); rapid growth in mariculture: Response : sub-tidal mapping of coastal habitats for IMCRA and NRSMPA; no clear management responses*

embedded in seagrass monitoring programs, apart from multi- million dollar beach replenishment program; promising proposal for Coorong fishery enhancement needs investment.

- *Victoria : mainly bay and estuary issues – widespread seagrass loss due to variety of causes has been accompanied by correlations with poorer fisheries yields; permanent opening at Lakes Entrance has had poorly documented effects on fisheries habitats inside Gippsland lakes; water quality issues are the over-riding threats to fisheries and mariculture (see Chapter 3): Response : no seagrass monitoring or research programs; excellent biotoxin surveillance programs need extension nationally (see Chapter 3, 4).*
- *Tasmania: mainly bay and estuary issues - widespread seagrass loss is poorly understood, Macrocystis kelp decline may be due to ocean warming; over-riding issues are water quality and introduced species as threats to mariculture and fisheries. Response : regional mariculture development plans to safeguard access and water quality; integrated R&D to avoid toxic blooms (see Chapters 3 and 5); new R&D on fisheries-seagrass links, but no systematic seagrass monitoring.*
- *Northern Territory: mainly floodplain issues - massive saline intrusion on the Mary River is poorly understood, but some control measures threaten barramundi ; ponded pastures and Acid Sulfate Soils are emerging threats. Response: some early R&D on fishway design to allow barramundi access to/from nurseries with lowered risks of being trapped.*

Table 2.1.1. Selected literature on coastal changes to drainage and habitat modification - documentation or effects on fisheries production and fisheries habitats.

State\ Issue	*Acid Drainage*	*Barriers to fish/tide*	*Canal Estates*	*Tidal/Wave climate*	*Saline Intrusion*	*Ponded Pastures*	*Direct Mangrove Destruction/ runnelling*	*Seagrass loss (see also Ch.3)*
NT		*Griffin (1994a)*			*Anon. (1995k), Griffin (1994a), Knighton et al. (1992), Woodroffe and Mulrennan (1993),*			
Qld	*Beumer et al. (1996),*	*Beumer et al. (1996), Bryan (1982), Bunn et al. (1996), Hogan and Graham (1994), Hogan et al. (1995), Jackson (1996), Lupton et al. (1995), Russell (1987, 1988), Russell and Garrett (1985), Tait (1996)*	*Beumer et al. (1996), Jarvis and Colvin (1981), Morton (1989, 1992), Williamson et al. (1994),*	*Thom (1989), Walker et al. (1989a),*	*Russell and Hales (1994), Russell et al. (1996 a,b)*	*Beumer et al. (1996), Byron (1991), Chuk (1991), Garrett (1991), Ponded Pastures Steering Committee (1996),*	*Beumer et al. (1996), Beumer and Halliday (1994), Bucher and Saenger (1989), Butler (1996), Duke (1997), Hulsman et al. (1989), Hyland and Butler (1989), Quinn and Beumer (1983), Russell and Hales (1994), Russell et al. (1996 a,b)*	*Beumer et al. (1996), Brodie (1996), Goldsworthy (1994), Poiner and Peterken (1996), Shepherd et al. (1989)*

State\ Issue	Acid Drainage	Barriers to fish/tide	Canal Estates	Tidal/Wave climate	Saline Intrusion	Ponded Pastures	Direct Mangrove Destruction/ runnelling	Seagrass loss (see also Ch.3)
NSW	*Callinan et al. (1989, 1993, 1995 a,b), Lehane (1996), Lin et al. (1995), Lines-Kelly (1995a,b),, Pearce (1990), Rodgers and Burke (1981), Sammut et al. (1993, in press), Virgona (1992), White et al. (1995, In Press)*	*Boon (1992), Bunn et al. (1996), Burchmore et al. (1993), Harris (1984), Mallen-Cooper (1993), Middleton et al. (1985), Pollard (1993a), Pollard and Hannan (1994), Shepherd (1992), Walker (1985), Walker et al. (1994), Webbnet (1996), Williams and Watford (1996a,b, In Press),*	*Scales and Alach (1981),*	*Bird (1996), Bird and Koike (1986), Mitchell and Carruthers (1996), Pollard (1994a,b),*			*Bucher and Saenger (1989), West et al., (1985)*	*Collett et al. (1981), Larkum and West (1990), Shepherd et al. (1989), West (1983,1990a,b), West et al., (1985)*
Vic							*Bucher and Saenger (1989,1991),*	*See Chapter 3; Edgar et al. (1993), Shepherd et al. (1989)*
Tas							*Bucher and Saenger (1989,1991),*	
SA		*Geddes and Hall (1990), Hall (1984), Olsen (1991),*					*Bucher and Saenger (1989,1991),*	*See Chapter 3; Clarke (1987), Clarke and Kirkman (1989), Shepherd et al. (1989)*
WA			*Atkins (1989)*	*Neira and Potter (1992b),*			*Bucher and Saenger (1989),*	*See Chapter 3; Hastings et al. (in press), Shepherd et al. (1989), Walker et al. (1989b), Walker and McComb (1992)*

2.1.3 FRDC action

The need for a coalition amongst R&D Corporations

Fisheries stakeholders share some common goals with other catchment users to rehabilitate water quality and environmental flows. Consequently there is an urgent need to coordinate and integrate FRDC investment with the other R&D Corporations servicing dairy, grazing, sugar, and Land and Water Resources. This has occurred for the first time with the recent scoping report by Webbnet (1996) on options for investment in R&D to address problems in northern NSW floodplains, but otherwise the links have been slow to evolve.

There are several major opportunities for the FRDC to find common goals and solutions for estuaries and the coast with other initiatives. For example, the recent "Wetlands R&D Program" Scoping Review by the LWRRDC did not cover estuaries, because of lack of resources, despite the inclusion of habitats such as mangroves in the LWRRDC mission statement. Similarly the National River Health Program does not yet cover estuaries and there is a CRC for Freshwater Ecology - but not one for Estuaries or the Coast.

The CSIRO Coastal Zone Program had cross-divisional goals to do landscape-scale research in "representative catchments", but the flux in staff and structure have not made it possible for us to identify clearly how effective this has been. One catchment - the Herbert River in the wet tropics - has been the subject of perhaps more process-oriented studies than any other, up to the point of production of decision-support systems and "Natural Resource Management Tools" (see Chapter 3), yet we did not find any attempt to incorporate studies of estuarine fisheries with the overall initiatives.

There is also a policy vacuum. One observer with a long involvement with fisheries habitat issues made the following observation:

> *"The lack of a coordinated coastal zone management policy has been noted in several recent reports on the coastal zone, and the Department of Environment, Sport and Territories recently published the Commonwealth Government's coastal policy ("Living on the Coast" May 1995). Unfortunately for fisheries and marine ecosystems, where this... discusses the population related impacts, an ineffective policy line emerges - a weak exhortation to manage the symptoms, while failing to address what causes the disease - as it treads softly past issues of population control and coastal land development."*

Robertson (in press) has provided a critical review of the key knowledge gaps, research and management structures, policy and training regimes, and ways forward for estuarine research:

- *R&D should be performed by teams which integrate physical, chemical and biological disciplines*
- *research will need to be better integrated with management needs, and management decisions need to reflect the findings of interdisciplinary work*
- *government policy should support long-term research and reflect the latest integrated knowledge about estuaries*

More emphasis needs to be given to long-term, catchment-scale, system level investigations in estuaries, because:

- *most management problems are caused outside the immediate boundaries of estuaries in entire catchments*
- *Australian rivers exhibit a higher degree of temporal variability than those in the rest of the world*

The best way to approach these recommendations would be a coalition amongst relevant R&D corporations as, in reality, their investments and R&D Programs have already directed and focussed the research by most institutions in the coastal zone.

The greatest challenge for all these R&D Corporations with the downstream effects of agriculture and development is to identify and implement better ways to transform scientific expertise and knowledge into information relevant to natural resource management - and to ensure this information produces outcomes that safeguard sustainable use of land and water resources.

The Integrated Catchment Management Committees (TCM in NSW and ICM in Qld) offer potential vehicles for Adaptive Environmental Assessment and Management programs that could focus R&D in such an integrated way (see Grayson and Doolan 1995, Syme et al. 1994 for definitions and review). The newly announced (mid-1997) disbursement of 1.8 billion dollars for "Coasts and Clean Seas" and the Natural Heritage Trust by the Howard government is aimed at works by community groups. With integrated involvement of R&D Corporations in catchment management groups this expenditure could be better focussed.

Cooperation between engineers and biologists in designing fishways is essential in restoring access along regulated rivers, and a coalition of the FRDC with the LWRRDC and the

Australian Institute of Engineers would assist this. However, in the late stages of our review we found that, in one important case on the Burdekin River in north Queensland, investments in relatively inefficient fishways were being considered because haste and engineering convenience were over-riding the biological advice on fish movement patterns and requirements. Fishways that restore some access only are simply not good enough when very large numbers of fish are trying to pass upstream, yet haste to fulfil objectives and spend allocated funds, as well as corporate parsimony, are new pressures on an old problem that may see Australia add to its list of failures to restore fish passage in coastal rivers.

Common R&D Goals with the LWRRDC Wetlands R&D Program

The Scoping Review and Background papers for the Wetlands R&D Program (see Bunn et al. 1996) short-listed seven priority issues. In descending order of priority these were :

1. *Water regime*
2. *Habitat modification*
3. *Pollutants*
4. *Weeds and feral animals*
5. *Monitoring*
6. *Wetland valuation*
7. *Information/technology transfer*

Our review shows a similar priority for "changes to drainage" and "habitat modification" as threats to fisheries habitats. We therefore recommend that the FRDC has specific, common priorities with the LWRRDC for :

- *determining the role of "environmental flows" of freshwater in estuaries and wetlands*
- *addressing the impacts of barriers to tidal exchange on aquatic habitats, introduced fauna flora and current land use practices on floodplains and near watercourses*
- *developing inventories, classifications and mapping methodologies of coastal wetlands and inter-tidal and sub-tidal vegetation*
- *developing integrated weed control programs and conservation of riparian vegetation*

In this regard, Moore and Lloyd (1996) (in Bunn (ed.) 1996) identified that :

- *there is an urgent need to investigate the importance of wetland inundation frequency, duration, peak flows, seasonality, and total water budget (groundwater and surface water) to key vegetation communities or species.*
- *time and money are generally not available to conduct exhaustive studies of individual wetlands in order to provide information to wetland managers. A classification system is*

necessary that incorporates the critical elements of water regime requirements of representative wetlands. The numerous wetland classification systems currently in existence provide an excellent basis from which a classification scheme could be developed.

- *decision support systems for environmental flows in river and streams must be developed to incorporate wetlands.*

The R&D proposed by Lukacs and Pearson (1996) in an overview in Bunn (ed.) (1996) included:

- *communication and education by developing a "Wet-Land Care" Program*
- *development of methods of inventory and classifications that overcome the difficulties of lack of clear boundaries of ephemeral wetlands*
- *development of a policy of "no nett loss of wetland area/function"*
- *close study of the potential as waste-water scrubbers of constructed wetlands (these could serve a fisheries function too)*
- *fencing of riparian vegetation from grazing pressure*

Some of the other issues we have identified would also benefit from coordination of R&D with some of the LWRRDC's 15 National Programs (see Lake 1994 for review). Most relevant are the:

- *National River Health Program – monitoring river health, and ensuring "environmental flows" (see Davies 1994b)*
- *Pesticides Program - eg endosulfans in cotton-growing regions have caused large fish kills of freshwater sportfish (see Chapman 1993)*
- *National Eutrophication Management Program - eg. blue-green algal blooms in the Hawkesbury River (eg. Harris 1994)*
- *Riparian Vegetation Program - eg preventing sedimentation of estuaries (see Price 1993, Campbell 1993 and Bunn and Pusey 1993 for review).*

Specific recommendations for FRDC investment

The recommendations we make in Table 2.1.2 reflect the need to integrate R&D with adaptive management responses to well-known problems, and to be more specific and proactive in identifying the prime fisheries habitats and corridors amongst them. For example, simply determining and communicating that freshwater wetlands are critical bass and barramundi nurseries has proven ineffective in protecting them from ongoing destruction and alienation - inventories to locate and conserve the major remaining nurseries of these (and most other major estuarine species) are needed.

We believe that the lack of basic life-history information and knowledge of habitat dynamics and inventories identified in Chapter 1 underpins all the recommendations we make in Table 2.1.2. Most importantly, many of these knowledge gaps can be filled in a Adaptive Environmental Assessment and Management Approach to rehabilitation of known problems.

For example, there have been few studies of larvae in estuaries, and no studies of the way that these and post-larval juveniles penetrate estuary mouths subject to strong tidal currents. These subject could be studied during design of fishways, rehabilitation of flow through floodgates and R&D aimed at determining the best timing for lagoon openings.

Better mapping techniques are needed to assess habitat status and dynamics, and to identify structures threatening fish passage or alienating tidal flow. Seemingly straightforward interrogation of aerial photographs and mapping of mangroves and other intertidal wetlands has suffered from lack of standardisation of scale ("fringe" habitats are not detected - yet may be important and vulnerable), standardisation of high water mark and classification of vegetation type. The existing inventories have never been formally integrated with fisheries production figures to gain overviews of production (see Chapter 1). This gap will be filled in Queensland by the Coastal Habitat Resource Information System project ("CHRIS" FRDC #95/167).

Floodgates and other major barriers to tidal and fish access are often not marked as such on maps and the benefits of the Williams and Watford (1996a,b) approach include widespread use of local fishermen's knowledge to help with the essential "ground-truthing" of the hazards posed by such structures. Extension of their methods for inventories of the rest of Australia's coastal waterways would be a basic step in assessing the priorities for rehabilitation.

Historically there has been a reactive approach by the science community to problems in fisheries habitats. Proper inventories of key habitats and threatening processes could be developed in a way that resource managers and catchment coordinating committees can be proactive in including fisheries values in regional planning initiatives. Knowledge of what to protect and restore and how to do it is a basic pre-requisite to the integrated coastal planning that is widely recommended as the only way forward for sustainable resource use (see Kenchington 1996, RAC 1993). Some regional planning initiatives that have attempted to incorporate fisheries intelligence are the FNQ 2000 and SEQ 2000 plans in Queensland in which QDPI (Fisheries) played an important role (p.c. #60 K.Derbyshire), and the aquaculture development and management plans in Tasmania and SA (eg. McLoughlin 1997, Preston et al. 1997).

Geographic Information Systems are at the core of some of these advances in planning and inventory (eg. Long et al. 1994b, Preston et al. 1997). Their development, application and testing provide many R&D opportunities.

There should be a lead role for the FRDC in developing fishway designs and monitoring programs suitable for native species. The performance of these fishways has been proven in freshwaters, but the proponents stress that monitoring fish movements both below and above the devices is essential to assure their success. Several States are investing in the engineering and infrastructure requirements for these fishways, but their success ultimately depends on R&D on native fish behaviour and requirements.

During our interviews we detected some scepticism about habitat restoration and rehabilitation in the scientific community. We believe this stems from over-estimating what is required for success in these endeavours. It should be emphasised here that restoration, rehabilitation or habitat creation in estuaries can be as "simple" as restoring tidal flow or a shallow sedimentary profile - natural recruitment of aquatic plants, fish and prawns will follow. There are also many opportunities for unavoidable habitat modification to serve a better fisheries role, as drains and other structures all have limited lives, and maintenance schedules offer the chance to serve fisheries better. For example, Cairns City Council has involved QDPI Northern Fisheries staff in designing urban drains that can act as barramundi, prawn and mud crab nursery habitat (Clarke et al. 1996). Morton (1993) has outlined further how unavoidable developments can be accompanied by some habitat enhancement.

However, the recent spread of mosquito-borne diseases such as dengue and Ross river fevers and Japanese encephalitis has caused concern for residents living near wetlands and development of "runnelling" and spraying programs with larvicides. We could find no studies of the effects of these practices on habitats and early life-history stages, and few publications on the ecology of mosquitoes and fishes within breeding sites (eg Hagan and Kettle 1990). There are many R&D opportunities for the FRDC in assessing fish-habitat-mosquito interactions, as proposals to restore fisheries habitats will undoubtedly be challenged at some stage by concerns about creation of biting insect habitat - even though fish may have a role in repelling oviposition by mosquitoes (Ritchie and Laidlaw-Bell 1994).

We have collated a detailed survey of all recorded habitat restoration initiatives in coastal Australia, apart from fishways, in Table 2.8. They share an almost ubiquitous lack of monitoring of performance in a fisheries sense, and many of them were designed to stabilise sediments and channels rather than have a fisheries production function. This has been a major concern amongst the scientific community for performance of QDPI's "no nett habitat loss" policies. We believe the demand for trade-offs in this policy is outstripping both knowledge about what to trade and restore, and also what function the exchange is having in encouraging mangrove growth and fisheries production.

R&D on the fisheries functions of "stands" versus "fringes" and different types and locations of mangrove forest are urgently needed to help this policy conserve fisheries values. A similar lack of knowledge for seagrass patches and assemblages (eg. invasive colonisers vs old-growth Posidonia) is under investigation in compensating for shell-sand mining scars by transplants and artificial reefs in Cockburn Sound. Unlike relict populations on the east coast, there does seem to be some restoration potential for Posidonia in WA given appropriate R&D. Many tropical genera offer much more potential and, given the right sedimentary profile and seedbanks, Heterozostera and Zostera will colonise disturbed habitats such as canal estates (Morton 1993, West et al. 1990, also see section 2.8).

A surprising feature of our review was the failure of the scientific community in taking up the opportunities for research offered by the multitude of alterations to habitat caused by smaller coastal developments. This may be due to the lack of funding for such work from both the developers and the funding bodies such as the Australian Research Council and the FRDC. However, there could be also be a lack of flexibility in identifying and pursuing such opportunities by some organisations who are locked into rigid planning of research activities.

Robertson (in press) has outlined how R&D could be better shaped to satisfy both the applied and strategic needs of managers.

For example, we could not find any Australian literature on effects of channel dredging or marina construction on fisheries (as distinct from canal estates), yet these activities have occurred on the "doorsteps" of some major institutions and have been the subject of much controversy from the fishing public.

Once an Environmental Impact Assessment is accepted and a development proceeds there is seldom any long-term monitoring in a controlled manner that allows key questions to be answered concerning effects of loss of mangroves, marina construction or channel dredging. These three disturbances are a feature of sub-tropical and tropical developments, but there is still insufficient knowledge to predict their cumulative effects on local fisheries with any useful level of certainty. The consent for development should include a requirement for longer term monitoring.

It would be almost impossible to obtain research permits to manipulate habitats in the way that these developments do, so researchers could do well to take advantage of unavoidable habitat losses in an experimental framework. Indeed, some of the most informative fisheries habitat research has been done during the planning for very large developments, such as the sandy beach and bay demersal work carried out as part of the Jervis Bay study (CSIRO 1994), and the seagrass restoration studies in Botany Bay (Gibbs, In Progress, see section 2.8) and Cockburn Sound.

Table 2.1.2. Summary of Major Opportunities for FRDC investment in addressing R&D Gaps in knowledge of "Changes to Drainage and Habitat Alteration"

R&D Gaps	*Main Habitat*	*Main Fishery*	*Key Reference*	*Key Initiative Underway*
Conservation, Rehabilitation and Restoration approaches - a need for objectives, techniques and measures of performance				
1) inventories of degraded habitats and major threats (structures, processes) of regional priority, in the context of fisheries production – what are the priority coastal locations for conservation, rehabilitation and restoration?	*All east coast estuaries;*	*Barramundi, Bass, Eels, Sea Mullet, Black Bream, Mulloway, school prawns, mud crabs, and most estuarine species*	*Williams and Watford (1996a,b), Bucher and Saenger (1989,1991), West et al. (1985),*	*see Table 2.8.1 for review, Streever (in press), CHRIS (FRDC #95/167)*
2) Adaptive research and management - identification, development, application and monitoring of rehabilitation techniques and approaches, in the context of "Area-Catch-Expense" frameworks and the "mosquitoes-fish-birds" dilemma	*canal estates, well-known degraded wetlands of key fisheries significance*	*as above*		
3) Design, application and monitoring of Fishways - the need for a national FISHWAYS Program?	*coastal rivers and streams in all States; Murray Mouth*	*All freshwater fishes; Barramundi, Bass, Eels, Sea Mullet, Black Bream, Mulloway and many estuarine species*	*Jackson (1996), Harris and Mallen-Cooper (1992)*	*QDPI "Fishways" Initiative - see Beumer et al. (1996); FRI NSW see eg Mallen-Cooper et al. (1995);*
Development and application of "no nett habitat loss " policies - lack of knowledge of criteria for site selection, design and performance monitoring - is the strategy working?				
mangrove "stands" versus mangrove" fringes" - how far do fish/prawns penetrate and what are the relative fisheries functions and values?			*Halliday and Young (1996), Vance et al. (1996a)*	
Effects of acid drainage on fisheries and oyster farming - a need for further understanding of the problem, its origins and dynamics and techniques for prediction and amelioration	*well-recognised in nthn NSW; emerging hazard in Qld*	*NSW estuarine and oysters; Qld estuarine*	*White et al. (in press), Pollard and Hannan (1994)*	*ASSMAC, Sugar Industry Infrastructure Package (Qld) Drainage schemes*

R&D Gaps	*Main Habitat*	*Main Fishery*	*Key Reference*	*Key Initiative Underway*
Development of objectives, techniques and measures of performance for rehabilitation of seagrass species with restoration potential	*tropical seagrass genera; some temperate beds*			
"Environmental Flows" in estuaries - what are the roles and requirements for freshwater pulses in estuarine fisheries production	*all estuaries with freshwater input*	*school prawns, Banana prawns, Barramundi, Bass, Eels, Mulloway; other catadromous and anadromous fish*	*Robertson (in press)*	
Effects of Modification of tidal regime and wave climate in enclosed waters (eg. by training walls and dredging)				
1) cascading effects of saline intrusion and erosion/accretion relationships - what are the fisheries implications and how can they be ameliorated?	*NT Mary River Floodplain; Mourilyan Harbour; Wallis Lake*	*Barramundi and other catadromous or anadromous fishes*		
2) Effects of hydrodynamic barriers and changes to lagoon opening regimes on access of pre-settlement stages to estuaries - how do juvenile stages cope and when should lagoons be opened?	*NSW and WA estuaries and coastal lagoons*	*larval and pre-recruit stages of estuarine fish and prawns*	*Gibbs (1996)*	
3) Ponded Pastures and their implications for fish nurseries	*wetlands, saltmarsh, mangroves; NT, Gulf Country, Central Qld*	*Barramundi, Arid Catfish; other estuarine species*		*Ponded Pastures Steering Committee (1996)*
Runnelling for mosquito control - what are the implications for fish nurseries and "connectivity" between saltmarsh and mangroves	*SE Qld mangrove/saltmarsh*	*sub-tropical estuarine*	*Beumer et al. (1996)*	

2.2 Coastal floodplains and wetlands - most vulnerable habitats?

Coastal floodplains and freshwater wetlands are probably the most threatened fisheries habitat in Australia, because of their vulnerability to destruction, alienation, pollution and deoxygenation throughout the country - even in the most remote regions, where grazing occurs. Catadromous species, which migrate from freshwater nurseries to breed in salt water, are very vulnerable on the east coast to loss of access to wetland habitat. Barramundi, Australian Bass and Eels are the most notable of these species in a fisheries sense, but Sea Mullet and school prawns are also known to penetrate habitually far into freshwater as juveniles.

Like Murray Cod, the first two species are "cultural icons" on a regional basis and, despite their low commercial value, depression of their populations has lead to conflict between anglers and netters so that many other, unrelated, coastal fisheries suffer. These conflicts lead to repeated calls for bans on coastal netting - for example, the angling media chooses to view the spectacular success of the Northern Territory barramundi sportfishery as a result of netting bans, not intact wetlands.

The fragmented administration and poor legislation concerning wetlands makes management and rehabilitation difficult in all States. For example, in Queensland:

- *the QDPI has powers up to the high water mark (seagrasses and mangroves are covered by the Qld Fisheries Act 1994, as they are in NSW; see Burchmore 1993)*
- *the Dept of Environment manages wetlands - but Melaleucas and emergent or submerged macrophytes are not recognised as "aquatic plants" under legislation*
- *the Dept of Natural Resources (Water Resources division) governs watercourses - but ephemeral corridors needed by fish for access to and from coastal lagoons are often not defined as watercourses*
- *in all, there are over 50 authorities involved with activities in Qld wetlands and watercourses.*

The failures of these arrangements to protect fisheries are not rare - perhaps the most striking example we found was the bulldozing in 1996 of trees and mangroves into the boundaries of, and acid drainage into, the Palm Creek Fish Habitat Area (FHA) in north Queensland, due to cane expansion. This and other failures have occurred despite the best practices advocated by *biologists (eg. Hogan and Graham 1994, Hogan et al. 1995), shire councils, cane assignment boards and even neighbouring cane farmers.*

It is hoped that a project reviewing all Australian legislation relevant to fisheries habitats (M. Mobbs and Associates) , commissioned by FISHCARE (now Fisheries Action Program) in 1994, will highlight these problems. They are beyond the scope of our review.

2.2.1 The acid sulfate soil problem

The most prominent single issue in our review, and perhaps the catalyst for FRDC's "Ecosystem Protection" Program, is the drainage of northern NSW floodplains and their acid sulfate soils and the resultant fish kills and red-ulcer disease. The slugs of acidic water that turn turbid estuarine waters disarmingly clear, kill gilled life that cannot move away and then cause chronic fungus infection and ulcers down to the bones on fish, are the result of a chain of anthropogenic disturbances to floodplains.

The following synthesis was drawn from personal communications with researchers at the CSIRO Centre for Environmental Mechanics (p.c.#360 I. White, p.c.#820 I. Webster, p.c.#850 Y.Tan) and from a seminar delivered by Dr Ian White (see White In Press).

Acid Sulfate Soils (ASS) and Potential Acid Sulfate Soils (PASS) are widespread on the entire Australian coast, but especially on the east and north coasts. They were formed 6 500 yrs to 10 000 yrs before present when organic matter (such as mangrove peats) was inundated during the Pleistocene sea level rise. They contain 0.1 - 15% sulphur – mainly in the form of Iron Sulphides (pyrite) – and produce sulphuric acid as a normal part of the sulphur cycle when oxidised. The process is catalysed by iron oxidising bacteria, and is governed by pH (about 3.0 is optimal), oxygen and temperature. The amount of sulfur present governs the rate of oxidation and the amount of acid produced.

Dairying, prawn aquaculture, Ti Tree farming, urban canal developments and resort developments have all disturbed acid sulfate soils at some locations, by excavation, to allow exposure to air and subsequent acid drainage. The cane farming and grazing industries, however, have created the greatest hazard in NSW. This is because over 90% of NSW sugar cane is grown on PASS and the position of the water table is fundamental to the problem.

Early problems caused by floods and ignorance of the risks and hazards of PASS saw extensive alteration and drainage of floodplains to mitigate flood damage through floodgates that let *water drain away at low tide, but not return. The State government encouraged this through "Drainage Unions" and rivers were straightened to help (see section 2.3.1). However, a simultaneous aim of the agriculturalists was to export as much excess rainfall as quickly as possible to prevent water-logging of the cane roots and encourage pastures. The natural drainage rate was about 100 days, but now it has been brought down to about 2-5 days – even less for pastures (<1-2 days).*

There has been widespread and irreversible shrinkage of soils and subsidence due to land use and drainage behind the floodgates. For example, a subsidence of 9-13 metres has occurred in parts of the peatlands in the Cudgen Lake catchment. There was coordination and integration in the design of the floodgates, but subsequent drainage of individual dairy and cane properties has mostly produced an "ad hoc" approach that is not attuned to the overall hydrology of the floodplains in northern NSW. Some dairy drains are 4 m deep, with large spoil banks made of oxidising ASS. Many cane farms there have been draining water tables too far below the cane roots (>80 cm), and have suffered yield decline as a result of acidification.

Hydrology and rainfall in the catchments govern acid production in a sequence of events that have the following major features and hazards:

- *after rainfall events and a rise in the water table Aluminium, Iron, Manganese and other ions are stripped out of soil by sulphuric acid. The Al and Fe comes from aluminosilicates (clay). The lower the pH the greater the amount of aluminium that is mobilised*
- *floods drain large "slugs" of this toxic water through floodgates to meet higher pH in the main estuary to produce aluminium hydroxide and iron hydroxide floccs in massive amounts*
- *about 1 tonne of Iron flocc is produced for every tonne of pyrite oxidised*
- *this produces a bluey-green stain in the estuary – the floccs then bind to clay particles and settle out to produce deceptively clear estuarine waters*
- *smothering of riverbed with floccs of Iron Hydroxide (up to 1 metre deep) and death of most gilled, benthic life*
- *during this time fish kills occur for a variety of reasons that depend on prevailing pH*
- *acid kills the fish at ph=3*
- *aluminium hydroxide floccs bind to clays and attach to skin and block gills at higher pH*
- *monomeric aluminium toxicity kills the fish at ph=5 [$AlOH_2^{++}$]*
- *fish with epithelial defenses weakened by metal floccs and acid suffer from Aphanomyces fungal infections*

- *these infections produce extensive ulcers ("red-spot", "EUS", "Bundaberg Disease") on fish that often are so deep that the caudal rays or neural spines of the backbone are visible*
- *survivors of these attacks invest so much in healing that there is no reproduction until condition is regained in subsequent years*
- *fish with ulcers or healed ulcer scars are unmarketable and have comprised up to 30% of some catches of whiting, bream, mullet and flathead*
- *poor crop and pasture growth prevails in acidifed parts of the floodplains*
- *lower animal production*
- *lower growth rates of prawns in pond aquaculture because of less bicarbonate is available to them in low pH and they will not moult (this is a problem in Clarence)*
- *recent focus is revealing a role of acid drainage in oyster health (mass mortality, disease, shell erosion and low growth performance) in Tweed and Hastings Rivers*
- *corrosion of pipes and cement structures*
- *acidification of aquifers and potential human health problems from groundwater consumption (high aluminium, acidity)*

After floodwaters have passed the acid drainage pools in the drains behind the floodgates. The deceptively clear waters and vegetation in these drains hides the poor water quality from the untrained eye. The giant water lilies (Nymphaea gigantea) thrive at ph=2.5, the sedge Juncus kraussii and the weed Sertaria are also acid tolerant and invade the riparian zone. A few fish species are tolerant of low pH – notably the Tarpon in Trinity Inlet and the Empire Gudgeon in northern NSW. The lily and weed growth chokes waterways, so that floods wash down rafts and mats of rotting vegetation to cause further problems with biological oxygen demand.

Acid budgets have been constructed that show the scale of the problem. In the Tweed River 706 tonnes of sulphuric acid went downstream in May 1992, with a total of 2600 tonnes for the year. Abundant fish kills along 27 km of Richmond River in 1987 were traced to 20 point discharges of acid and 600 tonnes were produced in one month in a later rainfall event.

The associations between acid drainage, Aphanomyces fungal infection and "red-spot" ulcer disease and fish kills have been reviewed by Callinan et al. (1989, 1993, 1995a,b), Sammut et al. (1993, in press) and Virgona (1992).

However, recent appearances (August 1997) of ulcerated fish in both Hinchinbrook Channel and the Embley River near Weipa have drawn a somewhat different response about the role of acid drainage in Aphanomyces outbreaks from local authorities. The following quote is *drawn from advice to the senior author from a principal veterinary pathologist working with fish diseases.*

"As in all infectious aquatic animal diseases there is an interaction between the environment, the host fish and the infectious agent (pathogen). In EUS the environmental conditions that allow the fungus to reproduce and the infectious stage (propagule) to survive is important. Also important is the immune status of the host fish population. EUS has been associated with spawning stress in (yellowfin) bream. In Queensland it has become clear EUS has not occurred in the same river/estuary system two years in a row. The immunity to EUS in a fish population is important in determining whether an outbreak occurs or not. Following an epizootic, a population develops a protective immunity which over a number of years wanes with recruitment of younger, naive fish to the fishery."

"The thing is, EUS can occur independently of acid water conditions. Experiments where fish are placed in low pH water, then the fungus added to the water does not always result in EUS. Epizootics have been seen in unfarmed, undeveloped areas of the Northern Territory. As EUS has spread throughout South-east Asia and South Asia, intensive research on environmental conditions (including pesticide residues and inorganic fertiliser use) has failed to identify a single factor that is consistently significant. The presence of Aphanomyces and the immune status of the fish are usually the only important factors. Acid water does not necessarily equal an EUS epizootic, and EUS does not necessarily equal acid water. Thus EUS may not be a good indicator of water quality degradation."

"The first EUS epizootic was in 1972 in Queensland. Some researchers have speculated the Aphanomyces was introduced with Koi carp from Japan. EUS has then appeared to spread to Papua New Guinea, then to Indonesia, Malaysia, Thailand and the Philippines, then to Indochina and the Indian sub-continent. EUS has occurred in Queensland in different areas, up and down the east coast, since 1972 at infrequent intervals. From QDPI records (not necessarily complete) there was an epizootic just north of Townsville in 1990 and another around Mossman in 1991. There is little control possible now that the disease is endemic throughout Australia. Disease eradication in wild populations of fish would be very difficult. "

This information highlights the need for more R&D on the problem, and shows the serious threats posed by potential for introductions of disease in the aquarium fish and other "live" trades.

National attention has been focussed on the various problems associated with acid sulfate soils through the formation of the Acid Sulfate Soil Management Advisory Committee (ASSMAC), whose activities can be followed through the newsletter "ASSAY" (Lines-Kelly 1995a,b).

2.2.2 Wetland loss

Coastal wetlands have poorly defined, ephemeral boundaries and connections to the sea that make them difficult to map and protect (eg. see Blackman et al. 1992). System-level processes in them are driven by seasonal flooding and drying and connectivity with other watercourses (see Pajimans et al. 1985 for review). A study by the LWRRDC found that since the start of the Burdekin River Irrigation Area in 1988 over 50% of the ephemeral wetlands in the lower floodplain have been lost. The Sugar Industry Infrastructure Packages (SIIP) in coastal Queensland provide an example of the loss of these remnant wetlands. On the Tully-Murray , Herbert and South Johnstone floodplains, the conversion of cleared grazing lands to intensive agriculture through extensive laser levelling and drainage works have obliterated wetlands. There have been surveys of fish faunas in some of the wetlands (Hogan and Graham 1994) and guidelines to safeguard this fauna have been identified in some assessments of the impact of further water management schemes proposed under the Sugar Industry Infrastructure Package (SIIP) (Hogan et al. 1995). The extent of adherence to these voluntary guidelines is unclear.

In the tropical grazing landscape, coastal wetlands often act as de facto ponded pastures (see below) – however, with the change in the landscape to cropping, these ephemeral wetlands can easily be filled, levelled and utilised. The high local land rates in some parts of those floodplains have made it an economic imperative to convert to cropping. All these areas contain poorly documented barramundi nurseries that arguably were the most productive on the east coast. Restocking has now commenced in the region.

Identification, conservation and restoration of such wetland nurseries could be a common, priority goal for the FRDC, the LWRRDC and Environment Australia - instead the fisheries R&D responses have included a rapid growth of translocations and restocking that poses an additional suite of risks and hazards (see Chapter 5).

Saltmarsh change in Australia

Salt marshes have been reclaimed for port, industrial and housing developments, road construction, parks and other recreational fields, marinas, resorts and canals. In Western Australia, construction of solar salt production ponds has resulted in some habitat loss. Much *larger areas of salt marsh have been damaged by rubbish dumping, construction and maintenance of easements, which have resulted in changes to vegetation and loss of biota, including fish. Stormwater drains discharge excess freshwater, pollutants, nutrients and weeds into salt marshes. As discovered in south-western Western Australia, excess freshwater can promote erosion and alter the natural salinity regime, promoting the spread of freshwater or brackish water species such as Phragmites australis and Typha spp, replacing more salt tolerant species such as Juncus kraussii (Zedler et al. 1990).*

All of these changes (most occurring on adjacent land) can severely affect salt marshes and marsh-dependent biota. Unfortunately, not only are exchanges between Australian marshes and adjacent ecosystems very poorly understood, but so are salt marsh fauna, productivity, energy and nutrient flows. In direct relation to adjacent catchment areas, research is urgently needed on links with fisheries and effects of pollutants, vehicle tracks and insecticides on marshes, and opportunities for control of weeds (eg. Spartina in Vic.) All of these problems have negative effects on the maintenance of high marsh and fisheries productivity (Adam 1990).

Losses in this wetland habitat are not often accurately quantified, and the estimate of 7,650 Ha lost through all Australia assembled by us from various sources is believed to greatly under-estimate the real loss (see Table 2.2.2.1).

Table 2.2.2.1. Estimated areas (Ha) of saltmarsh/saltpan habitat altered in Australian States.

	NSW	VIC	TAS	SA	WA	NT	QLD	Total
Reported Instances	5	2	3	2	6	0	43	83
Area Lost	>20	-	loss	loss	>3,617	-	>4,013	>7,650
Area Gain	-	gain	-	-	-	-	-	sl. gain
1989 Area	5,700	12,500	3,700	8,400	296,500	500,500	532,200	1,359,500

Mangrove change in Australia

Mangrove habitat was altered during the establishment of many Australian coastal towns and cities, but this loss has not been quantified in most cases. Detailed retrospective assessments are possible using aerial photographs dating back to the 1940's (eg see Burton 1982), but these are subject to variable accuracy in interpretation in the absence of "ground-truthing" for habitat that is now altered. Recent assessments, however, are not subject to these constraints, and there is a growing number of areas being accurately mapped, describing vegetation coverage and physical landforms (eg. Danaher 1995a,b,c, Danaher and Stevens 1995).

In our review, it was considered useful to identify the number of reported instances of habitat modification, noting that most were from Queensland (eg Arnold 1996) and NSW (the relevant tabulations can be obtained from the senior author). The results from these reports are summarised in Table 2.2.2.2 , where areas of mangrove loss and gain are summed, whilst recognising that these under-estimate the full extent of change.

The reported loss of mangroves in Queensland is ~1% of the total in the State, and reported change in other States appears minimal. It is significant that the area of mangroves has in some cases increased, but on the whole, losses outweigh gains. It is also relevant that new areas may not represent those lost elsewhere - there has been widespread change from "fringes" to "stands" with unknown effects on fisheries function.

Table 2.2.2.2. Estimated areas (Ha) of mangrove habitat altered in Australian States

	NSW	VIC	TAS	SA	WA	NT	QLD	Total
Reported Instances	10	1	-	1	1	2	68	83
Area Lost	>42	loss	-	loss	loss	>27	>2,816	>2,885
Area Gain	>53	-	-	-	-	-	>874	>927
1989 Area	10,700	4,100	0	11,100	156,100	295,200	342,400	819,500

Recent assessments in Queensland highlight several factors associated with change (see Table 2.2.2.3).

Table 2.2.2.3. Estimated change in area (Ha) and rate of change in some wetland areas in Queensland

Location	Wetland Type	1990s Area	Change Since Earlier	Change %	Change Rate Ha/yr	Comments
Johnstone River, 1951-1992. (Russell & Hales 1994)	Mangrove Freshwater	202 925	+26 -1,752	+15 -65	+0.6 -42.0	High rainfall area. Greatly altered by land clearing and development
Moresby River, 1951-1992. (Russell et al. 1996a)	Mangrove Freshwater	2,873 1,175	+640 -2,188	+29 -65	+15.6 -53.4	Moderate-high rainfall area. Greatly altered by land clearing and development
Hinchinbrook Channel Islands, 1943-1991 (Ebert 1995)	Mangrove Saltmarsh /Saltpan All Intertidal	3,790 46 3,836	+208 -161 +47	+5.8 -77.8 +1.2	+4.3 -3.4 +1.0	Moderate rainfall area. Not directly affected by development
Port Curtis, 1941-1989. (QDEH 1994)	Mangrove Saltmarsh /Saltpan All Intertidal	3,264 2,824 6,088	-646 -990 -1,636	-16.5 -26.0 -21.2	-13.5 -20.6 -34.1	Low rainfall area. Greatly altered by reclamation and development
Moreton Region — Coolangatta to Caloundra, 1974-1987. (Hyland & Butler 1988)	Mangrove Saltmarsh /Saltpan All Intertidal Freshwater Artificial Waterways	14,457 5,010 19,467 - 1,011	-1,234 -592 -1,953 > -591 -	-7.8 -10.6 -9.1 - -	-94.9 -45.5 -150.2 > -45.5 +45.2	Moderate rainfall area. Greatly altered by reclamation, development and construction of canal estates

- *gains in mangrove area may be at the expense of neighbouring wetlands higher up – eg. In the Moresby River, freshwater wetlands have been affected by saltwater intrusion and the recent establishment of mangrove species - by saline intrusion (se section 2.4) ; in the Hinchinbrook Islands, saltmarsh/saltpan areas have been taken over by mangroves*
- *gains in mangrove area downstream equate to erosion and loss of vegetation in the catchment area, where displaced sediment accumulates in the estuary and mangrove colonise these banks – eg. in the Johnstone River (see Russell and Hales 1994)*
- *losses in mangrove areas are greatest where there has been reclamation: – eg. for industrial , port and airport development at Gladstone and Brisbane; for canal estates and construction of artificial waterways in the Moreton region*

- *the rate of loss of mangrove habitat had reached around 95 Ha yr^{-1} in the Moreton region up to 1987.*

Seagrass change in Australia

Around Australia, there are numerous accounts of seagrass decline (see Table 2.2.2.4), describing a reduction in seagrass beds amounting to at least 173,662 Ha, or 3.4% of known seagrass beds in this country. Much of this change has taken place over the last 30-40 years. Proportional losses are much higher in southern Australia, with losses as high as 61% in Victoria, 19% in NSW and 10.3% in Tasmania.

These losses were caused by both human activities as well as natural events such as cyclones and floods. Some episodes of extensive seagrass loss are still largely unexplained in Tasmania and Spencer Gulf, and there is unlikely to be a single major cause of the losses in heavily populated NSW estuaries. Such dramatic decline in habitat is made more serious since there are few signs of recovery or increases. An increase in area was reported in only one instance (Hervey Bay, Qld) – however these were offset by substantial losses, more than 10 times greater, reported three years later following excessive flooding in the area (Preen et al. 1995).

Table 2.2.2.4. Estimated areas (Ha) of seagrass habitat altered in Australian States.

	NSW	VIC	TAS	SA	WA	NT	QLD	Total
Reported Instances	10	6	18	11	4	0	11	60
Area Lost	>2,901	>22,300	>5,139	>15,692	>4,830	-	>122,800	>173,662
Area Gain	-	-	-	-	-	-	>7,500	>7,500
1995 Area	15,300	36,400	50,000	500,000	2,200,000	unknown	2,320,000	>5,121,700

Australian seagrasses are seriously threatened - probably the next most vulnerable fisheries habitat after coastal freshwater lagoons. Most losses are attributable to reduced light from sedimentation and/or increased epiphytic growth from nutrient enrichment. In some cases, other factors such as sediment instability, dredging and poor catchment management interact and make the process more complex. In any case, recovery is rare in temperate Posidonia beds and long-term, more than 10 years, in tropical areas. The causes and effects of seagrass decline are reviewed by Hamdorf and Kirkman (1995), Hillman et al. (1990), Kirkman et al. (1991), Walker and McComb (1992) and Poiner and Peterken (1996).

There is a general ignorance of the extent and dynamics of Australian seagrass. This is a particular problem in the tropics where the spatial and temporal variability in most forms is so great that there will be a need for close monitoring to provide a basic sense of habitat status once initial inventories are completed.

A brief description of the causes of seagrass loss for some States shows the range and nature of the issues. For example, in NSW Posidonia in embayments is being replaced by Zostera, but the shifts in "function" (eg. for fisheries habitat) are unknown. For example, in Botany Bay in 1940 there were about 500 Ha of Posidonia , which has dwindled down to <100 Ha in 1990 (p.c.#610 P.Larkum, Larkum and West 1990).

In Gulf St Vincent SA there are various reasons for dieback relating to sewage discharge of nutrients and stormwater – and the subsequent reversal of sediment accretion and erosion rates – which has led to "blowouts" and collapse of some seagrass beds, followed by sedimentation and smothering of seagrass beds at "downstream" locations (eg. Outer Harbour). The Amphibolis species appear to be most vulnerable to even subtle changes in water quality - perhaps due to the location of SA beds on the edge of their tolerances and geographic range.

Tasmanian losses have been locally very severe - over the past 20 years in Norfolk Bay there was a loss of 1000 Hectares, representing about 58% of seagrass biomass; in Ralph's Bay a 100% loss; and in Pittwater a 94% reduction in cover. The causes are poorly documented (Rees 1996).

In the Success Bank area of Cockburn Sound there was a massive loss of 85% of seagrass since the 1950's due primarily to nutrient inputs (a fertiliser company and sewage outfalls). Losses were greatest at the lower portion of the Sound, and at the lower depth limit (<= 11 metres) of the seagrass beds. This "narrow-banding", or a decline in the depth limits of beds, occurs because of light attenuation by both water column chlorophyll and epifaunal/epiphyte growth on seagrass blades.
In Albany, sewage input and silt from run-off probably interacted to cause dieback. Later, seagrass species with runners (eg. Posidonia sinuosa) actually grew over Cladophora algal mats that resulted from eutrophication (p.c.#1350 P.Lavery).

Knowledge of the range, biology and recovery potential of different seagrass species is essential to predict the subsequent effects on fisheries production. These issues are discussed in more detail in section 1.3.3 and section 2.8.

At the time of writing, Environment Australia held a workshop to assess the issues in seagrass change in Australia, and the FRDC subsequently commissioned a review of R&D issues, needs and priorities for seagrass, due for completion in mid-1998.

2.3 Estuarine "Environmental Flows" of freshwater

The top priority issue identified in the LWRRDC "Wetlands R&D Program" Scoping Review (Bunn et al. 1996) was water regime, and the philosophy, measurement and determination, application and monitoring of freshwater "environmental flows" has been a major recent focus in rivers and inland wetlands (see Arthington et al. 1994, Arthington and Pusey 1993, 1994, Cullen 1994, Davies 1994a, Knights and Fitzgerald 1994, Swales 1994 for reviews).

Restoration of freshwater habitats and "fisheries function" in Australia has involved an early emphasis on manipulation and maintenance of flow in regulated rivers to provide spawning cues and restore access to floodplains and other resources (eg see Bales 1993, Bluhdorn and Arthington 1994, Gehrke 1992).

For example, in regulated rivers the seasonality, frequency, timing and duration of flooding of wetlands has changed. The near elimination of small floods in some rivers has caused declines in Murray Cod populations, which need minor floods for maintenance of "background" recruitment outside of major floods, when they take opportunity for recruitment on a much larger scale. In contrast the frequency of flooding of urban wetlands has increased due to high runoff coefficients of impermeable urban catchments. A summary of life-history knowledge for species threatened by the loss of access to, and flows of, freshwater is given in Table 2.3.1.

The well known freshwater impacts of river regulation have been cascading downstream in the Murray-Darling basin. At the Murray mouth now there is about 50% of natural flow and variability is 4 times larger for high flows. The timing and duration of flooding flows out of the mouth has been shifted backward by about six months. Robertson (in press) concluded that most of the system-level processes in estuaries are driven by these flow events.

Our literature searches found little application of the concept of "environmental flows" for the lower catchments where fresh and salt water meet to form zones of high productivity, based on:

- *supply of new nutrients*
- *remineralization and precipitation of sediments and detritus*
- *shelter from waves and wind*
- *shallow waters that encourage macrophyte growth*
- *shelter and food provided by aquatic vegetation and its detrital contributions*
- *long residence time of water*

The maintenance of a salt wedge and the shape and duration of flood and flow curves may be key determinants of spawning success, migration and recruitment of estuarine species - as well as determining some of the features listed above. For example, Gaughan (1993), Gaughan and Potter (1994, 1995, submitted) have identified enhanced zooplankton and larval fish abundance at the zone of mixing of fresh and salt water in WA estuaries, and McKinnon and Klumpp (in press) have demonstrated elevated rates of zooplankton egg production in response to freshwater flow events in a tropical estuary. The limited research on larval survival of estuarine species has shown a need for low salinities by Australian Bass (Battaglene and Talbot 1993).

Major gaps in knowledge of the relationships between physical, chemical and biological factors and the community ecology of estuarine fisheries frustrates accurate prediction here of the impacts of decreased "environmental flows" of freshwater into estuaries. As the lack of basic life-history information outlined in Chapter 1 is slowly filled the role of freshwater is emerging as a strong force.

For example, it is known that low salinities are favourable for larval survival of barramundi, bass and black bream. Strong correlations, without precise knowledge of mechanism, exist between rainfall and recruitment of Gulf of Carpentaria banana prawns, Clarence River school prawns, NT and Qld barramundi, black bream in the Gippsland Lakes and black bream and mulloway at the River Murray mouth (see section 1.4.5.1). As reliable ageing methods have only recently been applied to Australian fishes we expect a growth in exploration of relationships between rainfall and year-class strength through hindcasting from age structures of populations.

Seasonal floods may also suppress establishment of freshwater and marine pests, by flushing them out (eg. Mosquito fish, Water Hyacinth), overcoming their weak osmoregulation or limiting their illumination under turbid conditions (eg. Dinoflagellates)(see Chapter 5).

The influence of freshwater may extend onto nearshore and even shelf habitats. For example, Hoedt and Dimmlich (1995) note the tendency for both pilchard and anchovy to spawn close to the coast. They also suggest that there are links between anchovy spawning, zooplankton productivity and freshwater outflows - given the tendency for anchovy to spawn in bays, estuaries and bay entrances and the tolerance of young anchovy for lower salinities.

In discussion of the role of surface hydrodynamic features in structuring larval communities on the shelf, Kingsford and Suthers (1994) stress that freshwater plumes may provide critical cues and clues that pre-settlement stages use to find estuarine nursery areas.

There is an increasing awareness that spawning processes are not as simple as first thought for estuarine species – there are a variety of responses to cues that must flow together properly to allow elaboration of gonads and spawning to occur. For estuarine green-back flounder and black bream in SA there needs to be a smoothing of freshwater flow. The pattern as it is poorly managed now is for the Murray-Darling water to be held as long as possible, then released in a quick flush. There needs to be a computer-based system that integrates fish requirements with other users – as regulating freshwater flow depresses production pulses and cues for spawning and recruitment are lost (p.c. #1510 B. Pierce).

Table 2.3.1. Economically important fishes of coastal freshwaters threatened by changes to drainage. Primary Source = Merrick and Schmida (1984).

	Drainage	adult habitat	juvenile habitat	longevity (yrs)	spawning site	spawning salinity (ppt)	spawning temp. (°C)
Barramundi		tidal, non-tidal, longshore to headlands	upper tidal limits and non-tidal freshwater	>=10	sheltered estuary mouths, sandbars <2m deep	17-31	27-33
Jungle Perch	NE Coast	headwaters	headwaters	?	lower estuaries?	"brackish" ?	?
Australian Bass	SE Coast, NE Coast (lower)	tidal - non-tidal	brackish-water? ; submerged macrophyte beds	>=19	lower estuaries	12-15 (larvae best at >=20)	14-20
Estuary Perch	SE Coast, Murray-Darling	tidal - non-tidal	brackish-water?	?	estuary mouths in salt water	?	14-19
Blue Catfish (Arius graeffii)	Indian Ocean, Timor Sea, Gulf, NE Coast, SE Coast (upper)	tidal - non-tidal	tidal - non-tidal?	?	?mouth-brooder	?	?
Short-finned eel	Tasmanian, SE Coast, NE Coast (lower)	maturing adults migrate to sea	non-tidal, still waters	>=35	oceanic	?	?
Long-finned eel	NE Coast, SE Coast, Tasmanian	maturing adults migrate to sea	non-tidal, rivers	>=60 (for NZ eels)	oceanic	?	?
Congolli	SE Coast (lower), Murray-Darling, Tasmanian	mature females enter estuary mouths	? freshwater	?	?	?	?

2.3.1 Barriers and alienation of habitat

There is a crucial need to study and integrate the role of environmental flows as stimuli for fish migration with a national rationalisation of restrictions and barriers to fish movement. This has been recognised at the highest levels (eg. PMSEC 1995) for freshwater fisheries, but not yet for estuaries and lower catchments.

Barriers to movement have four main effects in lower catchments:

- *prevention of tidal access that transports eggs and larvae upstream into shallow, sheltered habitats of lower salinity*

- *concentration below barriers of adult fishes attempting to disperse upstream during rainfall events - these concentrations become "predation gauntlets" and a focus for poaching*
- *maintenance of poor water quality, weeds, pests and reduced habitat diversity upstream - in the extreme this may comprise acidic water (pH down to 2.5) - and trapped fish die*
- *pulse release of poor quality water during flood events that inundate barriers - acid and the production of dissolved metals has killed all gilled life in rivers in the short-term and resulted in longer terms of chronic "red-ulcer" disease*

The problems associated with major barriers such as floodgates and barrages have been known for several decades, but the enormous scope of the issue has only recently been documented, in studies by Williams and Watford (1996a, in press) of all NSW coastal catchments. In the first development and application of an appropriate assessment technique they found over 5300 structures between sea level and the +10m contour with potential to impede tidal flow and thus alienate fisheries habitat. There is not yet any estimate of the area lost to fisheries production behind these structures - but it is clear that even small culverts can produce subtle diminution of tidal access and fish habitat upstream.

The nature of the barriers will also vary from State to State. In NSW the major issue is floodgates on the northern floodplains, in SA the barrages at the Murray Mouth are a high priority and in Qld there have been no systematic studies in lower catchments, although problems with weirs, levees and floodgates are certainly present. Even small culverts in north Qld are known to have flow velocities that act as "hydrodynamic barriers" to dispersal of masses of forage fish such as carp gudgeons and bony bream.

Fisheries stakeholders do have some common goals with agriculture, road transport and local council authorities in the "rationalisation" of these structures, because they exist as infrastructure on maintenance schedules. There is consequently much potential to design and extend "fish friendly" devices, such as box culverts instead of round culverts into these maintenance schedules.

Larger barriers that service agriculture present more challenges for restoration of fisheries habitats because:

- *many floodplain lands have slumped behind floodgates and tidal intrusion cannot be predicted now with enough certainty for agriculture because of the lack of good elevation data and terrain models*

- *"chemical barriers" from poor water quality (eg. acid drainage) prevent migration of fish such as bass even if barriers are removed*
- *wildlife (eg. waterbirds and "Wallum froglet") have colonised drains and artificial wetlands behind the gates and could be threatened by saline intrusion*
- *restoration of tidal flow may encourage mosquito recruitment.*

To cope with some of these uncertainties there are emerging R&D opportunities with the concept of "leaky gates" that allow a compromise between fish and prawn passage and blocking of tidal flow (p.c.#1340 P.Gibbs).

An attractive and feasible example of this concept involves restoring some access upstream and appropriately timed freshwater flows through the Murray Mouth barrages to help rehabilitate a very important estuarine fishery for mulloway, black bream, flounder and yellow-eye mullet. This would occur mainly at the expense of what is now an ideal habitat for carp, and it shows the potential for "entrepeneurial" rehabilitation of fisheries functions in degraded habitats (see Pierce 1997).

The history of floodgates in NSW

Some economically disastrous floods occurred in the 1940's and 1950's on northern river floodplains of NSW and the early structural works that followed were unplanned and loosely coordinated by "drainage unions" of local land-holders. Then "flood mitigation authorities" were formed and there was an injection of many millions of dollars during the 1960's and 1970's (West 1993). Only about $2 million had been spent on these works until 1960, but then expenditure rose markedly – up to $80 million by 1980 (Pollard 1993a). As a result there are very few tributaries on the Richmond and Clarence Rivers that do not now have structural modifications.

These works were, ostensibly, to prevent flood inundation of certain areas, to guide overbank flows, and to reduce the overall period of inundation when floods occurred. However, a report by the State Pollution Control Commission (SPCC) in 1978 found that in many areas these works had the primary objectives of draining natural coastal wetlands outside of flood periods and thus providing landowners with access to large areas of land that would otherwise have been unsuitable for agriculture.

The NSW Fisheries submission to the SPCC inquiry stated that "in many cases these works appear more related to irrigation, drainage and water conservation than to flood mitigation" (Pollard 1993a). The concerns about the effects of changes to drainage are not recent. West (1993) noted that "by the late 1970's the SPCC was recommending the need to develop clear operating guidelines for flood mitigation structures and the assessment of the environmental impact of existing works. However, these recommendations have not been followed up and there remains no overall statement concerning environmental effects and no clear operational guidelines to reduce these impacts".

Other concerns listed by the SPCC (1978), cited in West (1993), were:
- *changes to salinities through loss of the buffering capacity of freshwater swamps*
- *creation of acidic conditions in coastal bogs*
- *loss of nutrient supplies through drainage of upstream swamps*
- *adverse effects of weedicides used in drainage channels.*

However, it is only recently that restoration and rehabilitation projects have begun to address these concerns (see section 2.8), perhaps speeded by the publicity surrounding the fish kills and ulcers borne by fish exposed to acid drainage (see section 2.2.1).

The effects of floodgates -- declining water quality, change and alienation of estuarine habitats

Flood mitigation works on the Richmond River since 1911 culminated in the early 1970's with the construction of a large barrage of floodgates (the Bagotville Barrage). This turned saline waters to freshwaters and killed off over 50% of the mangroves upstream of the gates – representing a decline of about 16% in overall Richmond River mangrove cover. The water quality above the gates then began to decline because of lowering of the surrounding water table to expose pyritic soils which released sulphuric acid.

The acidity of water entering the main river from Tuckean Swamp was pH <= 5, and often below pH=4. This was worsened by the fact that the Richmond's "prime" fish habitats were the Vallisneria beds and mangroves in the Broadwater just downstream of the barrages (West 1993), and the incidence of Epizootic Ulcerative Syndrome (EUS) was consistently highest adjacent to the Broadwater (Virgona 1992).

A 1980 estimate of the cost of the Tuckean works was $3 million, whereas the estimated agricultural and economic benefit was marginal ($200,000), but this figuring did not account *for losses in seafood production (West 1993). The overall effects included loss of access to upstream habitat, losses of estuarine and mangrove microhabitats, widespread decline in water quality and an increase in fires.*

There is a relatively long history, but few published studies, of the obvious effects of floodgates on estuarine flora and fauna. In the Macleay River, for example, a massive fish kill was reported in 1978 after release of poor quality, deoxygenated water from above gates at a time of low pH after flooding. Later, Middleton et al. (1985) noted a correlation between the decline in production of oysters, finfish and prawns with the construction and completion of many flood mitigation structures in the Macleay River area.

Pollard (1993a) quantified water quality parameters, and nature of submerged, emergent and riparian vegetation, land-use and fish community structure at 18 sites in northern NSW river floodplains. These parameters were compared:
- *at 10 paired sites (5 below/ 5 above floodgates on drains)*
- *at 4 sites on natural tributary streams*
- *at 4 sites in channelised flood mitigation drains gated at their mouths.*

Juvenile fish were sampled by using netting enclosures (25 m^2) and "rotenone" ichthyocide and larger fish were caught with multipanel gillnets (9 x 10 m panels; 25-127mm mesh in 12.7mm increments).

The major findings were:
- *floodgates were generally ineffective in preventing saline intrusion, because salinities differed only slightly between gated/ungated tributaries at similar distances from the sea, except during some winters and springs when salinities were lower above some of the gates*
- *floodgates were very effective in preventing recruitment and establishment of fringing mangroves*
- *floodgates were very effective in severely restricting passage of juveniles of estuarine/marine fishes and Australian bass*
- *floodgates generally degraded overall quality of habitat, by excluding mangroves in estuarine areas and also excluding overhanging Melaleucas in freshwater areas. Overhanging riparian vegetation is replaced by rushes and grasses.*
- *above the gates were primarily depauperate freshwater fish communities in habitats dominated by freshwater and terrestrial vegetation*

- *below the gates were estuarine/marine communities, the highest diversity and abundance of fishes, and highest proportions of economically important species*
- *number and diversity of both total and economically important species declined with both distance from the sea and decreasing salinity*
- *adults of the euryhaline sea mullet dominated the gillnet samples in gated sites in terms of abundance and biomass, but juveniles were not abundant there.*

Pollard (1993a) recommended that the floodgates should be left open at all times except immediately prior to and during floods. This relatively simple management strategy would improve flushing, allow mangrove colonisation and improve access by estuarine fauna and flora and economically important species. This has been confirmed and refined by Dr Philip Gibbs in the preliminary results of FRDC project #95/150 – significant recruitment of many important fish species does occur above partially open barriers, provided impacts on water quality (eg. from acid drainage) do not kill the fish or act as a chemical barrier.

Early studies in different regions have generally shown that sub-adult and adult sea mullet are more adept at passing through partially opened floodgates, or perhaps even leaping over closed gates, than most other economically important species. However partial opening may not be a solution to allow all fish to pass. McGregor (1979) (in Pollard 1993a) found that several predominantly estuarine-marine species (dusky flathead, mulloway, tarwhine and luderick) were found below, but not above, partially open gates on a tributary of the Hunter River. This allowed a 15% tidal exchange, but there were still only marginal improvements in the movement of juvenile fishes upstream to replenish the depauperate communities above the gates.

Channelised, but ungated, tributaries have been shown to support sea mullet, Australian bass, dusky flathead, estuary perch, mulloway, mud crabs and school and greasyback prawns on a tributary of the Richmond (Graham 1979 in Pollard 1993a) so restoration of passage should help rehabilitate fisheries production in "gated" habitats.

Other correlates between fisheries production and the effects of floodgates exist too – the Manning River has not had flood mitigation and oysters are grown there, but the floodgated Clarence and Richmond have no oyster farming (p.c. #840 Ian White).

2.3.2 The need for FISHWAYS

The largest barriers - weirs and dams - are best overcome with fishways. The original "fish ladders" copied from overseas salmonid designs simply do not work for native species. The flow velocities (usually >= 2 ms $^{-1}$) are too fast, eddies stop fish from entering them and they are also too dark, too deep or in the wrong places. Following an early lead by NSW FRI in freshwater rivers, there has been widespread recent interest in designing and applying fishways that are appropriate for the swimming abilities and migratory behaviour of native estuarine and freshwater fish. Vertical slot designs with flow velocities <= 1 ms $^{-1}$ offer much scope but usually are limited to barriers less than 6 m high, while locks and hydraulic lifts offer an expensive potential for barriers of 6-15 metres high if enough water is available. Both NSW and Qld are currently developing these and other designs to aid bass, barramundi and other fish to migrate.

Reviews by Harris and Mallen-Cooper (1992), Mallen-Cooper and Harris (1990), Mallen-Cooper (1992, 1993, 1994a,b), Mallen-Cooper et al. (1995) and Jackson (1996) show the failures, design options and needs for monitoring above and below fishways to improve their function. The value of these devices has been proven in freshwater, but will be extended to aid movement of estuarine species.

The number of barriers to fish movement is very high, but poorly documented in Australia. For example, Jackson (1996) has compiled a database on over 1000 licensed barriers to fish movement for the Murray- Darling in Qld, and Williams and Watford (1996a) have also documented the existence of 4230 structures in tidal zones of NSW - about 1388 of which are candidates for rehabilitation.

The reviews of the subject show that the basic requirements of design for a fishway include:

- *ease of access for monitoring*
- *economic efficiency and effective use of limited water resources*
- *allowance for fish passage both upstream and downstream*
- *thresholds of water velocity and turbulence that are suitable for all target species*
- *accessibility during all migration periods*
- *provision of "attraction flows" that induce fish to use the fishway.*

Key uncertainties concern the behaviour of native estuarine and freshwater fish, the timing of their movement and their swimming ability - there are many opportunities for productive R&D.

2.4 Saline intrusion and salinisation of estuaries

Grazing in wetlands was consistently highly ranked (about third in 13 issues) in all States, ahead of barriers to fish movement, in a scoping study of priority threats to wetlands (Lukacs and Pearson 1996). The levee banks and water retention and evaporation associated with "ponded pastures" for grazing pose a direct threat to fish movement and have unknown implications for nutrient cycling. Ponded pastures have trapped and killed barramundi in central Qld. This practice is occurring on several NT floodplains and is proposed for Gulf of Carpentaria floodplains. Introduced pasture grasses have been encouraged and spread widely from these ponded pastures (eg. Aleman Grass Hymenachne amplexicaulis) and become weeds in some catchments (see Chapter 5).

On the Mary River floodplain in the NT, landowners have introduced levees, ostensibly to halt saline intrusion, which act as ponded pastures. The Conservation Commission of the NT has erected bund walls there in a similar approach that blocked escape of barramundi juveniles.

The precise cause of the saline intrusion on the Mary River floodplain is not known, although there are at least six hypotheses - some including the trampling of low cheniers by introduced buffalo and the passage of water in the 'swim paths" they carved through emergent grasses during flood times. The resultant change from freshwater to saltwater wetlands has been dramatic - a thirty-fold increase in tidal extent upriver in 50 years, with loss of over 17 000 Ha of the original 90 000 Ha of freshwater wetland and floodplain, and immediate threat to another 40%. It is ironic that in the short term this has produced an internationally famous barramundi sportfishery at the upper tidal limit at "Shady Camp" barrage (Griffin 1994a).

A review of the hydrology and evolution of creek networks there by Woodroffe and Mulrennan (1993) and Knighton et al. (1992) has produced many lessons to be heeded in:

- *attempts at restoring tidal flow to acid sulfate soils or other disturbed soils of alienated floodplains.*
- *predicting the effects on fisheries habitats of sea-level rise and alteration of tide and wave regimes (see Woodroffe 1995).*

For example, once muds have been wetted and the clays lose their cohesiveness, incision can occur and creek depth increase rapidly to change to a low width-depth ratio, but cross-

sectional area then increases as the tidal prism gets larger. This process is amplified with each tidal cycle.

Despite the profound forcing by tides, waves and geomorphology in shaping the coast (eg. Clark and Guppy 1988) there has been little focus in the fisheries habitat literature of the effects of altering these forces, and not much recognition of the natural evolution of the coast. For example, estuarine infilling by sediment is a natural course of events which can include consolidation and invasion of sediment by expanding stands of mangroves (eg. Woodroffe et al. 1985, 1993).

The increase in area of mangroves in several areas has been documented (eg. Williams and Watford 1996b), but the implications for both fisheries and habitat managers are uncertain. Do extensive mangrove "stands" serve an equivalent fisheries function to mangrove "fringes"? How can demands for boat traffic and drainage be met in the face of aggressive mangrove expansion, under fisheries legislation protecting marine plants?

The closure of an estuary for extended periods is often accompanied by rising salinity. This was worsened in the Beaufort estuary of southern WA by salinisation of river water from an over-cleared catchment. After 3 years of closure the salinity was 60 ppt and only six species were found. Immigration of marine teleosts when the bar was breached after 4 years caused tripling of species diversity in ensuing months. Black bream formed major fisheries the southern WA estuaries, but their dependence on low salinity at spawning time has perhaps caused their decline in the rising salinity levels that prevail in some estuaries there now (p.c. #1360 R. Lenanton).

The variety of threats to coastal freshwaters is illustrated in Table 2.2.2.3. The invasion of freshwater wetlands by mangroves in the Moresby River catchment in north Queensland shows that the problems of saline intrusion are not restricted to the Northern Territory (see Russell et al. 1996a).

2.5 Training walls and channel modifications alter tidal and wave forcing

The biggest threat to sandy beach habitats and sandbar systems at estuary mouths are the effects of changes to tidal, wave and sediment regimes caused by the multitude of engineering works built at the mouths of enclosed bays and estuaries. Many of these have been designed to harbour fishing fleets working "outside" and safeguard their passage through sandbars. Although it is generally recognised that the sandbar and channel systems at the estuary mouths are the spawning microhabitat for yellowfin bream, sand whiting and barramundi on the east coast the implications for fisheries of this disturbance are completely unknown. There is also a lack of documentation of the effects on estuarine and bay fisheries habitats within the influence of the structures.

This is probably because the long history of such works was not accompanied by monitoring until recently. The influences on fisheries could come from:

- *tidal races that act as hydrodynamic barriers to larval and juvenile entry through entrances - even poorly flushed systems with minimal tidal range inside*

have very strong currents through entrained mouths (eg. Lake Macquarie)

- *increase in tidal range that exposes submerged and emergent macrophytes*
- *saline intrusion to non-tidal wetlands (see Table 2.2.2.3)*
- *decrease in tidal range that prevents transport upstream of fish and prawn larvae that rely on tidal currents (a "tidal choke" formed by a rock wall is a favoured option to stem the saltwater invasion of the Mary River floodplain).*

For example, the harbour entrance at Mourilyan in north Qld has been progressively widened and deepened since 1882. There has been strong speculation that this caused the saline intrusion that has changed freshwater wetlands in the Moresby catchment (see Table 2.2.2.3). There was a 65% loss of non-tidal wetlands and a 29% gain in tidal wetlands. Transitional wetlands there now are vast areas of dead, standing Melaleuca trunks with waters deeply stained by tannins - similar to the Mary River situation. Mangroves are recruiting and growing amongst the trunks (Russell et al. 1996a). Roy (1984) reported that training walls and dredging altered the tidal amplitude in Wallis Lake, yet we could find no studies of changes to seagrass or fringing mangrove communities there. There has been an increase in seagrass cover in the Macleay river since 1956 which was attributed by West (1993) to an engineered change to the position of the river entrance.

2.5.1 Lagoon opening regimes - foregone fisheries production due to opening or closure

Coastal lagoon fisheries in southern WA and southern NSW are known to suffer from the timing of artificial opening to the sea by local authorities, to allay fears of upstream residents and agriculturalists about flooding or for tourism purposes. The changes to opening regime cause immigration or emigration in populations of some species and can radically alter water quality.

Cases of lost fisheries production include:
- *prawns and finfish leave the lagoons on the south coast of NSW when openings are made to coincide with school holiday periods (see Gibbs 1997 for review and section 1.4.5.1)*
- *the total failure of the productive commercial black bream fishery in the Cullum Inlet in WA (from a high of 77 t in 1992/93) was due to departure of the population out to sea through construction of a semi-permanent entrance (p.c.#1360 R. Lenanton).*

Permanent changes alter both the fauna and water quality. For example :
- *the construction of barrages at the mouth of the River Murray in the 1930's completely altered the estuarine conditions above and below. When both barrages and Murray Mouth are closed there is no dilution or flushing of the hypersaline waters of the south lagoon. Wind-driven mixing can occur there and induce anoxia, particularly during summer. Extensive fish kills of yellow-eye mullet and flounder have occurred at these times and salinities have risen to 60 ppt (p.c. #1510 B. Pierce).*
- *the benefits associated with construction of the Dawesville Cut (see Chapter 3) in reducing macroalgal blooms have been accompanied by conversion of the Peel-Harvey estuary into a marine embayment, because of the lower residence time of freshwater from flow events. Species shifts in the fishery are now occurring as a result (p.c.#1420 G.Hyndes).*

New South Wales has drafted a policy to outline the problems and safeguard fisheries interests in artificial opening and closing of lagoons (see Lugg 1996 and Gibbs 1997). The intermittently opening lagoons in NSW remain closed to the ocean for the majority of the time by sand barriers at the entrance, and break out infrequently following a rise in water level associated with continued runoff from the catchment.

It is common practice for local councils and local residents to hasten the natural break-out process by digging artificial channels using hand tools or machinery. This is usually undertaken to *relieve or circumvent flooding problems. Other justifications, such as improving water quality, or allowing recruitment of fish and prawns, are also frequently given.*

Artificial manipulation of entrance conditions may have undesirable consequences for estuarine ecology, fisheries production, and conservation of biodiversity. Factors such as potential ecological impacts upon fish populations, fish habitats and riparian vegetation need to be taken into account in the decision making process to a much greater extent than they generally are at present.

Many of the commercially and recreationally important species of estuarine fish and prawns breed in oceanic or coastal waters and enter estuaries from the ocean as larvae and juveniles. Long periods (3 to 4 years or more) of entrance closure severely restricts the recruitment of many species to the lagoons. Enhancing the recruitment of fish (especially prawns) is often cited as justification for artificially breaching entrance barriers.

However, fish and prawn recruitment processes are not fully understood and are likely to be very dependent upon prevailing and preceding climatic factors, as well as a number of other seasonal variables. Therefore, artificially opening a lagoon entrance with the objective of enhancing fish recruitment would require monitoring of adjacent larval populations. Without such sampling, there would be haphazard chances of success. Further, artificial opening of a lagoon to promote production of one species or group of species (eg. prawns) may disadvantage other species with the final outcome being no nett benefit. There is no ideal time to open the lagoon for all species. A spring-summer opening favours snapper, sand whiting, luderick, leatherjackets and prawns while an autumn-winter opening favours yellowfin bream, dusky flathead and flat-tail mullet.

The chances of recruitment could be enhanced by a longer period of opening - but so would the chances of emigration. The fact that certain species (eg. prawns, sea mullet and yellowfin bream) can grow to a large size in a closed lagoon may enhance the survival and reproductive success of these individuals when the lagoon subsequently opens and they move into coastal waters. Therefore, not prematurely opening a closed lagoon entrance may assist fisheries production on a regional basis by enhancing the stocks of large breeding fish.

Consequently, Lugg (1996) concluded that "it is extremely difficult, if not impossible, to artificially manipulate entrance opening with any certainty of enhancing fish or prawn recruitment and production in subsequent months or years, either on an individual lagoon basis or on a regional basis".

2.6 Canal estates

These have generally converted saltmarsh, mangrove and seagrass habitats, or other "reclaimed" areas, into housing developments. In general terms their impact probably has depended on their design, but there have been no studies rigorous enough to quantify the implications for fisheries production. Our review shows that flushing regimes, depth, sediment type and particularly steepness of walls are major factors in design that affect fisheries production in them.

Older designs were fraught with poor tidal flushing and lower water and sediment quality. Even the newer designs with better flushing most commonly have steep walls which offer no shelter from predation for newly recruiting post-larvae of fish and crustaceans. Studies are underway now to test some hypotheses relating to the suite of fish likely to be found in canal estates of different age and design in comparison with nearby estuaries (Morton 1989, 1992).

The fish and crustacean faunas of canal estates are known to be determined by the flushing regime, the sediments and depth, proximity to spawning sites and possibly predation pressure. Diversity is often high - over 100 taxa in south-east Qld estates - and there are economically important species present. In sandy canals there are sand whiting and yellowfin bream, and in muddy ones there are greasyback prawns (Metapenaeus spp), golden-lined whiting (Sillago analis) sea mullet and dusky flathead. Recruitment of juvenile whiting, tarwhine, flathead and yellowfin bream does occur in some canal estates - and is higher than in adjacent estuaries for the tarwhine, which are herbivorous as juveniles. In older canals the glassy perchlets Ambassis are the dominant species and are highly piscivorous on larval fish, but southern herrings and the ponyfish Gerres spp predominate in newer canals (p.c.#920 J. Ross).

The construction of beaches is being encouraged in new designs, but biting midges breed in these in southern Qld and they are sprayed with pesticide. Raking can break the life cycle of the midges, the beaches can act as nursery habitat, and seagrass has colonised them in several locations from West Lakes in SA to south east Qld. There are R&D opportunities to enhance fishery value in the existing estates (see Morton 1993).

2.7 Sediment instability, seagrass dieback and “narrow-banding”

Seagrass dieback is the result of a sequence of destructive processes induced by sediment and/or nutrient loads, increasing turbidity and water column chlorophyll levels, and epiphyte growth and destabilisation of sediments. Reviews of the causes are given in Larkum et al. (eds) (1989) by Clarke and Kirkman (1989) and Shepherd et al. (1989). The extent of national seagrass loss is not precisely known, due to a lack of knowledge of the location and dynamics of tropical beds, but our collations of the literature show in Table 2.2.2.4 that at least 173,662 Ha, or 3.4% of known seagrass beds, have been lost in this country. Much of this change has taken place over the last 30-40 years.

Not included in our calculations was the recent (June 1997) release of a series of reports on the seagrasses of Torres Strait (see Long and Poiner 1997, Long et al. 1997a) where 1,199 km^2 or 60% of the seagrass was lost from the northern area.

In a proportional sense, the losses are much higher in southern Australia – as high as 61% in Victoria, 19% in NSW and 10.3% in Tasmania. Not only are these southern beds major sources of garfish, King George whiting and calamari squid production, they are comprised of vulnerable Posidonia and Amphibolis seagrasses. Disturbances to Posidonia beds in Jervis Bay and Spencer Gulf have not recovered after 20-80 years. Over 85% of seagrass in these 2 genera have been lost from Cockburn Sound, but effects on fisheries can not be assessed because the major fisheries there are for migratory sardines and pilchards.

The physical forces on the NSW coast have restricted seagrass growth to bays and estuaries, and these beds may be the most vulnerable in the country. Larkum (p.c.#610) predicts loss of all Posidonia in Botany Bay by the turn of the century, given the historical rate of decline, and more than 60% of seagrass has been lost in the Clarence estuary since the 1940’s. The NSW beds are known to have an outstanding nursery role for commercial finfish (see section 1.4.4.1).

The most widely cited studies of fisheries implications have been made in Victoria, where declines in the King George whiting, six-spine leatherjacket, rock “whiting” (Haletta semifasciata), green-back flounder and rock flathead catches have been related to seagrass dieback (Box 1.3.3.2 and review by Jenkins et al. 1993d). In Spencer Gulf the sea garfish *catch dropped by one half to a persistent low level in the region of an unexplained dieback in Posidonia, Zostera and Amphibolis after an El Nino event in 1992/93.*

The effects of seagrass dieback are not scale-independent. Dieback or destruction of Posidonia in large patches can cause wave or current induced erosion in the centre of the patch. This prevents colonisation by Halophila and other invasive species, and also causes erosion and spreading collapse of the rhizomes and seagrass at the edges of the patch. This is termed a "blowout", and the process of hydraulic erosion can continue after the original source of nutrient or sediment stress is removed. The rate of erosion is exceeding the rate of accretion and colonisation in Holdfast Bay in SA and blowouts are increasing in size (Clarke 1987, Clarke and Kirkman 1989).

In the Westernport there is no consensus on the cause of dieback of Heterozostera tasmanica and Zostera, but it was most probably linked to increased sediment loads from catchment clearing and reclamation of an upstream swamp. Raising up of intertidal mudbanks by seagrass consolidation of the sediments may have caused a summer dieback when the seagrass were exposed to heat and light. This may have then caused cascading effects of destabilisation, resuspension and movement of sediments and smothering of intertidal and subtidal seagrasses. The banks have since dropped in height. After the dieback of H.tasmanica, a congeneric form tolerant to exposure between tides (H. mulleri) is colonising in regrowth (p.c. # 1470 H. Kirkman).

Natural events such as cyclones and floods in the tropics cause similar disturbance on very large scales. For example, the destruction of 18,300 Ha in the Gulf of Carpentaria after Cyclone Sandy was estimated to have caused the later loss of 250-300 tonnes yr^{-1} of tiger prawn harvests before full recovery within 10 years (Poiner et al. 1993b).

A series of floods in Hervey Bay caused a loss of 1000 km^2 of seagrass beds and the later starvation and death of about 500 dugongs. It is not known if the effects of the floods and sediment mobilisation were aggravated by upstream clearing of the catchment. Turbidity causes retreat into the shallows and "narrow banding" of seagrass in the tropics - some beds only photosynthesise when exposed at low tide - and this has increased interaction between foreshore gillnetting and dugong grazing (see Chapter 5). The dugong decline has lowered the "tolerance" of the public and GBRMP managers for the relatively rare deaths of dugongs in gillnets.

Long et al. (1997a) reported that very unusual freshwater run-off from a nearby PNG river in a short, intense event at the end of the wet season correlated well with observed changes in seagrass, epifauna and areas with high abundance of sea urchins in the northern and north-eastern regions of Torres Strait.

The failure of studies such as Kirkman et al. (1991) and Kirkman and Manning (1993) to find differences in faunal community structure between disturbed and undisturbed seagrass meadows may be due to the concept of "intermediate disturbance" when seagrass is denuded or damaged in patches. That is, the formation of patches enhances community diversity because more complex habitats are provided.

Also, Robertson (1984) showed that dense seagrass in Westernport Bay had twice the total secondary production as lightly-grassed areas and bare mud, but only half the ratio of consumption to production. Predation by fish on epifaunal and infaunal crustaceans appeared to be a major factor in determining the distribution of theses animals in areas where seagrass is sparse or absent. The corollary was that seagrass loss would enhance fish predation, at least in the short term, and diversity and abundance would rise in the disturbed areas at these temporal scales. However, Edgar and Shaw (1995c) did not find that such a pattern was evident at larger, regional scales.

The effects of dredging on fisheries associated with seagrass are also an "intermediate disturbance". For example, Middleton et al. (1984) found little indication that there were marked differences between the Zostera fish communities at undisturbed locations in Botany Bay and sites disturbed by dredging, and the number of fish collected at each location was, overall, approximately the same. Burchmore et al. (1988) found an extraordinary abundance of sand whiting (Sillago ciliata) at a site where patchy Zostera predominated in western Botany Bay. They suggested that patchy sites offer better combinations of shelter (seagrass) and food (bare substrata) and that these are important nursery sites and should be maintained.

There are clear regional differences in the vulnerability of seagrass communities to permanent change, and threats and opportunities must be assessed accordingly. Along the high energy, wind-formed coasts of NSW, Victoria and Tasmania the only suitable habitats for seagrass may be in sheltered bays and estuaries that are the sinks for deposition of catchment influences. The combination of wave climate, depth, sediment type and salinity further restricts *distribution. For example, seagrasses occur in shallow channel fringes or cut-off arms near the entrances of NSW coastal rivers in salinities of 10-30 ppt.*

Relict populations of more robust species at the extreme latitudinal ends of their range are restricted to occur in these sheltered waters also (eg. Posidonia australis in Jervis Bay, NSW). These restricted distributions make some temperate and sub-tropical seagrass communities particularly vulnerable to permanent change, with little likelihood of success of restoration through artificial intervention or the natural influences of remote seedbanks.

However, there is recolonisation of disturbed areas by some genera throughout the range of seagrass in Australia - a key uncertainty concerns to what degree these colonisers provide fisheries functions through provision of nurseries and benthic infaunal food supplies. Studies have commenced in Cockburn Sound to address this question and assess recovery and restoration potential of several genera (see below).

2.8 Habitat rehabilitation, restoration and creation

The rehabilitation and restoration of fish habitats and creation of new fish habitats are rapidly becoming a priority for research and management under the frameworks of Ecologically Sustainable Development, "no nett (habitat) loss" policies and Ecosystem-based fisheries management flagged as new directions by State and Commonwealth authorities. Some additional impetus for the scientific community was given by papers (eg. Moberly 1993) at the 1992 workshop on sustaining fisheries habitats held by the Australian Society for Fish Biology in 1992 (see Hancock (ed.) 1993), and in the LWRRDC Riparian Zones Program (Newbury 1993, Newbury and Gaboury 1993). Freshwater environments have received the earliest attention (eg. Swales 1993).

There is also wide public perception that habitat degradation can and should be reversed, or compensated for in coastal development. This is encapsulated in legislation under Queensland's "no nett habitat loss" policy. Recent political changes have produced more focus than ever before on access by community groups to "Landcare", "Fishcare" (now the "Fisheries Action Program"), "Coastcare" and "Natural Heritage Trust" funds for such projects. This presents opportunities to incorporate R&D in steering such projects, but also presents the threat that funds may be "frittered away" on piecemeal, un-coordinated projects.

These directions and perceptions have, however, far out-stripped the empirical database on the feasibility, cost and results of such habitat manipulations in Australia. For this reason, strong proposals for R&D in this area would be ideal for FRDC investment.

For example, the QDPI policy of replacing mangrove habitat loss by planting elsewhere appears not to monitor the success of all replanting projects, or the fisheries function of new stands. The choice of replanting areas is possibly inappropriate in some cases since it causes other habitat to be lost, including saltmarsh/saltpan, mudflat, or seagrass. The policy might be more successful if areas of port constructions were planned to incorporate mangrove gardens along breakwaters and causeways. It is also possible that mangrove stands might add to the structural integrity of port facilities and protect them during major storms, as well as providing aesthetic and ecological benefits. In this way only damaged habitat need be restored.

The "Area-Catch-Expense" framework (Williams and Watford 1996a; FRDC 94/041) is the only Australian attempt to quantitatively incorporate fisheries values in prioritising habitat rehabilitation on the coastline. These studies and Williams and Watford (in press) outline the most cost-effective methodologies associated with broad-scale identification of, and options for, areas suitable for habitat manipulation. They found that loss of tidal access caused by floodgates and culverts was the major threat to estuarine production in NSW, but warned that other States will have different risks and hazards.

However, the benefits of their approach include:
- *a priority for use of detailed, local knowledge (fishermen, fisheries officers and regional biologists) to identify threatening structures and processes*
- *inclusion of the builders/owners of such infrastructure in assessment of the feasibility of rehabilitation*
- *recognition that all structures have limited lives, and most have maintenance schedules that allow opportunities for improvements*
- *ground-truthing of map-based information to reveal structures that are incorrectly labelled or are not recorded.*

The problem does remain though that there are no procedures by which new structures, or upgrading of old structures are recorded on the NSW FRI database by local councils and the NSW Department of Lands.

Streever (in press) has provided the first review of broad objectives and methods in Australian wetland creation and rehabilitation projects. No comprehensive database exists for Australia *and Drs Anne Jensen and Mark deJong of DENR (SA) were undertaking a similar review for the IWRB (International Waterfowl and Wetlands Research Bureau).*

Our informants indicate that both these inventories were biased by low response to voluntary questionnaires used to gather information, and that notable seagrass restoration projects were not identified (see below).

It is not possible to determine the fisheries value and function of the projects listed by Streever, because key findings from the review of 61 projects were:

- *"Mangrove" (15) and "Salt marsh" (10) habitats were in the minority compared with "Inland swamp" (trees or shrubs) (18) and "Inland marsh" (herbaceous) (34) and there were no reports of seagrass rehabilitation*
- *the most common plant genera used were Eucalyptus (river red gum, black box) Melaleuca (paperbark) , Muehlenbeckia (Lignum), Juncus (giant rush), Avicennia (grey mangrove) and Typha*
- *The breakdown of number of projects by State was - Qld (12), NSW (27), Victoria (2), Tasmania (5), SA (16), WA (5) and NT (2)*
- *the oldest project began in 1963, but most projects began in the period 1990-1996*
- *the most common threats that required rehabilitation were "filling and draining" and "altered hydrology"*
- *"excavation" and "planting" were the most common rehabilitation methods*
- *only 65% of projects addressed the cause of impacts*
- *only one project each addressed "acidic soil" and "weed invasion", despite the fact that these threats are well-known hazards and risks*
- *only one project reported an effort to coordinate total catchment management with rehabilitation*
- *most projects are faced with attempting rehabilitation in the face of continuing impacts of adjacent agriculture, mining, urban development and exotic species invasions*
- *habitat "improvement" was the most commonly stated objectives of projects*
- *of the projects that supported monitoring, fewer than 25% appeared to monitor variables that were closely linked to project goals*
- *of the 61 projects identified, only 36 contained elements of research projects*
- *the projects manage less than 1% of existing wetlands – an estimate of at least 149,530 Ha should be considered a minimum for project after a loss of 50% in the past 200 years*
- *the median project size was 115 Ha*

- *monitoring of mangroves in Qld (Quinn and Beumer 1983) suggest that at least 20 years must pass before re-establishment of original species and height composition*
- *private wetland creation costs can be adequately offset by better crop yields, but the institution of tax or rate relief incentives would accelerate such initiatives.*

A key conclusion from Streever's review was that rigorous monitoring at long time scales (not pseudo-replicated) is needed and that several projects are taking the lead of Underwood (1994) in employing BACI designs (Before-After-Control-Impact sampling designs with multiple controls). The "Kooragang Island Study" has led to development of a model that describes the role or research, including monitoring, in rehabilitation (eg. see Williams et al. 1995). Management sets the agenda, organises rehabilitation activities, and occupies a central position that can function in the absence of research. Reactive research, or monitoring of ecosystem response following rehabilitation, is considered separately from proactive research, which addresses issues relevant to management before rehabilitation is undertaken.

Overseas studies generally conclude that fish readily use artificially excavated habitats (Zedler et al. 1997) and that fish assemblages relate more to estuarine channel morphology than to type (natural versus constructed) in the USA. Constructed channels are generally deep and wide, whereas natural channels and creeks comprise a range of depths and sizes. The needs for R&D then fall into distinguishing:

- *what mix of channel and sub-channel excavations should be made to restore function for all life-history stages?*
- *how much integration and inter-digitation should there be with artificial and natural habitats? – it may be that the algae and periphyton in isolated artificial basins and channels will not provide the detrital bases for food chains that adjacent saltmarsh and mangrove or seagrass habitats do.*

The interplay between geomorphology, energy flow paths, tidal regime and sources of primary production in artificial versus natural estuaries are the subject of a rapidly growing literature in the USA (Zedler et al. 1997). This has been driven by demand for "mitigation banking", the failure of engineering solutions that are not sustainable due to sedimentation and anoxia, and fears that artificial habitats sometimes become havens for exotic species.

Key uncertainties in the USA concern the need of fish populations at the regional scale for many, small or fewer, large wetlands. These questions are being revisited in Australia with *questions concerning the roles of "fringes" versus "stands" of mangroves, and in trade-offs in QDPI's "no nett habitat loss" policy.*

In Table 2.8 we have built our review findings onto the efforts of Craig Copeland (NSW Fisheries, Wollongbar Veterinary Laboratory) in collation of all recorded habitat restoration projects on the Australian coast. There are several key features:

- *proposed benefits are not always associated with enhancing fisheries production*
- *performance in enhancing fisheries is generally assumed - but seldom measured*
- *"simply" restoring tidal access or restoring a gentle sedimentary profile allows recruitment of mangroves and seagrass*
- *small changes ("tweaking the system") to tidal regulation can offer fisheries benefits at relatively small cost - but conflicts with agriculture, mosquito control, requirements of other wildlife (eg. water birds, wallum froglet) and estuarine navigation must be considered*
- *there are many opportunities to fill important R&D gaps in knowledge of life-histories and dynamics of larval transport and recruitment in estuaries by monitoring performance of rehabilitation projects.*

We believe that R&D to measure the performance (fisheries function) of such projects could be extended beyond surveys of distribution and abundance to include:

- *the microtagging of fish released in different microhabitats used in assessing the success of restocking (eg. Russell 1996, Russell and Rimmer 1997)*
- *the use of otolith microchemistry to trace adults back to nurseries (eg. Courtney et al. 1994)*
- *the use of biomarkers (stable isotopes and marine chemistry) to distinguish sources of primary and secondary production in estuaries and "restored" habitats (eg. Loneragan et al. in press)*

There was a workshop held in 1989 to assess the need and potential for recovery and restoration of seagrass habitat of significance to commercial fisheries. The resulting papers summarised by Edgar and Kirkman (eds) (1990) indicated a need for further research on the dynamics and means of spread of both natural and artificially propagated seagrass beds, but also outlined the lack of recovery of some Posidonia beds disturbed earlier this century. We found in our interviews some disagreement amongst seagrass authorities on the potential for restoration of Posidonia and Amphibolis species in disturbed areas in the subtropics. Reviews of natural dynamics and preliminary planting trials by Kirkman (1989b, 1990a,b) showed little *potential, but the issue is being re-examined now in attempts to minimise damage caused by "shell-sand" dredging in Cockburn Sound.*

There is dredging through seagrass associated with "shell-sand" mining in WA and "coral-sand" mining in Moreton Bay. In WA, Cockburn Cement Pty Ltd has been mining shell-sand since the mid-1970's, and a government agreement has guaranteed access until 2030 -- a review of their operations has recommended that for long-term access the company must show some seagrass restoration and rehabilitation. There is now an $1.8 million dollar research project to examine baffling, sediment stabilisation, epifaunal production and sedimentary processes to ensure that disturbances are minimised (see Walker et al. Unpubl.).

The dredging cuts down from 5-15 metres into banks of large particles of calcium carbonate that have been accumulated and deposited by hydrodynamic features - the seagrasses have colonised these, but not acted to accumulate them. Nearly 85% of seagrass has been lost in Cockburn Sound (main assemblages affected were Posidonia and Amphibolis) so there will also be research on the Heterozostera and Halophila recolonisers to determine what ecological function these colonisers will serve in dredged areas (p.c. #1350 R. Lavery).

The key question will be "can "function" be maintained by replacing a unit area of one assemblage with an equivalent area of another assemblage of recolonisers?"

The Cockburn Cement project has revealed that previous attempts at replanting may not fully reflect the potential for restoration of Posidonia and Amphibolis. The results of preliminary experimental work show that mortality of transplanted plugs has been due to insufficient anchorage, sediment smothering, enhanced epiphyte growth, and damage by grazers:

- *there are more sea-urchins in disturbed areas, and the transplants act as "beacons" to attract the urchins which then graze them down*
- *there is also an effect of "being alone" - in dense seagrass stands the blades continually brush each other and this acts to clean off epiphytes. When transplants are tethered out alone there is up to 5 times more epiphyte biomass on them*
- *transplant plugs need to take both the sediment microhabitat and the seagrass when cored - the new Cockburn Sound plugs are 50cm^2*
- *bigger transplants dilute the effects of grazers.*

Past problems with growing seedlings may also have been due to necrosis, wash-aways, fungus and lack of anchorage because of inappropriate techniques - use of "off-the-shelf" jiffy pots, geotextile matting, grids and spun "rock wool" isolated the rhizosphere from the sediment.

These factors are being reviewed now with genetic work in meadows to examine the extent and implications of "self-recruitment" and colonisation by propagules. There has been regrowth of Heterozostera and Amphibolis in the dredged channels (p.c. #1440 E. Paling).

The dynamics of estuarine Ruppia and Zostera are also being investigated in WA to determine the options for encouraging recovery or replanting. The theme of this research is to distinguish the sources of natural recovery - is it mainly seedstock or a small number of individuals contributing to the gene pool? (p.c.#1350 R.Lavery). Similar research on seedbanks, dispersal and transplant potential is being carried out for the genus Halodule by the CRC for Coral Reefs (G.Inglis JCUNQ), and by CSIRO Cleveland (p.c.#310 R.Kenyon) for several other genera.

Several respondents considered that seagrass transplants are a waste of effort in the wrong conditions - eg. an area was engineered to supply suitable sandy substrata for transplanted plugs of Zostera (about 100 plugs of 60cm diameter) in Botany Bay to investigate partial compensation for loss of 60 Ha of seagrass during construction of the third runway for Sydney Airport (p.c. #540 R. West). For some estuarine genera there will be natural recolonisation of *disturbed areas (eg. canal estates) if sedimentary profiles are appropriate and propagules are available from adjacent seedbanks.*

A paper on the results of seagrass restoration in Botany Bay is in preparation by Dr Philip Gibbs of NSWFRI (Gibbs, in progress) and the following extracts explain the rationale and results.

Botany Bay has been the focus of many developments over the past century and most natural aquatic habitats in the Bay have been heavily modified. The most recent significant changes were the construction of the Sydney airport third runway in 1994 and the construction of a series of rock groynes in 1997 along Lady Robinsons Beach to the west.

The construction of the third runway resulted in various fish habitat changes including the loss of 18.75 Ha of the seagrass Zostera capricorni. A condition imposed on construction of the runway was for subsequent fish habitat compensation. This compensation required establishment by natural recolonisation or artificial propagation of Zostera seagrass meadows on 30 Ha of substrata "created" between the two runways and on the eastern side of the new runway.

Natural recolonisation of the two areas by seagrass has been monitored since January 1995. The two "created" areas have shown differing responses, with the successful colonisation of scattered patches of Zostera on the eastern side of the runway but not between the runways. Halophila has colonised both areas. The poor success between the runways has been attributed to the reduced probability of a seedling entering the gap between the runways, and the higher wave climate there reducing successful attachment and survival of propagules.

In 1997 construction commenced of rock groynes to protect Lady Robinsons Beach from erosion. A consequence of this development was the potential smothering of approximately 1.8 Ha of seagrass. The airport runway project was therefore enhanced by the transplanting in April 1997 of approximately 1.8 Ha of seagrass into 16 experimental plots taken from the rock groyne construction area at Lady Robinsons Beach. The transplanting was done by Land and Marine Pty Ltd for the construction consultants and the Sydney Ports Corporation.

The monitoring program has found that 3 months after the 16 large plots were transplanted, Zostera is present at all 8 sites on the eastern side of the runway. Between the runways no seagrass remains at two sites while the other 6 sites have a few small scattered clumps *generally less than 0.025 m^2 in area and some isolated individual plants. This is a positive result given the significant storms in late April 1997 that uprooted or buried much of the transplanted seagrass.*

Artificial seagrass units (ASU) were used in some experimental plots to stabilise the sediments, reduce wave action and initially protect the transplanted seagrass. After 3 months these contained only a small amount of seagrass, possibly due to abrasion by the artificial seagrass blades which are heavily fouled by epiphytes. However, the plants present near the ASUs are longer, denser and appear to have been grazed less than the other surviving transplants.

Natural colonisation of the two areas remains dominated by Halophila with some significant meadows developing, especially on the eastern side of the runway.

Censuses of fish using the "created" habitat showed that in addition to yellowfin bream, dusky flathead, glassy perchlets (ambassids) and sand crabs (Portunus pelagicus), "seagrass associated" fish such as leatherjackets and pipefish were recorded in very low numbers for the first time.

This project represents the first large scale successful transplanting of Zostera on the Australian east coast. The long-term survival, growth and change in the structure of the seagrass beds and the utilisation of them by fish and invertebrates is being monitored.

Table 2.8. Status of fisheries habitat restoration, rehabilitation and creation projects on the Australian coast.

Location	Area (Ha)	Problem	Engineering Solution	Biological Solution	Species Selected	Proposed Benefits	Status	Contact
Cairns	?	channelisation of creeks for stormwater drains	research to formulate plans and guidelines to maintain some fisheries values in placement, design and maintenance of urban drains			drains will have some fish habitat function, including sportfish and crustacean nursery. Better planning and integration of resource values	ongoing	Anne Clarke, Northern Fisheries Centre (NFC), QDPI, Cairns
Trinity Inlet, Cairns	80	acid drainage from ASS disturbed by mangrove destruction, floodgating	3 options include full or partial reflooding with seawater, or no action	natural recolonisation by Melaleucas or mangroves		developers donated site, has potential as estuarine fish/prawn nursery habitat	research underway to explore options	Dr John Russell, Project Manager, Trinity Inlet Mgmt Program, NFC QDPI
Ellie Point, Cairns and Green Island		[research project] recovery and succession of tropical seagrasses		[research aims] recovery rate of seagrasses, relative importance of sexual and asexual reproductive stages	Zostera, Cymodocea	establish mechanisms for recovery of intertidal and subtidal tropical seagrass communities	proposed	Michael Rasheed, Northern Fisheries Centre, QDPI, Cairns
Mourilyan Harbour				transplant adult trees			no reports	QDPI (1997), Steve Hillman QPC (1997)
Babinda Creek Rehabilitation Project	3.5 km long	siltation, clearance of riparian vegetation, invasion by exotic pasture grasses	Catchment Mgmt C'tee to develop a proposal for LANDCARE funding	[research to provide baselines and develop options]	freshwater creek	restoration of freshwater fish habitat and development of CMC expertise	proposal submitted to NLP	Sue Helmke, NFC QDPI

Location	Area (Ha)	Problem	Engineering Solution	Biological Solution	Species Selected	Proposed Benefits	Status	Contact
Tully River Floodplain	*?*	*widespread problems with Tully River associated with upper catchment activities*	*excavation of basins by landholder to receive and process drainage from caneland before discharge to river*	*natural recolonisation by sedges and aquatic macrophytes*		*wetlands act as nutrient and sediment scrubbers and provide freshwater sportfish habitat*	*completed*	*Ross Digman, Cane Framer, Tully*
Oyster Point, Cardwell	*4*	*removal of fringe caused erosion*	*loose timber removed; protective devices for individual seedlings installed*	*growout of seedlings; plant-out at 4-5 leaves stage along a seaward zone 25 m wide*	*Avicennia marina*	*erosion control; complex political objectives*	*commenced 1994*	*Dr N. Duke AIMS (1997)*
Pallarenda and Magnetic Island (Townsville) and Hinchinbrook Channel, Cardwell	*3*	*[research project] restoration ecology of tropical seagrass beds, improving efficiency of transplanting*		*[research aims] suitability of species for transplants, utility and cost of "plug technique" in transplanting, impacts on donor seagrass beds*	*Halodule, Cymodocea*	*establish an efficient species-specific technique for transplanting seagrass*	*proposed*	*Naniel Aragones, James Cook University, Townsville*
Port of Gladstone	*0.8*	*loss of mangrove by reclamation*	*excavation of artificial tidal channel in claypan*	*plant mangrove propagules*	*Avicennia, Rhizophora*	*develop a method for conversion of marginal tidal land to a productive mangrove community*	*current*	*Noel Bowley, Gladstone Port Authority*
Calliope River, Gladstone	*0.2*	*loss of mangroves during reclamation*	*stream bank re-profiled, slope reduced to increase planting area and improve seedling establishment*	*plant mangrove propagules*	*Avicennia, Rhizophora*	*restore mangrove communities along foreshores of reclaimed tidal lands*	*current*	*Noel Bowley, Gladstone Port Authority*

Location	Area (Ha)	Problem	Engineering Solution	Biological Solution	Species Selected	Proposed Benefits	Status	Contact
Port of Brisbane	*?*	*visual impact of reclamation*	*subtidal bund profiling, substratum stability (longems), wave-breaking baffles*	*natural propagule recruitment + assisted propagule establishment*	*Avicennia*	*increased local primary productivity, aesthetic values, visual screen*	*proposed*	*Dr Michelle Cousineau, PPK Rust P/L, Consulting Engineers, IBM Centre*
Port of Brisbane	*?*	*unstable channel banks*		*plant mangroves on slopes*	*Aegiceras*		*current*	*Jeff Borschmann, Greening Australia*
Loder Ck, Southport		*community concern over lack of mangroves*	*nil*	*plant nursery-reared seedlings and transplant naturally occurring seedlings*	*Avicennia, Sporobolus, Casuarina*	*community involvement and education*	*completed April, 1995*	*Kym McGauge, Fisheries Division, QDPI, Brisbane*
Dynah Island, Moreton Bay	*5*	*disposal of dredge spoil onto intertidal island*	*modification of tidal profile by construction and filling of bunded area with dredge spoil*	*extensive natural colonisation of mangrove spoil banks*	*Avicennia*	*extension of existing mangrove community and stabilisation of dredge spoil*	*current since 1992*	*Brad Zeller, Marine Fisheries, QDPI, Brisbane*
Saltwater Creek, Moreton Bay		*control mosquito breeding in tidal salt marshes*	*excavation of artificial "runnelling" drains*	*natural recruitment of mangroves into runnellings*	*Avicennia*	*biological control of mosquito larvae & extension of adjacent mangrove community*	*current*	*Brad Zeller*
Serpentine Creek, Brisbane	*0.3*	*floodway erosion*	*floating boom and fencing to restrict vessel/public access*	*plant nursery-reared seedlings, transplant naturally occurring seedlings, and natural recruitment*	*Avicennia, Aegiceras, Sporobolus*	*stabilise channel banks, restore mangrove community, improve aesthetic values*	*completed 1982*	*Ralph Dowling, Qld Herbarium*
Brisbane River	*0.2*	*loss of mangroves during wharf construction*	*stream bank re-profiled, "polymesh" laid to stabilise substratum and reduce seedling washout*	*plant nursery-reared seedlings*	*Avicennia*	*maintain a healthy mangrove community in a high-usage community recreation area*	*completed November 1992*	*Kym Briese, Q-Build Project Services Brisbane*

Location	*Area (Ha)*	*Problem*	*Engineering Solution*	*Biological Solution*	*Species Selected*	*Proposed Benefits*	*Status*	*Contact*
Norman Creek, Brisbane	*0.1*	*mangrove mortality and reduced recruitment die to channel diversion*	*stream bank re-profiled, "geotech" laid > HWS to promote terrestrial grasses*	*plant nursery-reared seedlings and natural regeneration of grasses*	*Avicennia, Cynodon*	*restore tidal plant community, improve aesthetic values, community involvement/education*	*completed December 1992*	*Marjorie Semple, Brisbane City Council*
Wallum Creek, North Stradbroke Island	*20*	*mangrove mortality due to prolonged inundation*		*transplant naturally occurring seedlings, and natural recruitment*	*Avicennia*	*improve understanding of natural and assisted mangrove revegetation processes*	*completed 1983*	*Dr John Beumer, Marine Fisheries, QDPI, Brisbane*
Serpentine Creek, Brisbane	*12.5*	*[research project] bank stabilisation and erosion control of an artificially modified tidal channel*		*biological methods for channel bank stabilisation by revegetation with mangroves*	*Avicennia, Aegiceras*	*low cost channel stabilisation and erosion control*	*completed 1985*	*Ralph Dowling, Qld Herbarium*
Tweed River Mouth	*17*	*degradation of wetlands by restricted tidal movement from channel dredging*	*alteration of size and shape of culverts, creation of wetlands, redirecting human access*		*mangrove and saltmarsh, estuarine lakes and creeks*	*partial compensation for wetland loss, improved fish and wildlife habitat, community education*	*proposed to commence 1996*	*Craig Copeland, NSW Fisheries, Wollongbar*
Richmond River, nr Broadwater	*>200*	*acid drainage from ASS, floodgates and wetland drainage*	*modify drainage and flood mitigation structures*	*replanting riparian vegetation in upper catchment, natural recruitment of supra/sub-tidal vegetation*	*Melaleuca forest, sedgelands, mangrove, saltmarsh, Ruppia, estuarine creeks and inlets*	*restoration of fish access, improved fish habitat, improved agricultural productivity, reduced drainage of acid*	*commenced 1994*	*Craig Copeland*

Location	*Area (Ha)*	*Problem*	*Engineering Solution*	*Biological Solution*	*Species Selected*	*Proposed Benefits*	*Status*	*Contact*
Rocky Mouth Ck, nr Woodburn on Richmond River	*500*	*acid drainage from ASS, floodgates blocking tidal access*	*installation of manageable floodgate system*	*natural regeneration*	*wet meadows and estuarine creeks*	*decreased drainage of acid, improved access by fish*	*completed 1995*	*Craig Copeland*
Everlasting Swamp, Clarence River	*1930*	*loss of extensive areas of fish habitat through floodgating, acid drainage from ASS, grazing impacts*	*landholder consultation*	*natural regeneration*	*wet meadows, sedgelands, estuarine and freshwater creeks*	*decreased drainage of acid, improved access by fish*	*proposed*	*Craig Copeland*
Clarence River nr Maclean		*loss of fish habitat through floodgating*	*installation of floodgate management system*	*natural regeneration*	*estuarine creek*	*increased utilisation of creek by fish*	*on hold, floodgates installed 1994, side gates not operational*	*Craig Copeland*
Yarrahapinni Wetland, Macleay River nr South West Rocks	*860*	*loss of wetlands and fish habitat through floodgating, acid drainage from ASS*	*floodgates to be opened and placed upstream of former estuarine wetlands*	*natural regeneration [research aims to monitor recovery of fish, benthos, vegetation, birds, water quality using BACI design]*	*mangrove, saltmarsh, seagrass communities, estuarine creeks*	*increased utilisation of area by fish and other wildlife, decreased drainage of acid*	*commenced 1991, floodgate opening planned for July 1996*	*Craig Copeland, Dr Philip Gibbs (BACI fish study) NSW Fisheries Research Institute, Cronulla*
Hunter River, nr Newcastle	*2000*	*Loss of freshwater and estuarine wetlands due to drainage, floodgates, grazing and acid drainage*	*Catchment Management Committee, floodgate opening and purchase of private land*	*natural regeneration*	*mangrove, saltmarsh, wet meadows, sedgeland and rushlands, estuarine creeks*	*increased utilisation of area by fish and other wildlife, decreased drainage of acid*	*strategy report completed, "background" monitoring to commence late 1995*	*Craig Copeland, John Holliday, Philip Gibbs, NSW Fisheries Research Institute, Cronulla*

Location	*Area (Ha)*	*Problem*	*Engineering Solution*	*Biological Solution*	*Species Selected*	*Proposed Benefits*	*Status*	*Contact*
Kooragang Wetland, Hunter River, nr Newcastle	*1410 (3 sites)*	*large loss of estuarine wetlands following industry development and floodgating*	*culvert replacement to allow tidal access, re-profiling to encourage saltmarsh*	*rainforest planting, creation of migratory wader roost sites [BACI research to establish change in tidal prism, fish, benthos and mosquitoes]*	*mangrove, saltmarsh, wet meadow, littoral rainforest, intermittent freshwater swamps, estuarine creeks and rivers*	*increased utilisation by fish and other wildlife, community education, adaptive research to establish restorative methods*	*commenced 1992*	*Peggy Svoboda, Project Coordinator, Kooragang Wetlands Centre, Bill Streever, University of Newcastle*
Gippsland Coast, Corner Inlet, Western Port, Barwon River	*150-280*	*Invasion of intertidal habitats by exotic Cordgrass (Spartina)*	*Controlled use of herbicide "Fusilade"*			*restore wading bird habitat*	*trials completed*	*Grant Hull, Dept Conservation and Natural Resources, East Melbourne*
Coorong, Murray River Mouth	*?*	*Coorong barrages completely block fish passage upstream and modify freshwater environmental flows*	*confidential research trials*	*restore passage and critical environmental flows*		*resumption and enhancement of historically famous fishery for mulloway and black bream, reduction in carp habitat*	*research proposal*	*Brian Pierce, SARDI, Fisheries and Aquatic Sciences, West Beach, SA*

ISSUE 3:
Nutrient and Contaminant Inputs

3.1 Overview and FRDC role

3.1.1 The issues

Like other nations, Australia's coastal lagoons, enclosed bays and are becoming increasingly subjected to anthropogenic inputs of dissolved and particulate materials that are having severe impacts on coastal food webs. The consequences of such inputs are potentially worse in Australian waters for several reasons:

- *lack of significant upwellings of cool, nutrient-rich water*
- *few major river systems depositing materials in the coastal zone*
- *a large proportion of our coastal waters are subtropical-tropical , with characteristically low concentrations of nutrients (and hence low productivity)*
- *Australia's soils are ancient and greatly weathered, and low in available phosphorus*
- *temperate and subtropical coastal waters are very clear with a benthic flora geared to high light levels.*

These characteristics maintain coastal and shelf waters that are naturally low in concentrations of dissolved and particulate carbon, nitrogen, phosphorus, and various trace elements. Natural estuarine and marine communities in Australia are therefore adapted to clear, low nutrient waters. Thus they are more susceptible to even moderate increases in nutrient and sediment concentrations than similar communities inhabiting many other coastlines.

The major sources of introduced nutrients, sediments and contaminants are:

- *run-off from agricultural land of fertilisers, animal wastes, and soils;*
- *point source discharges from industrial plants, stormwater and sewage drains, and aeolian deposits;*
- *effluent run-off from mariculture ponds, racks and sea cages*
- *wind-blown agricultural chemicals (eg. from Yorke and Eyre Peninsulas in SA)*

These inputs often accompany other impacts such as habitat modification and destruction, disruption of coastal hydrological cycles – including river discharge– shoreline erosion and siltation, and poor land-use practices (see Chapter 2). It is critical to note that a dynamic interaction exists amongst water, land, riparian zone and land use planning and management issues. We have separated some of these in this review for convenience only, in our mandate to evaluate the ranking of issues specified at the Cronulla 1994 workshop (Williams and Newton 1994). Acid drainage is a major contaminant of estuarine fisheries habitats, but we have discussed it in association with changes to drainage in Chapter 2.

Nutrient and contaminant inputs from point and diffuse sources were considered in the SOMER report to be the highest priority in all enclosed waters from Perth to Brisbane (eg. Edyvane 1996a, Winstanley 1996). However, in the North East of the country run-off and mobilisation of sediments may pose a greater threat to nearshore habitats - particularly in overgrazed catchments of the dry tropics. This threat is poorly documented and not understood well, because of a background of naturally high turbidity, and a lack of seagrass monitoring and other baseline data.

Many of Australia's coastal waterways have, in recent years, suffered from eutrophication caused by high concentrations of nutrients from sewage and runoff from agricultural land. Eutrophication (an increased rate of supply of nutrients leading to enhanced primary production) is caused mainly by loading of nitrates and phosphates, and secondarily by organic matter.

In marine systems, global reviews generally conclude that the response of "nuisance" phytoplankton and macroalgae are always in an opposite direction to benthic macrophytes such as seagrass. That is, the nuisance species always bloom and shade seagrass with combinations of epiphyte loads, water column chlorophyll and particulates.

The most infamous episode has been the 1992 blue-green algal blooms along more than 1000 km of the Murray-Darling. However, many sheltered marine waters in Australia have, to some extent, been affected by enhanced nutrient supply, including:

- *Peel-Harvey Estuary, WA (phytoplankton and macroalgal blooms)*
- *Swan River, WA (phytoplankton and macroalgal blooms)*
- *Cockburn and Warnbro Sounds, Albany Harbours, WA (seagrass dieback, seabed anoxia)*
- *Barker Inlet (macroalgal blooms) and Port River, SA (dinoflagellate blooms)*
- *Holdfast Bay, Proper Bay, SA (seagrass dieback and blowouts)*

- *Derwent River, Tas. (dinoflagellate blooms)*
- *Port Phillip Bay and the Gippsland Lakes, Vic. (phytoplankton and dinoflagellate blooms, seabed anoxia)*
- *Botany Bay, NSW (seagrass decline)*
- *Hawkesbury River, NSW (phytoplankton blooms, excessive macrophyte growth)*
- *Tweed River, NSW (seagrass decline)*
- *Moreton Bay, QLD (phytoplankton blooms)*
- *Coastal Reefs, Great Barrier Reef, QLD (fears for macroalgal blooms - but little evidence ; coral decline)*

The symptoms of advanced eutrophication at higher latitudes have been alarming – with massive changes in the short and longer terms to the benthic and pelagic primary production of entire bays and estuaries. These changes characteristically involve:

- *blooms of toxic cyanobacteria, dinoflagellates or other phytoplankton*
- *permanent or long-term dieback of very large areas of temperate seagrass due to shading or epiphyte growth at the scale of tens of thousands of hectares*
- *destabilisation of sediments after seagrass loss, leading to "blowouts" and sediment smothering of other seagrasses*
- *blooms of nuisance macroalgae at the scale of entire bays and estuaries, in biomass of tens of thousands of tonnes*
- *changes to denitrification cycles in sediments and bay-scale bottom anoxia*
- *choking of mangrove pneumatophores and excessive biological demand of rotting drift-algae, leading to anoxia of shallow waters.*

There are also tertiary effects of loss of seagrass from sediment loading - the spatial interaction between endangered dugong and east coast gillnets may be aggravated by "narrow-banding". The declaration of Dugong Protection Areas has resulted in exclusion of gillnetting from some bays (see Chapter 4).

There is a further linkage of the eutrophication issue to the introduction of marine pests (see Chapter 5). The Port Phillip Bay Study showed that the assimilative capacity of the Bay for nutrient and contaminant inputs depended on aerobic denitrification cycles deep in sediments. A rapidly escalating coverage of the seabed in Port Phillip Bay by the fanworm Sabella spallanzani poses an unknown hazard to these cycles, but the risks are enormous. There may be also aggravation of the establishment and blooming of the toxic introduced dinoflagellates in elevated nutrient regimes.

Whilst some authorities suggest that nutrient inputs could enhance our low coastal fisheries production they have overlooked the fact that sewage and stormwater inputs are invariably accompanied by contaminants, pathogens and bacteria to some extent. These components of the wastewater cycle pose the following threats:

- *heavy metal, organochlorine and hydrocarbon contaminants are concentrated in food chains or "banked" in sediments*
- *coliform bacteria and other human pathogens (eg. hepatitis in Wallis Lake Oysters) can shut down shellfish mariculture with cascading effects on all sales of seafood due to human health scares.*

Finally, there has been poor performance of the programs monitoring seagrass decline using aerial photography and underwater surveys. Many of them are merely documenting the loss of the resource without any clear procedures or triggers for action - there is an urgent need to apply biomonitors (Dennison 1994) that give information about the cause of stress to seagrass.

The overall threats from contaminants are not well understood, due to a lack of systematic monitoring of sediment, water and biota throughout the nation's waterways, but the present threats seem to be localised to the immediate vicinity of heavy industry (eg. Selenium and other heavy metals in Lake Macquarie) and particular types of agriculture. For example, contamination of rivers by endosulfan pesticides from cotton farming has caused repeated, large fish kills in some catchments. The best documented instances in the marine environment (Port Phillip Bay metal pollution; Mercury in Albany Harbour and tributyltin (TBT) in oysters) show that the hazards usually recede when sources of pollution are removed and contaminants are buried in sediments.

However, gastropod imposex is still widespread near ports, due to continued use of TBT on international vessels over 20 metres length, and may pose a threat to western rock lobster stocks near Fremantle (p.c.#1400 C. Simpson). TBT levels in Port Phillip Bay are reportedly still high and require monitoring.

The historic focus on water quality standards and water column sampling may have under-estimated the local threat of contaminants to fisheries. New studies on the water-air and sediment-water interfaces show much higher concentrations than in the water column. Innovative biomarkers of contamination show that the sea-surface microlayer is a zone of *concentration of many organic and inorganic contaminants that may pose a threat to neustonic egg and larval stages of coastal fishes. The techniques to assess this threat are now available (eg. Klumpp and von Westernhagen 1996) and should be applied.*

The existing "cross-gill" toxicity testing protocols to determine water quality standards have also been questioned by fisheries authorities - more informative testing can be done by looking at uptake of some contaminants through feeding trials. Some species (notably prawns and mud crabs) have naturally very high levels of cadmium in their digestive tissues, and at the time of writing the ASIC was proposing that maximum permissible levels in food standards be raised to accommodate this fact.

The management response to the threat of contamination has generally been temporary or permanent closure to harvesting of some organisms in some "heavy metal hotspots" (eg. upper Spencer Gulf, Albany) near industrial sites and temporary closure to harvesting of shellfish upon the appearance of human health risks. Sea ranching of fin-fish can occur in badly affected areas, such as Port Davey in Tasmania, because the captive fish are isolated from local food chains.

The incidence of pesticide application for biting insect control in fish and prawn nurseries is widespread in more tropical areas, and increasing as development encroaches on mangroves, floodplains and waterways. Public health concerns about arboviruses are also rising as epidemics of Dengue and Ross River virus and Japanese encephalitis occur. There is a lack of knowledge of the toxicity of the popular "Abate" mosquito larvicide to prawn, crab and fish larvae - laboratory studies underway at the University of Queensland show lethal effects of small doses on zooplankton (p.c.#920 J.Greenwood), but the actual field toxicity is unknown.

Oilspills have very high public profile. The limited literature in Australia suggests they pose a transient, episodic threat to fisheries - but the longer term effects of hydrocarbons on egg and larval stages in the sea-surface microlayer have not been investigated. There has been recent focus on the effects of oilspills on mangrove ecosystems. Recovery from oiling may take several decades, but the effects of chronic oilspills (eg. in Botany Bay) are much worse. Mangrove trees, seedlings, sediments and key infauna, such as burrowing crabs, are badly affected by this local threat. We could find no assessments of the effects of oilspill dispersants on fish or commercially important shellfish and crustacean larvae.

3.1.2 The literature

The breakdown of "eutrophication" literature cited in Table 3.1.1 shows that R&D effort has mainly followed four different but complementary avenues:

- *documentation and monitoring of decline in seagrass and increase in macroalgae*
- *determination of cause of seagrass decline and macroalgal increase*
- *understanding phytoplankton blooms to provide capacity to predict and avoid the consequences*
- *direct study or correlations between macroalgal increase or seagrass dieback and changes in fisheries production*

Major reviews of the subject show that phytoplankton and macroalgal blooms and loss of seagrass inevitably occur at some stage in the eutrophication cycle, but the paths and stages differ greatly amongst locations and between different nutrient regimes (see Nielsen and Jernakoff 1996, Gabric and Bell 1993, Hillman et al. 1990 for reviews). There are benefits for some taxa (and losses for others) in these cycles.

Ultimately light and oxygen availability become the major forcing functions for benthic and pelagic communities, but studies of phytoplankton dynamics have shown a complex interplay of nutrients, interspecific competition, trace elements and rainfall. In this regard there is not yet a sufficient understanding to precisely predict the occurrence of monospecific blooms destructive to mariculture.

Seagrasses are important fisheries habitats, nurseries and bases of detrital food webs. The literature shows vast spatial differences in the levels of understanding of the threat of nutrients and contaminants - the division falling roughly between tropical and temperate meadows and east and west coasts. For example:

- *the extent of southern seagrass is well-mapped, but there is not yet a complete spot map of their northern occurrence from Brisbane to Perth*
- *seagrass decline has been mapped in all estuaries of NSW, in the Gulfs of South Australia, around the entire Tasmanian coast, in the entire south-west of WA, and in the Gulf of Carpentaria, but some of these inventories need updating*
- *the reasons for decline are best understood in SA, south-western Australia, Moreton and Hervey Bays and the Gulf of Carpentaria*
- *reasons for decline are suspected, but poorly known, for Tasmania, Victoria and NSW*
- *effects on fisheries have been published only for Westernport Bay , Cockburn Sound and Gulf of Carpentaria*

- *the most powerful biomonitors of the reasons for decline have been developed in southern Qld (see Dennison 1994).*

There is consequently a mis-matched mosaic of national understanding of seagrass dynamics and anthropogenic threats, and seagrass loss and fisheries implications. For example, Clarke (1987) has documented well the causes of loss of seagrass in Holdfast Bay in St Vincent Gulf, yet no studies have been done there on the response of fisheries - that type of study is presently confined to dieback episodes in Spencer Gulf where the causes are not related to nutrient inputs.

Finally, the paradigms presented by Edgar and Shaw (1995c) allow some tests of predictions concerning food-chain responses to seagrass dieback, but to our knowledge those tests are not being pursued.

There have been relatively few studies of the effects on fisheries of eutrophication in Australia. Best documented are the benefits for fisheries at some stages in the eutrophication cycle in the Peel-Harvey estuary, followed by anoxia and fish kills. There has not been close coincidence of studies determining the causes of seagrass loss and studies of fisheries decline. Studies of fish communities and production associated with seagrass dieback have mainly occurred after the seagrass has declined (eg. Westernport Bay) or are far removed from the location of studies where the causes of seagrass dieback have been investigated. We discuss in this chapter and section 2.7 why some of these correlations have not produced intuitive results due to the "intermediate" nature of disturbance, the persistence of detrital pools, differences in fisheries targets and other factors.

Interviews with researchers suggested that some herbivore populations on the SA and NSW coasts (luderick, sea mullet, yellow-eye mullet, tarwhine) may have benefited from estuarine eutrophication, but we could find no confirmation of this intuitively attractive hypothesis in CPUE figures.

Our searches produced a large number of studies of contaminants in coastal ecosystems. The breakdown in Table 3.1.2 incorporates a relatively large body of literature on design of monitoring programs, measurement and assessment of contaminants, and an abundance of "one off" local studies that documented many cases of elevated levels of contaminants. We could not assess from the literature whether the numerous studies of metals reflects their true *risks and hazards relative to the organometals and organic pollutants -- or mostly historical concerns amongst the public and ease of measurement and analysis.*

We could find no literature on the effects of pesticides in fish and prawn nurseries, and very little information on pathogens in wastewater and their implications for shellfish mariculture. This may be due partly to our search strategies and the separation of ecotoxicological and medical literature from marine research databases.

A feature of the "contaminants" literature is the periodic focus on a particular problem or region followed by apparent periods of inactivity and lack of monitoring. This may reflect the lack of systematic monitoring in Australia identified by Ashbolt (1996) and Richardson (1996) in the SOMER reports, but also indicates the limitations of our literature searches. For example, we found mention of a Market Basket Survey by the National Health and Medical Research Council (NHMRC) for seafood contaminants but there was no record of this initiative anywhere in the indexes we searched - it may be documented in medical or other bibliographies.

Table 3.1.1. Selected literature on the effects of nutrients and sediments in the coastal zone, by broad region or habitat type

	seagrass dieback - causes	seagrass dieback - effects on fisheries	algal blooms- causes	algal blooms- effects on fisheries	sediment/water quality and effects on communities	innovative biomarkers and biomonitors
temperate zone	Bulthuis et al. (1984,1992), Bulthuis and Woelkerling (1983), Clarke (1987), Clarke and Kirkman (1989), Neverauskas (1988a,b), Nielsen and Jernakoff (1996), Shepherd et al. (1989)	Edgar et al. (1993), Peterson et al. (1994), Hamdorf and Kirkman (1995), Jenkins et al. (1993d, 1994), MacDonald (1992), Seddon (In Progress),	Bunn et al. (1996), Butler et al. (1995), Cannon (1990, 1993), Hallegraeff (1992a, 1995,1996), Harris (1994,1995), Heath et al. (1981),	Gwyther (1990), Hamdorf (1993), Nicholson (1992), Parry et al. (1989), Winstanley (1996),	Axelrad et al. (1981), Nielsen and Jernakoff (1996), Woodward (1989),	Anon. (unpubl.), Ahokas et al. (1994),Arnott (1990a,b), Brumley et al. (1995), Heggie et al. (1994), Leeming et al. (1994), Moverley et al. (1995), Neverauskas (1987a,b), O'Leary et al. (1994), Parslow (in press),
sub-tropics and tropics	Bastyan and Paling (1992, 1995), Cambridge et al. (1986), Cambridge and McComb (1984), Clarke and Kirkman (1989), Hastings et al. (in press), Hillman et al. (1990,1991), King et al. (1986), King (1988), Kirkman (1978,1994), Kirkman et al. (1991), Larkum and West (1990), Lee Long and Coles (1997a,b), McComb et al. (1991b), Shepherd et al. (1989), Silberstein et al. (1986), Walker (1990b), Walker and McComb (1992), West (1990a,b), Wnuczynski and Thorogood (in press)	Dybdahl (1979), Halliday (1995), Jonker (1993), Walker et al. (unpubl.),	Bunn et al. (1996), Birch (1982), Birch and Gabrielson (1984), Birch et al. (1983), D'-Adamo et al. (1992), Hillman et al. (1990, 1995a), Hodgkin and Birch (1982,1984,1986), Humphries et al. (1984), Lavery et al. (1991, 1995), Lavery and McComb (1991), Lukatelich and McComb (1986), McComb et al. (1981a,1984), McComb and Humphries (1991, 1992), McComb and Lukatelich (1986,1990),	Gehrke and Harris (1994), Growns et al. (1996), Humpage et al. (1994), Lenanton et al. (1984,1985), Potter et al. (1983b),	Bastyan et al. (1994), Bunn et al. (1996), Cullen (1995), Gabric and Bell (1993), Lord (1994), McCook and Price (1997), Nielsen and Jernakoff (1996), Otway (1993,1995), Otway et al. (1995a,b),, Smith and Simpson (1993),	Abal and Dennison (1995, 1996), Abal et al. (1994), Dennison (1994), Hosja et al. (1994), Lavery et al. (1993), Nichols et al. (1994), Perry et al. (in press), Udy and Dennison (1995)

	seagrass dieback - causes	*seagrass dieback - effects on fisheries*	*algal blooms- causes*	*algal blooms- effects on fisheries*	*sediment/water quality and effects on communities*	*innovative biomarkers and biomonitors*
mangroves					*Cook (1996), Robertson and Lee Long (1991), Robertson and Phillips (1995), Robertson and Ford (1995), Rothlisberg and Barlow (1996), Soukup et al. (1994), Tam and Wong (1994),*	
tropics - coral reefs					*Bell (1992b), Brodie (1994,1996,1997)*	

Table 3.1.2. Selected literature on the effects of contaminants in the coastal zone, by contaminant type and broad region or habitat type.

Zone/Issue	pathogens in mariculture	heavy metals	tributyltin	organochlorines and pesticides	Oil spills and hydrocarbons	innovative biomarkers of stress
temperate - fish	Langdon (1990), DPIE (1996)	Fabris et al. (1992), Glover (1979), Langlois et al. (1987), Mosse and Kowarsky (1995), Nicholson (1992), Olsen (1983), Phillips et al. (1992), Vas et al. (1990), Walker (1981,1982), Ward (1989)		Batley (1992), Nicholson et al. (1994), Phillips et al. (1992),	Langdon (1986), Nicholson et al. (1994), Phillips et al. (1992),	Ahokas et al. 1994), Brumley et al. (1995), Holdway et al. (1995), Volkman et al. (1994a,b),
temperate-shellfish	Ashbolt (1996), Anon. (1978), Herfort and Kerr (in press)	Coleman et al. (1986), Fabris et al. (1994), Kitching et al. (1987), Richardson et al. (1994), Ritz et al. (1982), Smith et al. (1981), Walker (1982), Wootton and Lye (1982), Cooper et al. (1982), Ward (1989)	Foale (1993), Nias et al. (1993), Scammell et al. (1991),	Richardson and Waid (1983),		Moverley et al. (1995)
sub-tropics - fish		Anon. (undated b,c), Airey (1984), Bebbington et al. (1977), Caputi et al. (1979), Chvojka et al. (1990), Edmonds and Francesconi (1987), Edmonds (1981), Edmonds and Francesconi (1981), Francesconi and Edmonds (1993,1995), Francesconi and Lenanton (1992), Francesconi et al. (in press), Hamdorf (1992b), Leadbitter (1992), Maher (1984,1987), Maher et al. (1992), McLean et al. (1991), Mills (1987)		Anon. (1993g), Miskiewicz and Gibbs (1992,1994), Hamdorf (1992c), Novak and Ahmad (1989), Nowak (1992), Powell and Fielder (1982,1983), Richardson (1996),	Connell (1996), Cullen and Connell (1992), Hawker and Connell (1986), Kayal and Connell (1995), Miller (1982),	
sub-tropics - shellfish	Roubal et al. (1989),	Anon. (undated b,c, 1993g, 1995f,i), Brown and McPherson (1992), Batley (1996), Francesconi (1989), Francesconi et al. (1991, 1993,1994, 1995), Le Provost and Chalmer (1983), Mortimer and Miller (1994), Talbot (1983, 1985, 1990), Talbot and Chigwidden (1982),	Batley et al. (1989,1992), Batley (1996), Peterson et al. (1993), Wilson et al. (1993),	Just et al. (1990), Korth (1995), Scanes et al. (1993), Shaw and Connell (1982),	Mortimer and Connell (1993),	

Zone/Issue	*pathogens in mariculture*	*heavy metals*	*tributyltin*	*organochlorines and pesticides*	*Oil spills and hydrocarbons*	*innovative biomarkers of stress*
mangroves/ seagrass		*Harbison (1986), Lenet et al. (1992), Mills (1987),Tiller et al. (1989), Ward (1984, 1987), Ward et al. (1986), Ward and Young (1981, 1982)*			*Butler (1995), Connolly and Jones (in press), Clarke and Ward (1994), Grant et al. (1993), Hatcher and Larkum (1982), McGuiness (1990), Raaymakers (1996), Wardrop et al. (1987),*	
tropics -fish		*Hortle and Pearson (1990), Lyle (1984),*				
tropics - shellfish		*Darmono and Denton (1990), Denton (1986), Denton and Breck (1981), Denton and Burdon-Jones (1986a,b), Jaffree and Brown (1992), Klumpp and Burdon-Jones (1982), Klumpp and Peterson (1981), McConchie and Lawrence (1991), McConchie et al. (1988,1991), Peerzada and Dickinson (1988,1989), Peerzada et al. (1990,1992a,b,1993), Talbot (1986)*	*Kohn and Almasi (1993),*			*Klumpp and von-Westernhagen (1995), von-Westernhagen and Klumpp (1995),*
tropics - coral reefs		*Burdon-Jones and Denton (1985),*		*Smillie and Waid (1985), Shaw and Connell (1985)*	*Coates (1985), Smith (1985), Smith et al. (1987),*	

3.1.3 FRDC action

The greatest strategic challenge facing the FRDC and its stakeholders with the downstream effects of nutrients and contaminants from agriculture and development is to identify and implement better ways to transform scientific expertise and knowledge into information relevant to natural resource management - and to ensure this information produces outcomes that safeguard fisheries values.

For example:
- *studies on the wastewater-induced Posidonia dieback have not yet produced an outcome whereby sewage inputs are halted, reduced or improved in quality in St Vincent Gulf*
- *several seagrass monitoring programs (eg. Botany Bay, Holdfast Bay) are merely documenting the decline of this fisheries habitat - without any clear procedures in place or triggers for action to address the problem*
- *the Westernport Bay fish-seagrass studies have not been followed up by monitoring programs of recovery paths for seagrass and fisheries*
- *some "Fisheries Habitat Areas" in north Qld are protected from mangrove destruction, but receive acid drainage, nutrients and sediment from adjacent disturbances (eg. fish kills in Palm Creek FHA)*
- *dredging in northern NSW estuaries has been implicated in seagrass decline, but there is no R&D on which to base management options*

Prevention and rehabilitation of the eutrophication cycle from diffuse sources are certainly feasible - but all situations require a coordinated approach in research and management to achieve outcomes. The most notable successes and approaches come from Western Australia, where the Estuarine Research Foundation of WA has State Government funding and has produced an admirable focus in the efforts of most of the relevant scientific community in universities and government departments.

These initiatives are couched within models (eg. COASEC) to balance the requirements of "drawing conclusions" (experimental approach) and "making decisions" (modelling approach). Steering committees ensure that the models have captured the right processes at the management scale and match the model to the decisions and questions required by managers and users (eg. Parslow 1992).

Disposal of wastewater is a national concern and a growing number of multi-disciplinary, model-based projects have addressed the issue of assimilative capacity in major bays and *estuaries at the "landscape-scale" (see Lord 1994). Invariably these models require strong knowledge of hydrographic and biogeochemical processes, and uncertainty increases sharply when it comes to the first levels of secondary production. However, the modelling process also serves to identify key uncertainties and early research needs (eg. Spear and Hornberger 1980).*

As pointed out by Robertson and Phillips (1995), key research questions need to be answered before predictive models can be constructed estimating the capacity of a system to tolerate nutrient loading:

- *what nutrient loads can cause complete anaerobiosis of sediments and plant mortality?*
- *what is the long-term assimilative capacity of sediments for dissolved nutrients?*
- *how do different sediment types affect the retention and transformation of nutrients?*
- *what nutrient loadings have a detrimental impact on benthic fauna?*
- *what is the impact of loss of bioturbating benthic fauna, such as crabs?*
- *what combinations of nutrient loadings and hydrodynamic regimes cause anoxic/hypoxic conditions in estuarine and coastal waterways?*

These questions reflect our current level of ignorance with respect to nutrient impacts and tolerances of ecosystems.

Our recommendations for FRDC action are outlined in Table 3.1.3. A first step will be to coordinate with the LWRRDC (Pesticides Program) and the CRC for Wastewater to identify common priorities.

At the large, bay and estuary scale there is a role for the FRDC in coordinating with, and adding value to, initiatives such as the Moreton Bay Wastewater Management Study through strategic R&D on parameters estimating the routes, rates and sources of secondary production. Our review has found a surprising lack of any comparative studies contrasting fisheries production in the bays and estuaries at similar latitudes to make inferences about the processes governing production. There is consequently a poor understanding of the potential and ceilings for our inshore fisheries, and a lack of informative hypotheses at this level to predict the effects of moderate nutrification.

At the smaller scale of effluents from mariculture operations the key questions and processes are still the same but the FRDC will have the lead role to invest in the multi-disciplinary research required to address them. Regional planning of the location and management of aquaculture is a high priority to ensure sustainable development of this industry and has *proven successful in Tasmania and elsewhere (see McLoughlin 1997 and Preston et al. 1997). The Fisheries Environment and Health Committee (FEHC) has produced a definitive summary of the threats of nutrient inputs to shellfish mariculture (Hamdorf 1993).*

The FEHC has produced fishery-contaminant matrices, prioritised risks, hazards and threats to fisheries habitats, and canvassed the States on their responses to issues raised in the SOMER report (see Appendix 2, Hamdorf 1994, 1995).

Maintenance of water quality underpins all aquaculture, yet prawn pond effluents and seafloor souring from sea cages can threaten adjacent fisheries habitats or reduce their own sustainability. We see a lead role for the FRDC in developing techniques to assess and manage the "effects of mariculture on the environment" as well as "effects of the environment on mariculture". This issue extends from monitoring viral, hormonal, faecal coliform and other contaminants in and around farms into development of pellet feeds with better food : biomass conversion ratios and less waste and faecal matter. Risks occur from viral contamination of mariculture sites, but these are not detected by "traditional" monitoring of faecal bacteria levels. There are also R&D opportunities to study the use mangrove habitats in a dual role as nutrient sinks and scrubbers and fisheries habitats in association with tropical prawn aquaculture.

It is not possible for us to recommend specific R&D that will aid all integrated modelling approaches. Instead, we recommend that the FRDC continues to:

- *invest in close coordination with FEHC and other R&D Corporations on catchment-scale issues*
- *identify processes and structures (eg. Integrated Catchment Management Committees) with common visions for fisheries outcomes, and effectively communicate existing R&D knowledge to them*
- *coordinate with and respond to the R&D needs identified by Adaptive Environmental Assessment and Management projects (AEAM) , such as the Tuggerah Lakes project run by Wyong Council.*

The review by Webbnet (FRDC# 95/172, Webbnet 1996, p. 71) has outlined how research proposals can be evaluated to assure their impact in regard to the need for coordination and integration. Boehmer-Christiansen (1994) has shown how political forces can be harnessed to bring about better implementation of R&D results in environmental management, and

Creighton et al. (1997) provide an outline of the scale of catchment management involved now in minimising nutrient and sediment export into the GBR lagoon.

This approach is rapidly being adopted to confront catchment-scale problems throughout Australia (see Chapter 2) and the production of "Natural Resource Management Toolkits" (Walker et al. 1997) has been a major product of the CSIRO Coastal Zone Program. There has been investment in this area by the FRDC to explore options on the northern NSW floodplains (Webbnet 1996) and in the "Huon Healthy Rivers Project" (FRDC #96/284).

However, we do strongly recommend that strategic R&D is needed to encourage and further develop biomarkers and other innovative surveillance techniques to :

- *assess, predict and avoid problems associated with declining water and sediment quality*
- *identify and monitor stress and stressors*
- *trace trophic links and movement of nutrients and particulate matter (eg. away from mariculture sea cages; through food chains).*

This would immediately aid in safeguarding mariculture and could, ultimately, assist in prevention of the upstream causes of such pollution - but only if such R&D is couched in Integrated Catchment Management and sound regional planning. Such an approach could be coordinated with the current development of Estuarine Indicators under "State of the Environment" Reporting.

As marine plants such as seagrass and mangroves fall specifically under Fisheries Acts in several States there is a clear role for the FRDC in addressing gaps in knowledge about the stressors, dynamics and potential for restoration of these habitats in the face of increased nutrient, sediment and contaminant loads through:

- *employing and developing newly emerging biomonitoring techniques to allow an assessment of stressors of seagrass beyond the sensitivity of traditional monitoring*
- *identifying natural dynamics and ecophysiology of tropical seagrasses, and avenues for restoration*
- *better definition of seagrass-fisheries relationships, especially in the tropics, would help understand the implications of dieback (previous FRDC studies initiated development of paradigms about secondary production that are the first available for any Australian fisheries habitat).*

Unfortunately we can not clearly identify paths for linking such R&D results to management outcomes for the Posidonia dieback issue because the scale of the problem is outside the *spatial boundaries of existing management structures such as Integrated Catchment Management and Fisheries Legislation. There are clearer opportunities through R&D for conservation and restoration of seagrass in estuaries and canal estates in the sub-tropics and tropics.*

Our literature searches uncovered insufficient information to make comprehensive recommendations for R&D on contaminants. For this reason we recommend that the FRDC work closely with the Fisheries Environment and Health Committee to prioritise and identify R&D in this field. The FEHC has produced a "fishery-contaminant" matrix and a review on the threat posed by organochlorine termiticides (Hamdorf 1992).

We have identified a need for the FRDC to help develop and apply innovative techniques to identify and assess the sub-lethal effects of various contaminants on wild fish stocks, especially early egg and larval stages, which may live in the surface layers (neuston) where hydrocarbons, organochlorines, tributyltin and other contaminants are in highest concentration. Such pollution is not detected by traditional water column sampling. Interrogation of multifunction oxidases (MFOs) in adults and embryonic abnormalities in early life stages show promise to help understand the true threat of contaminants. Unexplained declines in the Port Phillip Bay anchovy fishery, for example, may be explained by egg and larval mortality induced by neustonic pollution.

There are also challenges in relating laboratory toxicity testing to field situations for some pesticides and herbicides. Traditional "cross gill" exposures to determine water quality guidelines tell nothing of cumulative impacts through food chains, and the threat to estuarine fauna of supposedly "safe" pesticides, such as "Abate" is inadequately known. Mosquito larvicides and other "vector control" chemicals need particular attention from the FRDC, as they are being applied more widely as human inhabitation of lower catchments increases.

*Table 3.1.3. Summary of Major Opportunities for FRDC investment in addressing R&D Gaps in knowledge of "Nutrient and Contaminant Inputs" (*PMCWS = Perth Metropolitan Coastal Waters Study, MBWWS = Moreton Bay Wastewater Study, PPBES = Port Philip Bay Environmental Study)*

R&D Role for the FRDC	*Main Habitats*	*Main Fishery*	*Key Reference*	*Initiatives*
Explore techniques by which existing and new scientific expertise can be transformed into information relevant (and acted on) by natural resource management - the Adaptive Environmental Assessment and Management initiatives	*all coastal catchments and their deltas*	*estuarine and riverine fisheries*	*Preston et al. (1997), Walker et al. (1997), Webbnet (1996)*	*CSIRO Coastal Zone Program, ICM (Qld) and TCM (NSW)*
Understanding algal blooms - development of techniques to predict and manage the threat to mariculture (eg. water quality sensors) -- and testing hypotheses on effects on fish harvests of macroalgal blooms	*temperate bays and estuaries*	*all mariculture*	*Arnott (1990), Parslow (in press),*	*Huon Healthy Rivers Project FRDC #96/284*
The need for Biomonitoring and Bio-indicators -- the integrated approach to identifying and assessing environmental impacts of sediment and nutrient flux on primary producers	*Tropical and temperate seagrass; mangroves*	*all estuarine; prawn nursery*	*Dennison (1994)*	*Moreton Bay Wastewater Management Study*
Lack of knowledge of nutrient, carbon and contaminant cycling in mariculture - the need for development and maintenance of locally relevant water and sediment quality standards and monitoring techniques to identify and manage impacts of effluents and contaminants (eg. viruses)	*sea-cages and racks in temperate bays and estuaries; prawn ponds*	*SB Tuna, Atlantic Salmon, shellfish and prawn mariculture; oysters*	*Butler et al. (1995)*	*Tas. Shellfish Quality Assurance Program, FRDC# 96/284*
Lack of understanding of water quality role in oyster dieback due to diseases and acid runoff- predicting and avoiding the symptoms	*NSW estuaries*	*oysters*		
Egg, larval and adult health in contaminated plumes and fishing areas - development of techniques for surveillance and assessment of the emerging risks and hazards, and the need for a move from "cross gill" to "food uptake" tests in assessing toxicity	*polluted bays (eg. PPB) and sewage plumes*	*egg and larval stages of inshore species*	*Klumpp and von-Westernhagen (1995)*	*FRDC #97/217*
Ecotoxicology of mosquito larvicides and oilspill dispersants	*mangroves and saltmarsh*	*egg and larval stages of prawns, mud crabs, fish*	*Beumer et al. (1996)*	

R&D Role for the FRDC	*Main Habitats*	*Main Fishery*	*Key Reference*	*Initiatives*
Seagrass and Mangrove Dieback and Restoration - some dieback situations are still not understood; others may be amenable to transplants and restoration of profiles -- R&D is needed (See also Chapter 6)	*Zostera, Heterozostera seagrass; mangroves*	*Garfish, King George Whiting; east coast estuarine*	*Soukup et al. (1994), Kirkman (1990)*	*Cockburn Cement Pty Ltd Seagrass Transplants - also see Table 2.8.1*
What are the trophic links between fisheries and estuarine and nearshore habitats – a role for marine chemistry to distinguish amongst natural and artificial sources of primary production	*Tropical and temperate seagrass, mangroves and algae*	*all estuarine fisheries*	*Leeming et al. (1994), Loneragan et al. (in press)*	
Understanding secondary production in sheltered waters - life-history, trophodynamic and demographic parameters to add value to Landscape-scale Models of the processing of nutrients	*WA estuaries, SA, Tas and Vic bays, Moreton Bay*	*fin and shellfish mariculture; coastal finfish*	*Lord (1994), Gwyther (1990)*	*PMCWS*, MBWWS*, PPBES*, Swan River*
Fisheries significance of tropical seagrass, and understanding of the roles of multi-species patches and mosaics versus "stands" of temperate seagrass	*Posidonia and Amphibolis seagrass*	*Garfish, King George Whiting*	*Halliday (1996),*	*Walker et al. (unpubl.) in Cockburn Cement shellsand mining project*

Our interviews suggested that there may be scope for including the addition of silica in late stages of sewage treatment to grow diatoms that are useful in fisheries food chains. Silica limits growth of these organisms in the presence of excess nutrients and they are out-competed by monospecific blooms of nuisance or toxic dinoflagellates and blue-green algae. There may be a role for the FRDC in encouraging such R&D.

Finally, there has been a trial of a map-based, coastal marine bibliography "CAMTEXT" that links scientific publications to catchments, to allow catchment managers and other groups to easily find site-specific information (see CSIRO, DWE 1995). CAMTEXT and other tools have been developed under the "CoastNet" pilot study to make marine and coastal information more freely available on the Internet (see http://www.erin.gov.au:80/sea/sea.html). These platforms would be a very effective way of extending the findings of the FRDC final reports in the "Ecosystem Protection" Program.

3.2 Effects on ecosystems - seagrass dieback, algal blooms and the need for biomonitors

General changes to benthic communities in bays and estuaries in response to eutrophication include a shift in primary producers from large macrophytes, which are capable of nutrient storage and are more competitive at low ambient nutrient concentrations, towards ephemeral algae and phytoplankton which are more competitive at high nutrient loadings. In the case of secondary producers there are generally shifts from large fauna towards small opportunists - generally dominated by deposit-feeding polychaetes.

A review of all relevant Australian and international literature by Nielsen and Jernakoff (1996) has shown the following patterns for benthic community response.
For seagrasses:

- *there are no consistent links between nitrogen concentrations and either seagrass shoot density, biomass or production*
- *seagrass shoot density can show a negative log-linear relationship with pore-water ammonium concentrations - but relationships between other growth parameters and water and sediment nitrogen concentrations are not clear*
- *seagrass growth parameters show strong positive relationships to irradiance, and hence negative relationships to light attenuation*
- *epiphytes have demonstrable, negative effects on seagrass production by blocking light access to the leaves*

- *nutrients are more likely, therefore, to have indirect effects on seagrass growth by promoting epiphyte growth and/or water column turbidity - both of which would reduce light reaching the seagrass leaves (see also reviews by Hillman et al. 1991, Kirkman et al. 1991b, Shepherd et al. 1989, Walker and McComb 1992)*
- *measuring the relationships between nutrients, epiphytes and light attenuation may be more important than direct observations of nutrient-seagrass relationships when trying to determine the likely effects on eutrophication on seagrasses.*

For macroalgae, which are either attached to hard substrata (eg. Enteromorpha), free-floating (eg. Ulva) or epiphytic on seagrass blades (eg. Asparagopsis):
- *all nutrients must be obtained from the water column (and cannot be stored or recycled in the case of ephemeral algae) - they therefore have higher nutrient demands than seagrasses, and are not competitive at low ambient nutrient levels*
- *as nutrient concentrations increase, fast-growing macroalgae and phytoplankton are more competitive because they capture and use light more efficiently*
- *positive correlations between macroalgal biomass and production and nutrient concentration are not always present - they are confounded by processes such as luxury uptake and storage and nutrient release during decomposition*
- *biomass and production are strongly related to irradiance, but this response is influenced by other factors too - in particular seasonal differences in physiological conditioning (not just temperature).*

A superficial glance at the eutrophic estuaries around Australia shows striking differences in the visible symptoms - Ulva in Barker Inlet, cyanobacteria in the Peel-Harvey and no visible symptoms in Trinity Inlet in Cairns (see also King and Hodgson 1995). Current research on the dynamics of macroalgae in WA estuaries is yielding knowledge on the differences in these symptoms, which are largely enforced by a suite of physical factors and inter-specific differences in physiology.

For example, Peel Inlet in WA is unusual in that it is "light limited" and has no significant sewerage inputs. The primary rivers flow in winter in WA, so the Peel Inlet receives a once-per-year plug of terrigenous inputs through river flow events, which drive all subsequent changes in the amount of humic substances (and hence light) and also nitrogen and phosphorus. There are very rapid shifts from Ulva to Chaetomorpha and the disappearance of Cladophora that can be explained by:

- *Ulva invasion needs constant eutrophication (hence their prevalence in Barker Inlet which receives sewage effluent all year)*
- *Chaetomorpha out-competes all others when there is intermittent eutrophication*
- *Ulva cannot cope with low winter salinities and therefore "catches" only the tail end of nutrient availability afforded by river flow*
- *Cladophora is a ball-forming species that sinks and embeds into the sediment, so as to build up a thick rotting layer. The balls rise up and are blown into shore where they build up in foul-smelling mats. The mats have since disappeared - perhaps because of cyclonic disturbance, a virus or bacterial infection, or grazing*
- *in WA the estuaries are shallow (2-3m deep) and daily sea breezes and heating and cooling cycles produce resuspension of macroalgae, and stratification causes short-term bottom anoxia - international research results are not appropriate for predictions of local dynamics (p.c. #1350 P. Lavery).*

There are also long-term cycles in the response of primary producers to eutrophication which have important implications for fisheries. The history of the problem in the Peel-Harvey was firstly vast increases in Ruppia production, (and also the seagrasses Halophila and Heterozostera), then a predominance of macroalgal biomass followed by an increase in blue-green algal blooms. Whilst the early changes were considered to be beneficial to fisheries production, the cyanobacterial blooms were probably negative. The changes are still occurring - the intermittently open Wilson's Inlet is probably in the state now that the Peel-Harvey system was in 20 years ago (p.c.#1360 R. Lenanton).

The effects on fisheries of these cycles will in some part depend on the original types of primary producers present in estuaries and bays. For example, permanently open systems in WA have a much higher diversity of primary and secondary producers that range from "colonising" (Heterozostera) and old, "permanent" (Posidonia) seagrass beds to Cladophora and Ulva. In contrast, the intermittently open estuaries have Ruppia, Polyphysa, Lamprothamnion as the major benthic primary producers.

Nielsen and Jernakoff (1996) report that increases in fish abundance, growth rate, biomass and productivity have been documented in areas experiencing eutrophication but :
- *increases in yield have generally been linked with greater fishing effort rather then to the direct influence of eutrophication*

- *empirical links between nutrient loads and fish abundance, biomass and production are difficult to quantify due to the high degree of variability associated with measurements of these parameters*
- *changes in community size-structure and species composition have resulted as a result in changes to the quality of benthic habitats or as a result of periodic anoxia*
- *declines in fish biomass have been empirically linked to low water column oxygen concentrations.*

Anoxia may affect most the eggs and larval stages of important fish and crustaceans, as these are least able to avoid such stress and may migrate vertically into anoxic layers – unfortunately studies are lacking in Australia on these life-history stages. Low, but non-lethal, oxygen tension is known overseas to lead to increased predation on fish larvae by scyphomedusae and decreased predation on larvae by planktivorous fish.

Anoxia does occur here, even in large bays such as Cockburn Sound where there is a 1 m deep anoxic layer above the sediments in the main basin due to stratification. For example, a mass-mortality of the cockle Katelysia occurred in Princess Royal Harbour at Albany due to anoxia (Peterson et al. 1994). Adult abundances crashed, but recruitment of young Katelysia was also negligible, at levels two orders of magnitude less than previously observed. These dramatic declines in abundances of a previously dominant component of the fauna of Princess Royal Harbour co-occurred with eutrophication, seagrass die-off and macroalgal blooms, suggesting that the environmental problems of this harbour have cascaded through the ecosystem to alter its ability to sustain natural secondary production and ecosystem function.

There are few Australian studies on the effects of eutrophication on fisheries production, and we have discussed some of these in detail in sections 1.3.2, 1.4.4.1, 2.7 and elsewhere. The gaps in knowledge of natural dynamics of fisheries and habitats have hindered prediction of the effects – Gwyther (1990) concluded that "habitat requirements of all the species in Port Phillip Bay are not known sufficiently for accurate prediction of species interactions and effects if nutrient loading caused increased phytoplankton and seagrass dieback".

The long-term comparisons of community structure and trophic links in Port Phillip Bay have not produced any clear patterns that can be attributed to the input of nutrients. Rather, competitive interactions have been proposed as the mechanism behind the few, unexpected changes in numbers of some taxa (eg. small rays), and shifts in food chains have been caused *by consumption of introduced crabs and bivalves (see Hobday et al. 1996, Officer and Parry 1996, Parry et al. 1995).*

Gwyther (1990) proposed that nutrient enrichment would have to be very high to detect an increase in fish production in Port Phillip Bay, because carbon transfer efficiencies are generally 0.1-1%. Adverse effects would be seen with water quality before signals could be detected in fisheries production. Apart from general declines in landings for some species, and peaks in others, Gwyther (1990) could find evidence of change only in increased growth rates of scallops, and a higher growth rate of young snapper in Port Phillip Bay compared to other parts of their south-eastern range.

Nutrient inputs have caused algal blooms, seagrass dieback and anoxia in Cockburn Sound but relatively high fish production has been reported there in the review by Gwyther (1990) (see Table 1.3.2.3). However, two planktivores (Sardinops sagax and Sardinella lemuru) formed the bulk of catch and these are not directly dependent on seagrass. Dybdahl (1979) warned that seagrass detrital material is at the base of the food chain there and takes a long time to decompose. Therefore the effects of seagrass loss will not be immediately evident. There may even be local and short-term increase in diversity and abundance as habitat diversity increase in seagrass patches and dieback causes more detritus to pool in sediments.

The studies by Lenanton et al. (1985) and Potter et al. (1983b) have shown the importance of anoxia in the effects of eutrophication on fisheries production. The most prolific and prolonged blooms of the cyanobacterium Nodularia spumigena occurred in Harvey estuary and the western half of Peel Inlet. Blooms there were so intense that secchi disk readings were as low as 2cm. The blooms were highly seasonal, but also peaked after large river discharges of freshwater and nutrients.

Chlorophyll (chl a) measurements were good indicators of Nodularia abundance and the threshold for visible affects on fish abundance was 100 micrograms chl a per litre. Comparisons of fish community structure found 4 species responsible for the difference in "Nodularia" and "non-Nodularia years" when sampling was done by Potter et al. (1983b) in the same places. These were the mouth-almighty Apogon rueppelli, the trumpeter Pelates sexlineatus, Gymnapistes marmoratus and yellow-eye mullet Aldrichetta forsteri.

Declines in bottom oxygen tension were associated with blooms and it was therefore most notable that benthic species died, and the recruitment of the demersal Apogon rueppelli was *suppressed during blooms. Hundreds of dead blue swimmer crabs (Portunus pelagicus) and "cobbler" Cnidoglanis macrocephalus were found in summer when temperatures were at their maximum and blooms were intense. Several lines of evidence showed fish were moving away from the blooms and out of the estuary. Fishermen suspended operations and made good catches in unaffected areas. More active and mobile teleosts such a yellow-eye mullet did not suffer conspicuous mortality during blooms – they moved away and the fishery shifted to follow them.*

Potter et al. (1991) reported that the macroalga Cladophora montagneana coated much of the substratum in the Peel-Harvey estuary during the late 1960's until 1979 and commercial catches of western king prawns (Penaeus latisulcatus) were very low. They inferred from this that the preferred sandy substratum of juvenile stages of this species was lost and that this affected abundance. The biomass of macroalgae was estimated to have fallen from 27 thousand tonnes in 1978 to 2.6 tonnes in 1981-1988.

The massive growth of macroalgae (Cladophora and Chaetomorpha) were accompanied by greatly increased fish catches - a feature that Potter et al. (1990) suggest reflected a reduction in predation from avian piscivores as a result of greater shelter from predators provided by the algae.

During the era of macroalgal and cyanobacterial blooms the Murdoch University environmental studies group sampled the Peel-Harvey in comparison with the Swan estuary (relatively non-eutrophic) with a focus on community structure and distribution of fish, crabs and prawns. They noted:

- *a dramatic increase in fish catch in the 1970's due to amphipod and copepod production in algal beds (amphipods Melita do not feed on the Ulva, instead they use it as shelter and graze on the epiphytic diatoms that live on Ulva)*
- *decline in western king prawns because of loss of nurseries in sandy substrata*
- *a State-wide increase in tarwhine numbers has been perceptible - these are herbivores as juveniles and recruit to vegetated habitats*
- *in the Swan estuary CPUE developed, peaked and then declined in association with macroalgal blooms - but shifts in targeting confounds looking at species shifts (eg. demand for yellow-eye mullet as rock lobster bait decreased)*
- *the Dawesville Channel option was chosen to reduce the residence time of phosphorus by increasing flushing – marked changes in access by marine species have occurred*
- *in winter the Peel Inlet was hyposaline, but freshwater is now quickly flushed away*

- *this enables year-round access of blue swimmer crabs, tailor and herring Arripis georgianus*
- *juvenile western king prawns are very abundant, because there are better, sandy areas for recruitment now – anglers have perceived improvement in catches but the strong currents in the channel have prevented proper sets of commercial gear and catches have declined*
- *high productivity of bacterial films remaining on sediment surfaces after the bloom episodes may provide food later for prawns, crabs and some shellfish.*

In South Australia, there have been no measurable changes in fish production associated with Ulva blooms that appeared, seasonally at first, in the early 1970's although:

- *the year class strength of recruits of yellow-eye mullet rose since 1980-1985, and this may be related to Ulva abundance*
- *the biomass of Ulva prevents use of jet-nets to sample post-larval western king prawns and repeat surveys done before blooms prevailed*
- *Barker Inlet remains the most important nursery for King George whiting in St Vincent Gulf (see Jones et al. 1996 and p.c.#1560 K.Jones, p.c.#1550 M. Kangas, p.c.#1520 A.J. Fowler).*

Of all finfish species fished commercially, we would expect to see signals of eutrophication in greater production of omnivorous yellow-eye mullet and herbivorous sea mullet and luderick, yet there are no definitive studies for these species.

3.2.1 Regional variability

The impact of excess nutrients are greatly complicated by a combination of physical, chemical and geological characteristics of a given system. Most simply, an enclosed water body with long residence times would be more affected than an open embayment with short residence time of water. Indeed, coastal lagoons are among the water bodies most badly affected. Coastal lagoons such as the Peel-Harvey system and Moreton Bay make up 11% of Australia's coastline and are especially susceptible to eutrophication.

Most of our coastal rivers and embayments receive elevated nutrients from population centres and land uses within their catchments. For example, treated sewage enters the Richmond River at 8 point sources and enters the Clarence River at 7 point sources. Water quality measurements in the Clarence River by the SPCC (see West 1993) reported 30-40 micrograms of phosphorus per litre – only slightly below the values considered to define eutrophic waters (40-60 micrograms per litre). The poorly flushed Tuggerah Lakes and Lake

Illawarra have a problem with nutrient inputs and there is a proposal to make a cut (similar to the Dawesville Channel) to flush nutrients.

Similar problems with sewage inputs and low flushing have also occurred at Mallacoota Inlet and the Gippsland Lakes – there are annual cyanobacterial blooms there, and fish kills have occurred due to low oxygen levels (see Longmore et al. 1990).

In SA, windblown nutrients from superphosphate use on the two peninsulas are thought to be a "sleeping giant" in terms of enhancing algal growth in epiphytic communities on Posidonia and Amphibolis. For example, early monitoring of seagrass and epiphyte biomass started in 1970's in SA and at the "control" sites in Port Victoria there are significantly more epiphytes now. On south-east Yorke Peninsula near Edithburgh there is a seasonal (summer/autumn) burst in algal growth in a narrow band - almost as if a nutrient slug has occurred- but there are no freshwater or sewage inputs. It may be that wind-driven, seasonal resuspension of sediment loads of phosphorus are responsible for this bloom. Cadmium is a tracer for superphosphate and may be used to explore the cause of unexplained epiphyte outbursts (p.c.#1500 J.Johnson).

Some systems are unique from a global perspective. The Great Barrier Reef lagoon is such a system and is thought by some to be increasingly affected by human encroachment. Catchment areas have been greatly modified by sugarcane farms, clearing for housing and tourism developments and prawn ponds, grazing, and urbanisation.

Approximately 77,000 tonnes of N and 11,000 tonnes of P per year are transported into the GBR lagoon (Alongi 1997). These amounts have been estimated to be nearly four times greater than pre-industrialisation. There is current debate that coastal reefs such as the Whitsunday Isles, Low Isles, Green Island and Magnetic Island are deteriorating in live coral cover, coincident with increases in macroalgal (Sargassum) standing crops and turnover.

Unfortunately, the data are conflicting – water-column and sediment nutrient concentrations do not suggest that eutrophication is occurring, and long-term data are lacking, as well as information on the capacity of coastal muds and muddy sand areas to assimilate and adsorb excessive nutrients, if any. Preliminary experiments on the responses of Sargassum to nutrient and sediment have produced counter-intuitive results - they have responded negatively to additions of these materials (see McCook and Price 1997). Biogeochemical studies to construct nutrient budgets may help to estimate the capacity of the lagoon and its reefs to *withstand nutrient inputs above natural levels. Such estimates would in any event be complicated by effects of cyclones and summer monsoons that would tend to mask any deleterious impacts by humans.*

3.2.2 Biomonitors and the symptoms of eutrophication - the need for innovation

Nielsen and Jernakoff (1996) and Ward (1989) have outlined the weaknesses of prevailing monitoring methods that focus on water column concentrations of nutrients. Some of the methods such as bay-wide measurements of nutrients and macroalgal biomass are so coarse that by the time a signal is perceived there will already be a serious threat from algal blooms and anoxia. They have proposed alternatives that may be more useful and quantify better the responses of primary producers to nutrients. Examples for macroalgae include the use of tissue nutrients and long-term changes in macroalgal depth distributions.

In this regard the laboratory of Dr W.Dennison at the University of Queensland has produced an innovative, comprehensive package of techniques for interrogation of biomonitors, to determine the source and proximity of nutrient and sediment stressors (see Dennison 1994, Abal and Dennison 1995,1996, Udy and Dennison 1995, Perry et al. in press).

These techniques deploy cultured phytoplankton and macroalgae bio-indicators, and examine isotopic ratios and depth range in seagrass tissues and beds, to trace the source, transport, fate and impacts of nutrients. This has provided a cohesive, powerful approach to enable inferences to be made over a range of spatial and temporal scales. The suite of techniques has been used in the sub-tropics and tropics, but will be applicable to temperate systems too, because nutrient inputs are not as pulsed and episodic as they are in tropics.

The measurement of phytoplankton productivity defines limiting nutrients. The method involves in situ inoculation of bags of local seawater with nutrients. The premise is that there is very little stimulation by the inoculation for phytoplankton in habitats where high levels of nutrient enhancement are not usually experienced – therefore a sharp response to an inoculation shows that the community has developed in past conditions of nutrient enhancement.

This approach satisfies the need for measurement of rates and dynamics of primary productivity - in stark contrast to the traditional measurement of static water quality parameters. In the laboratory, phytoplankton are pushed to their physiological limits to get *tolerance profiles for nutrients, then these dose/response curves are applied in a predictive manner to measurements obtained in a field situation.*

Static measurements tell very little about the nutrient regimes - a small value or concentration of a nutrient can reflect high turnover, rapid uptake and low residual levels. Over time phytoplankton assemblages shift to be dominated by those with increasing ability to take up nutrients as nutrient levels increase (p.c.#650 M.O'Donohue).

A macroalgal bio-indicator has tissue pigments that act as sentinels for nutrient levels when the alga is deployed in the field. Gracilaria is used and is euryhaline, but the marine Laurencia also has potential. The Gracilaria tissue-nitrogen tracks water column nitrogen - it is sensitive even to immeasurable levels of nitrogen. The procedure involves keeping laboratory cultures in low nitrogen regimes so they are "nitrogen-starved". The algae are then deployed in the field.

Pigments, tissue nitrogen and phosphorus and amino acids are measured after exposure and enable the type of nitrogen source to be identified. There is visible change in pigments from transparent to deep red-brown correlated with nutrients.

Seagrass depth range is correlated with a suite of water quality parameters. Laboratory and field experiments have calibrated the decrease in depth range with increasing "Kjeldahl Number", increasing nitrogen and increasing light attenuation. Local correlations can be applied elsewhere (work is underway at Albany), and a model linked with GIS can be constructed to predict where seagrass should be found on the basis of the calibrations.

Vegetation isotopic ratios can be studied to assess the physiological health of seagrasses, mangroves and other marine plants. Nutrients from sewage also have characteristic isotope signatures. The N_{15} *isotope is anthropogenic and can be used as a good bio-indicator. The* C_{12} : C_{13} *ratios can vary with plant stress. There is less discrimination between them when plant activity is very high, but when activity slows down, the plant takes up the lesser weight molecules selectively, and the ratio in tissue changes. The same process occurs with delta N* (N_{14}: N_{15})*. Delta N can change from 10 to 2 within a range of 30 km – this has serious implications for food web studies inferred from isotope work (also see Bunn et al. 1995). Delta N is very high in the Logan River, and West Moreton Bay and near Tallebudgera sewage outfall, but low at Currumbin where there is no effluent.*

Nitrogen is limiting in marine waters, and comes in the forms of ammonia, nitrate, urea, and amino acids. The ability of plants to take up nitrogen from sewage depends on the medium and mediators. For example, Trinity Inlet is eutrophic and poorly flushed, but it is turbid and therefore light limited. The major symptoms of the nutrient inputs are therefore confined to a downstream gradient in phytoplankton production and a heavy epiphytic load on mangrove pneumatophores (p.c. #650 W. Dennison).

In general terms there is a very important role for of applications of marine chemistry in studying the fate and effects of sewage and mariculture effluents and papers by Heggie et al. (1994), Leeming et al. (1994), Nichols et al. (1994) and O'Leary et al. (1994) give excellent examples.

It is also somewhat surprising that an early lead by Nichols et al. (1985, 1986) in identifying seagrass bases in food-chains using isotope signatures has been poorly followed up in this country (see Hemminga and Mateo 1996 for review). Notable recent exceptions include Loneragan et al. (in press) and Bunn et al. (1997).

3.3 Effects on ecosystems - de-nitrification cycles and phytoplankton blooms

The most comprehensive studies of nitrification (eg. Port Phillip Bay Study) show a natural "assimilative capacity" for nutrients in bays and estuaries - but also warn of high uncertainty of thresholds and major hazards if denitrification cycles in sediments are disrupted. These studies show the need for bay- and estuary-scale modelling of major ecological, chemical and hydrodynamic processes to understand nutrification - and a better recognition of the importance of sedimentary processes (eg. Lavery and McComb 1991).

Port Phillip Bay is arguably the best-studied coastal bay in Australia, with predictive models now available to estimate critical nutrient loading levels into the system (see Port Phillip Bay Environmental Study Final Report, Harris 1996).

Major sources of nutrients are sewage treatment plants, the Yarra and Maribyrnong Rivers, and smaller rivers, creeks and drains, groundwater, and the atmosphere. In 1994-95, 52% of the nitrogen (N) and 67% of the phosphorus (P) entering the bay came from the Western Treatment Plant, the major site for treatment of wastewater from Melbourne. The remaining P and N comes from the above-mentioned rivers. These inputs are balanced by major losses via denitrification (70-90%) and minor export of roughly 1000 tonnes N yr^{-1} to Bass Strait. Further inputs are predicted to result in net accumulation in bay sediments. In contrast, the P budget is balanced by precipitation and burial in sediment and some export to Bass Strait.

The study revealed that the main pathways of nutrient flux were through the sediments – an abundant and actively bioturbating benthic fauna is responsible for rapid recycling and return of nutrients and other solutes to the water-column where they can again be taken up by pelagic and benthic photoautotrophs.

Thus the concentrations and fluxes of major elements in Port Phillip Bay waters are controlled by biogeochemical processes in the sediments. One of the main conclusions of the study was that in order for water quality in the bay to be maintained, the benthic ecosystem must be protected from excessive disturbance such as dredging and deposition of solids. In future, N loads to the bay should not exceed present levels – a reduction of 6500 tonnes yr^{-1} would result in a dramatic improvement in water quality in the bay. However, introduced fanworm beds pose a major threat to the denitrification cycles in the sediments beneath them in the bay (see section 5.2.2).

3.3.1 Mangroves as nutrient scrubbers

Estimating the extent to which subtropical and tropical ecosystems, such as mangroves and seagrasses, would be more sensitive to excessive nutrient loading require more information on biological productivity, nutrient concentrations and fluxes in overlying waters and sediments than currently available.

A good example is the estimate by Robertson and Phillips (1995) of the amount of nutrients from aquaculture ponds that mangroves can utilise without detrimental effects. Using budgets of nitrogen and phosphorus output for prawn ponds combined with estimates of total net primary production in Rhizophora forests, they were able to estimate the ratio of mangrove forest to prawn pond area necessary to remove nutrients from the pond effluent.

Their calculations showed that for a 1 Ha pond, between 2 and 22 Ha of mangrove forest are needed to assimilate all of the effluent N and P – the wide range of forest area reflects dependence on pond management practices. More importantly, they stated that before mangroves can be used in such a manner, more information is urgently needed on nutrient transformation processes in mangrove sediments, and the extent to which tree growth is nutrient limited in undisturbed forests. Data from an AIMS monitoring study near Port Douglas indicate that pond effluents have a greater short-term impact on creek hydrochemistry and plankton processes than on within-forest processes. This may be due to the adsorption of nutrients to clay particles, assimilation by trees, denitrification, and drainage into the creeks via porewater seepage.

3.3.2 Key uncertainties

Similar estimates have not been made for Australian seagrasses or macroalgal beds due to lack of information on basic nutrient recycling processes, especially in sediments. However, studies from other regions have indicated possible impact of excessive nutrient inputs. Most plants respond positively to nutrient additions because most plants are nutrient-limited. However, species richness declines and biomass of the most tolerant or most rapidly growing species increases at the expense of the others. Small nutrient additions are beneficial, but larger additions promote epiphytic growth on seagrasses, shading light and causing seagrass demise. What amounts constitute "small" and "large" are difficult to estimate unless plant productivity, sediment adsorption capacity and other such factors are known. As pointed out by Robertson and Phillips (1995), key research questions need to be answered before predictive models can be constructed estimating the capacity of a system to tolerate nutrient loading:

- what nutrient loads can cause complete anaerobiosis of sediments and plant mortality?
- what is the long-term assimilative capacity of sediments for dissolved nutrients?
- how do different sediment types affect the retention and transformation of nutrients?
- what nutrient loadings have a detrimental impact on benthic fauna?
- what is the impact of loss of bioturbating benthic fauna, such as crabs?
- what combinations of nutrient loadings and hydrodynamic regimes cause anoxic/hypoxic conditions in estuarine and coastal waterways?

These questions reflect our current level of ignorance with respect to nutrient impacts and tolerances of ecosystems, and they are of profound importance to sustain aquaculture without causing seafloor souring and other environmental hazards in the ponds and under the racks and cages. The major threats of nutrient fluxes to molluscan mariculture have been reviewed by Hamdorf (1993).

For example, in Tasmania 11 areas are zoned for aquaculture and there about 150 aquaculture farms including 15 salmon cage operations. Farm developmental plans for each area are being developed now to cope with :

- effects of the farms on the environment - oyster farms take out nutrients, but salmon farms put nutrients into the system
- effects of catchment use on farms – relationships between catchment use and mariculture operate at small scales (even low numbers of dairy cows in a NZ catchment have been known to prevent oyster harvests because of E.coli contamination).

Seafloor souring under salmon cages is visible as a white bacterial mat that bubbles with methane and hydrogen sulphide. Preliminary studies have shown sediments to be organically enriched within <=5 m of cages, with some influence measurable at 5-10 m away and enrichment finishes at 10-40 m distance. However, use of isotopes to trace nutrients has shown influence of the cages up to 80 m away (p.c.#1280 J. Moverley).

The problems associated with sea-cage fish farming and seafloor souring have been reviewed by Trendall (1992) in response to demand for coastal sites for tropical barramundi farming. However, seafloor souring due to faeces and uneaten pilchards is also an issue for the southern bluefin tuna farmers in Boston Bay. The main R&D objective there is to determine what is the best way to assess the degree of souring, the recovery rates of the benthos and the *farm-management requirements to move cages. Development of artificial feeds with better assimilation ratios would also be desirable to reduce seafloor souring. This is yet another example of the possibilities for cross-linking between the various FRDC Programs to achieve desirable outcomes for the environment.*

3.3.3 Toxic and nuisance phytoplankton blooms

Hallegraeff (1992a, 1993,1995,1996) has reviewed the risks and hazards posed by blooms of phytoplankton and dinoflagellates in Australian coastal waters. He proposes that there has been an increasing awareness of the problems rather than an increase in occurrence of the blooms.

Important points to note are:

- *overall they are natural events (eg. the bloom in Jervis Bay was a coccolithophorid - Blackburn and Cresswell (1993); Trichodesmium fixes atmospheric N)*
- *captive fish are extremely sensitive to blooms because they cannot escape them - some blooms produce slime or chemicals that clog or destroy gills*
- *the issue of ballast water introductions is a serious one, but it is extremely difficult to prove a species is introduced – DNA fingerprinting will help*
- *there are over 2000 species of dinoflagellates in Australian waters, and about 40 of these could create nuisance blooms*
- *only Gymnodinium catenatum, and possibly a strain of Alexandria (catenella), are known to have been introduced*
- *Gymnodinium catenatum produces cysts, and cores showed that it came in to Australian in 1973, but the sources of other species have not been examined so closely yet*
- *it is not easy to measure the toxin producing paralytic shellfish poisoning (PSP) – artefacts of acidification in assays can cause over-estimation of toxin power; the threat in our waters is not as severe as that posed by PSP toxins in USA and Japan.*

There are three main types of nuisance and toxic algal blooms:

- *slimy algal blooms - eg Thalassiosira* see *Griffin et al. (1997)*
- *exuders of chemicals that destroy gills - eg the 1995 bloom in Coffin Bay that killed rays and bivalves*
- *creators of toxins responsible for shellfish poisoning - eg paralytic shellfish poisoning (PSP), amnesic shellfish poisoning (ASP), neurotoxic shellfish poisoning (NSP) and diarrhetic shellfish poisoning (DSP).*

Fish larvae of some species are very sensitive to blooms, and blooms have been identified as the cause of disappearance of whole year classes of fish overseas.
Overseas, picoplankton blooms can persist for 5 yrs and have killed off whole seagrass beds in Texas and Long Island Bay in the USA.

Blooms are unexpected in well-flushed areas, but enclosed bays and estuaries receiving nutrients and subject to calm, stratified conditions are the areas most likely to have blooms

Coastal algal blooms are driven by nitrate enhancement, but there is also much more to the process that makes blooms poorly predictable. For example:

- *terrigenous runoff is a major factor – in Port Phillip Bay and Tasmania blooms occur after major rainfall events, probably because of some micronutrient that is not related to nitrogen or phosphorus*
- *recent research has shown that iron and humic substances interact with nutrients, to sometimes make nitrate more, or sometimes less, available.*

Key uncertainties and threats of blooms concern the reasons why monocultures develop. For example, in a stable water column, the diatoms will sink while the dinoflagellates migrate vertically after taking up nutrients at depth. Sometimes species are avoided by grazers (especially cyanobacteria) and so there is also a release from predation. Other species grow very fast because they can take up and utilise nitrate better than other taxa.

In many situations of coastal eutrophication (not all) there is more algal biomass, but our present knowledge is inadequate to explain whether the resultant biomass will be toxic or a nuisance, or beneficial diatoms that support food chains. It is also apparent that blooms can remain relatively benign until certain thresholds in concentration are reached.

Turbidity is also a major factor in determining the frequency and composition of blooms. For example, there are very high tannin loads and resuspended sediments in the Derwent , so despite excessive nutrient loads - phytoplankton are light limited there. The Huon estuary is even more coloured by tannins from button-grass plains, and hence is a very good choice for the location of fish farms, as phytoplankton are light-limited there too.

Salt-wedging at the interface of freshwater and the sea makes turbidity rise in estuaries to suppress blooms, so freshwater diversion and river regulation can have profound effects on later frequency of algal blooms. Land-uses in catchments such as deforestation can also have indirect effects on algal community change by causing enhanced supply of iron and other micronutrients.

Dinoflagellate cysts are tolerant of anoxia, and they have a dormancy period. Burial in anoxic sediments keeps them "asleep". Cues for breaking of dormancy are oxygen supply which causes germination, but then temperature, light, and nutrients govern survival and bloom dynamics. Dredging (such as for scallops) awakens dormant cysts (p.c. #1300 G. Hallegraeff).

These are further examples of the interactions of habitat disturbances.

Australian research is attempting to put blooms into the context of different sources of nutrients and pin down the key causes of blooms. For example, in Port Phillip Bay nutrient levels are high, but other factors are involved in limiting blooms - monitoring has shown a series of events involving temperature, stratification of water column, rainfall and then a quiescent period, plus and unknown chemical trigger. These are now almost regular, annual blooms of Gymnodinium catenatum in Tasmania, and the shellfishery has to be closed.

Sanitation procedures are in place with a notification scheme under the "shellfish quality assurance programs" in Tasmania and Victoria (Arnott 1990a,b), but at the time of writing several respondents suggested involvement of the FRDC in extending these programs to a national standard in biotoxin surveillance programs (p.c.# 1020 G.Arnott, p.c. #1270 C. Crawford).

In Victoria, there is now a major concern for predicting and managing the effects of toxic dinoflagellates that involves monitoring both the water column and testing for biotoxin in products. In Port Phillip Bay the MAFRI monitors 15 stations on a fortnightly basis, as the phytoplankton community can change very quickly. The dinoflagellate Alexandrium catenella *is the greatest threat and it blooms about one week after heavy rain in the Yarra catchment. The spores may need both turbulence and freshwater from storms to hatch, and the development of blooms requires suitable temperatures, nutrients, and a calm stable water column. Blooms reach densities of up to 1-2 million cells per litre.*

In January 1992, PSP was up to 125 times the health limit in the northern end of the Bay, and eating 6 mussels could have proven fatal, but there has been insufficient appreciation or funding of the problem at top Ministerial levels. Planktivorous pilchards and anchovies also affected by PSP, and the toxin has been measured in both rock lobster and abalone, but pilot surveys of major seafood industries are needed as a baseline. There is a precedent for concern in that Japanese markets rejected Spanish abalone imports because of PSP.

Rhizoselenia chunii leaves an intensely bitter taste and there were 3 major blooms in August in 1987,1993,1994, in PPB. This makes mussels inedible, but the toxin is mainly in the gut, so shucked and gutted scallops are marketable. Domoic acid is a toxin produced by diatoms (Pseudonitzschia and Nitzschia), which causes amnesic shellfish poisoning overseas – there have been blooms of Pseudonitzschia in the Gippsland Lakes system. In Tamboon Inlet, a neurotoxic shellfish poison (NSP) came from Gymnodinium comparbrevi and this has now been found in Port Phillip Bay blooms. Alexandrium catenella has now spread to Sydney Harbour (p.c. #1020 G. Arnott).

The threat of ciguatera poisoning is a concern for recreational and commercial fishing interests along the Great Barrier Reef and especially Hervey Bay. Gambiertoxins from the epiphytic dinoflagellate Gambierdiscus toxicus (and other toxins) are transferred through the food chain to predators such as spanish mackerel and coral trout. There have been repeated claims that anthropogenic disturbances to corals aggravates the problem by creating ideal habitat for Gambierdiscus (Bagnis 1994), but such a hazard is not supported by Australian research (see Lewis and Holmes 1993 for review).

3.4 Contaminants and pathogens

The risks and hazards to fisheries of contaminants and pathogens appears to be localised to some coastal areas, particularly those with heavy industry, transport, and highest human population densities. From a fisheries perspective, the most commonly reported symptoms are "fish kills" from pesticides in coastal rivers (eg. Anon. 1993g), "kerosene tainting" or off-flavours in sea mullet, and closures to harvesting (see Leadbitter 1992). It was difficult to find the results of any results of systematic monitoring of coastal organisms and their environment in Australia, but the need for long-term programs has been indicated for some time (eg. Martin and Richardson 1991, 1995, Miskiewicz 1991). Instead, the literature comprises an abundant collection of "one-off" reports of contaminants in localised areas and development and testing of sentinels and protocols (see Table 3.1.2).

We also found evidence of high risks of disease in cultured organisms when water quality is lowered due to contamination, but the hazards have been poorly documented (eg. Roubal et al. 1989). The introduction of cholera in ballast water is a major risk for shellfish mariculture (see section 5.2.3).

3.4.1 Hydrocarbons

Surveys around the Australian coastline of concentrations of residual petroleum hydrocarbons (PAHs) in most seawater and sediment have found levels at or near background (< 1 μg litre^{-1} total hydrocarbons) (see Connell 1996). Localised areas of contamination include the Parramatta, Yarra, and Brisbane Rivers, and some parts of Port Phillip Bay and Western Port. The level of contamination in birds and marine organisms is more difficult to assess due to naturally produced hydrocarbons. Nevertheless, there appears to be some localised contamination (eg. some fish and birds in southern Queensland), but no large-scale pollution. Most PAHs are thought to enter coastal ecosystems via urban runoff, sewage and some leakage from container ships and petrochemical instillations (eg Edyvane 1991, 1995a, Liston and Maher 1986).

Mangroves are classified as being particularly susceptible to damage by oil pollution (Volkman et al. 1994b). Mangrove trees are killed by oil when floating oil deposits on their exposed roots and stems and contaminates sediments as tide levels drop. They die from either a toxic or suffocating effect, and from the result of oiling of burrowing animals. These animals, including crabs and worms, usually die within a day after oiling, whilst trees die after one or two months (Duke 1996).

Oil can persist in mangrove sediments for decades (Burns et al. 1991) and, in these circumstances, there is little degradation or change in composition of oil in the usually anaerobic sediments. Oil penetrates into mangrove sediments by diffusion from the surface, but the main mechanism for oil penetration is through crab holes and old root castes during low tides. Once the crabs die, the crab holes close over and the oil becomes trapped beneath the surface, affecting living roots and fauna in the vicinity.

Recovery of oiled areas largely depends on the degradation of oil, the re-establishment of the burrowing infauna, and the root development and growth of mangrove plants.
In Australia, mangroves have been killed and affected by large oil spills in at least seven sites around Australia (Grant et al. 1993, Volkman et al. 1994b). In Botany Bay, land and ship-based oil spills over the period 1979-1987 caused widespread mortality of seedlings and defoliation of lower foliage of Avicennia marina trees. Many contaminated areas have been recolonised by seedlings, but recurrent oil spills make it difficult to predict how long the mangrove habitat will take to fully recover. In the absence of more spills, it was estimated that the population structure would take several decades to recover.

The total amount of damage caused by oil spills is expected to remain small in view of the extent of mangroves in Australia. However, the impact at a local-scale is likely to major, effecting not only the mangrove habitat but also the neighbouring habitats which depend on mangroves.

3.4.2 Metal contamination

Like PAHs, heavy metals find their way into coastal waters and biota via urban and industrial effluents, explaining why localised contaminated areas are restricted mostly to coastal areas in proximity to the large cities and industrial installations. In most estuaries, while water concentrations of heavy metals are at or near background, much lower than concentrations in coastal areas of the Northern Hemisphere, metal levels in sediments are less than those in most other industrialised nations, but higher than in overlying waters and in dredge spoil.

Of much greater concern is the bioaccumulation of metals in coastal biota (eg. Ward 1989, Phillips et al. 1992). A variety of small-scale studies have indicated that tissue contamination can be attributed to point-sources in proximity to urban and industrial sites. For instance, in Port Phillip Bay, mercury levels in fish have been found to sometimes exceed international guidelines. Similarly, in the Georges River in NSW, copper in oysters exceeded guidelines and *was attributed to antifouling paints. Some evidence suggests high levels of mercury in sharks and cadmium in crustaceans, particularly prawns. Metal levels, haemosiderosis and other disease in fish has been studied in areas of Port Phillip Bay polluted by metals (eg. see Fabris et al. 1992, Langdon 1986, Nicholson et al. 1994, Phillips et al. 1992). A limited review of the national outlook is given by Batley (1996).*

Cadmium is perhaps of most concern to the national fishing industry, mainly in crustaceans, and the export trade could be most at risk due to levels exceeding food standards. Crustaceans (prawns, crabs, bugs) that feed on bivalve molluscs naturally accumulate levels of cadmium that are relatively high (or exceed) in comparison to the original Maximum Permitted Concentration (MPC) set by National Health and Medical Research Committee (NHMRC) in the 1960's. Indeed, some individuals and species far exceed the MPC in areas remote from any industrial sources of metal pollution.

In view of the high levels of cadmium naturally accumulated by crustaceans (particularly in the hepatopancreas, or "brown meat"), and other factors, the Australian Seafood Industry Council (ASIC) applied in 1995 to the National Food Authority to have the MPC for cadmium raised to 2 milligrams per kilogram (equivalent to molluscs), with an exemption for products comprising crustacean hepatopancreas material.

The best documented episode of mercury pollution in Australia occurred with widespread pollution in Princess Royal Harbour (see Hancock 1990, Francesconi et al. in press for review). The area was closed to all fishing, and even pelagic planktivores that are known to be migratory (herring Arripis georgianus) had unacceptably high levels of methyl mercury in their tissues. The source of pollution was removed and, after more than a decade, fish tissue levels have fallen to limits safe for fishing. Selenium often naturally occurs in fish flesh at levels around the MPC, but in Lake Macquarie the higher liver values were quoted in the media as high flesh values, in part of a political argument where anglers wanted commercial netters removed from the lake (p.c. #680 I. Hamdorf).

The best documented contaminant budgets exist for Port Phillip Bay as part of the Port Phillip Bay Environmental Study. Overall, all metals are well below water quality criteria when averaged over the whole Bay waters, but there is a problem with scales in measurement, and some ranges at localised sites do exceed the criteria. For example, in flathead, mercury and arsenic are highest at stations near Werribee outfall (0.3 ppm vs MPC of 0.5 ppm). In sediments, Corio Bay generally has high cadmium, lead and zinc close to existing or old *industrial point sources, but not as severe as both Lake Macquarie and Sydney Harbour where extremely high zinc (1000's ppm) prevent life of any infauna in some sediments (p.c. # 990 G. Batley).*

"Heavy metal hotspots" exist in Spencer Gulf near a lead smelter in Port Pirie where seagrasses are contaminated by zinc, cadmium and lead (see Ward 1984, 1989, Ward et al. 1986). In a review of the occurrence of metal accumulation and its impacts on seagrass and associated fauna, Ward (1989) developed clear recommendations for biomonitoring of metals in seagrass habitats and the use of sentinel accumulators and indicator species. We did not ascertain whether or not these monitoring studies have been pursued, but there have been recent closures to mollusc (Pinna bicolor) harvesting in parts of Spencer Gulf. Ward (1989) outlined the complexities in determining the impacts of the three metals, and concluded that seagrass species are moderately resistant to the direct effects of metals, but that the fauna inhabiting the seagrass meadows are much more likely to be sensitive and they are at risk.

3.4.3 Organochlorines and organometals

Prior to a ban imposed in 1988, tributyl tin from antifouling paints was a contaminant problem, usually in southern waters – levels in waters, sediment and biota are now within the guideline concentration of 2 nanograms litre^{-1} (Batley 1996)– but there is still evidence of widespread gastropod imposex (eg. see Nias et al. 1993) so the hazard has not been removed. There may be a threat to western rock lobster pueruli in the Fremantle area, as gastropod imposex is known to extend for a radius of about 30km in either direction of port facilities there (p.c.#1400 C. Simpson).

Organochlorines may be the most dangerous chemical compounds introduced into the marine environment. Although concentrations in Australian waters and in coastal sediments are low, these compounds are preferentially solubilised in tissue fats, and can accumulate in very high concentrations above environmental concentrations.

Localised studies indicate that pesticides are present in tissues of many estuarine and marine organisms, especially in hot spots in proximity to urban areas and agricultural land. Much research has focussed around the Sydney sewage outfalls (see below, and Otway 1992, Miskiewicz and Gibbs 1992,1994). It was found that fish such as the red morwong (Cheilodactylus fuscus) contain lindane and heptochlor in concentrations exceeding permissible levels by 50-120 times. This situation has improved since fishing was banned within 500 m of the outfalls, and continues to be closely monitored. Today, use of organochlorines such as

DDT, aldrin, chlordane, heptachlor and dieldrin is not permitted, and use of other compounds, such as lindane are restricted. Nevertheless, no national surveys or monitoring programs are being conducted to determine the extent of the problem in fisheries products (but see Hamdorf 1992).

Best studied from a fisheries viewpoint is the assessment and identification of impacts of endosulfan pesticides leaching into upper catchments from cotton growing areas, for which the LWRRDC has a national R&D program (see Arthington 1995, Korth 1995, Novak and Ahmad 1989, Novak 1992 and section 2.1.3).

3.4.4 Sewage plumes

Until 1991 sewage was discharged into the coastal waters off Sydney through seven cliff-face outfalls. The effluent consisted of a cocktail of domestic and industrial wastes, and – although freshwater was the major constituent of the discharge – it contained contaminants in solution and suspension, as well as varying concentrations of pathogens, bacteria and toxic substances. These included metals such as cadmium, chromium, zinc, mercury and lead.

Gray et al. (1992) sampled larvae in and below plumes and compared these with sites >8km away. They could not detect any significant differences in densities of fishes in plume and non-plume waters, but did suggest that differences may exist between water masses of the plume, plume front and adjacent ocean. The scale of sampling has been shown to be very important in detecting differences amongst plumes and other water bodies.

Gray (1996) sampled in the effluent plume, along the frontal edge of the plume and just outside (approximately 500m) the plume in clear shelf water. He found that sewage plumes form a turbid, 1-5 m deep lens of lowered salinity overlying clear, shelf waters. Many fish were concentrated in plume fronts and advection or active attraction influences distribution of pre-settlement fish at scales <1km - this may prolong exposure of these stages to pollutants.

In fact, Kingsford and Gray (in press) and Kingsford et al. (1994) looked for effects of the plume on condition of larvae and rates of abnormality in the larvae. They concluded that bending of the notochord was caused by the plume - but this has been disputed by others who consider it may be more an artefact of capture (damage by fibres and other debris).

In any case, Otway (p.c.# 450) has pointed out that this observation may tell little about the source of stressor. Identifying impacts is a much different process than assessing impacts (see also Smith

1994, Keough and Quinn 1991). For example, effluent is a complex mixture – the cause of some observed effects could be just the freshwater in the plume. Experiments must proceed after such observation of effects to isolate causes, and the experimental treatment should be delivered in the same form as the field effluent.

A problem with such impact assessment also concerns the lack of direction of precision and power by users of the information. Managers should communicate the level of change that is "unacceptable" (eg. <= 50%) – politically or ecologically – then experiments and monitoring can be designed accordingly. Power and precision analyses can then be done to address the level of change that needs to be detected.

There is also concern that there has been a relatively intense focus on the effects the five ocean outfalls off Sydney yet there is little consideration of the vast "background" plume of contaminated sediments coming out of Sydney Harbour - the legacy of 150 yrs of industry. Storms rework sediments on the Sydney shelf down to 80 metres depth and at these times the Sydney Harbour source swamps the relatively meagre budgets of contaminants from the outfalls

Slicks on the sea surface are caused by the aggregation of large organic molecules and there is the potential for contaminants of a variety of types to be concentrated in these structures, especially in the sea surface microlayer (see Volkman et al. 1994a for review). There is also a similar boundary layer at the sediment-water interface. The elevated levels of contaminants in these layers casts some doubt on the adherence to water quality standards that measure only water column concentrations. Many species have egg and larval stages that are neustonic in the sea surface microlayer, or epibenthic. The threats of contamination are poorly known for these stages, but a new project (FRDC#97/217) will be assessing the utility of some innovative techniques to identify the risks for eggs and larvae (see Klumpp and von Westernhagen 1995, von Westernhagen and Klumpp 1995).

There could be more widespread use of measurement of multi-function oxidases (MFOs) (see Holdway et al. 1995 for review) to assess the risks and hazards associated with contaminants that will help overcome the poor power of traditional surveys of abundance in assessing impact of oil-spills and other contamination (eg. Connolly and Jones in press).

Perhaps of more immediate concern to managers of mariculture and fisheries are the introduction of pathogens associated with sewage pollution, and the proliferation of litter such *as plastics, glass and other garbage in our waters. Seabirds, turtles, cetaceans and fish may ingest this material or may become entrapped in nets, six-pack yokes and other synthetic debris leading to suffocation and a variety of injuries (see section 4.7).*

Moreover, the occurrence of bacterial and viral pathogens, parasitic protozoa and worms, and toxic algae is increasing in our waters (Ashbolt 1996) – these pathogens pose a health risk not only to humans, but to marine organisms as well (see section 5.2.3). Unfortunately, the magnitude of the problem is unclear due to the lack of studies and monitoring programs around Australia. The Standing Committee on Agriculture and Resource Management (SCARM) held a series of "Aquatic Pests and Diseases" Workshops in September 1996 and the proceedings covered these threats.

ISSUE 4:
Effects of Harvesting on Biodiversity and Ecosystems

4.1 Overview and FRDC role

4.1.1 The issues

There is a widespread, growing concern about the effects of commercial and recreational fishing on ecosystems amongst the public and within the industries. A recent public survey of scope for a national oceans policy ("Waves" 1997) revealed that over 70% of respondents viewed the effects of commercial fisheries as their most important concern – the second highest score after water quality - yet recreational fishing was a priority for only about 8%. Fisheries are also rapidly expanding into the deeper parts of the EEZ, usually ahead of any understanding of the habitat involved or its importance, and fishers are almost the only users of the resources there.

It is difficult to over-estimate the publicity generated by such fisheries as the orange roughy, gemfish, southern bluefin tuna and northern prawn. Bad public perceptions of imminent fisheries collapse, conflicts in resource sharing and environmental damage have become a major threat to fisheries. In the past few years the Biodiversity Unit of Environment Australia (formerly the Australian Nature Conservation Agency ANCA) has received nominations of oceanic longlining, prawn trawling and gillnetting for consideration as key threatening processes in management of endangered wildlife under the Endangered Species Protection Act 1992. Also, the failure of traditional yield-based management elsewhere has caused a push for adoption of the "precautionary approach" in fisheries management (Hilborn, 1996). This has been interpreted by some (eg. Dayton et al. 1995) to imply that the "burden of proof" (of low risk impacts) lies with the exploiter.

If nominations of prawn trawling and gillnetting succeed and a formal listing occurs, then these sectors of the industry are required to develop Threat Abatement Plans (TAPs) to mitigate threats to the survival of endangered species within three years of the listing date. Such nominations may spread to other fisheries as the conservation status of other marine animals *deteriorates. For example, nominations for grey nurse, great white and school sharks as "vulnerable species" under the Endangered Species Protection Act 1992 are being considered.*

Here we summarise the knowledge of effects of harvesting on Australian ecosystems -- but with only brief focus on the effects on target stocks. As a guide we have addressed all the issues identified in the global review of environmental effects of fishing by Dayton et al. (1995). We chose this particular review as a good starting point because it covers such a great variety of known and suspected impacts of harvesting. In contrast, the special volume (number 41, 1990) of the Australian Journal of Marine and Freshwater Research titled "Effects of Fishing" is somewhat of a misnomer, with a very narrow focus on issues associated with prawn trawling, particularly bycatch.

Some major Australian issues are outlined in Figure 4 (in Volume 1 of this review) and we have summarised R&D gaps and opportunities in Table 4.1.2.

The major concerns in Australia for effects of harvesting are :

- *bycatch and wastage of fishes, elasmobranchs and crustaceans and incidental take of threatened, endangered or "charismatic" wildlife*
- *habitat damage by demersal trawls and scallop dredges*
- *indirect effects of reductions in target species and scavenging of discards*
- *generation of plastic debris and their environmental consequences*
- *changes in target species demography under fishing pressure (covered very briefly here).*

These issues form an integral part of the FRDC core business and we conclude our coverage of them with sections reviewing current studies and knowledge on reducing and assessing the effects of harvesting. An informative overview of the policy and legislative framework behind some of these issues is given by Caton et al. (1997).

4.1.2 The literature

Australian literature on the effects of harvesting can be broadly broken down in Table 4.1.1 into three categories:

- *bycatch documentation- by fishery type, depth, region and season; an entire issue of the Australian Journal of Marine and Freshwater Research (1990 Vol. 41 (1)) was concerned mainly with this issue: the first focus on effects of a particular fishery is documentation of bycatch composition and catch per unit of fishing effort. Informative reviews of the bycatch in prawn trawl fisheries have been published by Andrew and Pepperell (1992) and Kennelly et al. (1992b).*

- *development and testing of bycatch reduction devices and practices to avoid habitat damage and make fishing gear more selective – "monster" excluder-bars, square-mesh panels; semi-pelagic trawls; mesh-selectivity studies - cooperation of science and industry in R&D with high returns for investment. Informative reviews on R&D approaches and outcomes in reducing bycatch in the trawl industry have been presented by Brewer et al. (1997) and Kennelly (1997), and a full description of the various devices used in the prawn trawl fisheries has been published by Eayrs et al. (1997).*
- *studies that measure or infer effects of harvesting disturbances on benthic and fish communities, scavenger populations and populations of specific, non-target species – includes studies of the mortality of megabenthos in trawl paths; fate of discards and scavenging routes; species shifts on fishing grounds; capture of juvenile stages of targets of other fisheries; changes in seabird populations. Reviews are not uncommon, as some major studies are still underway (eg. Blaber et al. 1994a, 1995a, and see FRDC#96/257) and the results of others are still being refined (eg. Moran et al. 1995). The broad results of the work done on the effects of fish trawling on the North West Shelf fisheries-megabenthos relationships has been reviewed by Sainsbury et al. (1997).*

A somewhat neglected field of research in Australia has been sources of "unaccounted for " mortality of fish that have come into contact with fishing gear and escaped or otherwise been affected by fishing. A global review of these different sources of mortality has been presented by Chopin et al. (1997), with a focus mainly on trawling. In Australia, we found relatively few studies of short-term survival of turtles, fish and other organisms caught on hooks or in trawls, and only a single study of the possibilities of "ghost-fishing" (by snapper traps; Moran and Jenke 1989).

There is a growing body of literature that recognises the importance of assessing survival of animals that are caught and discarded (eg. turtles, Poiner et al. 1990, Ward 1996) or escape through bycatch reduction devices (see Brewer et al. 1997, Broadhurst et al. In Press a, Broadhurst et al. subm. c).

The survival of hooked fish released in recreational fisheries (eg. because they are undersize, unwanted species, or have been tagged) has been very poorly studied in Australia, despite a long history of overseas concern to improve such survival (see Muoneke and Childress 1994 for review). The survival of fish caught on hooks in shallow water has been the subject of some recent study (coral reef fish, Diggles and Ernst 1997; yellowfin bream, Broadhurst et al. (subm. c); mulloway, Broadhurst and Barker (subm. e), and the results of telemetry of hooked and *released billfish in north Queensland should be available soon (see FRDC#97/113).*

A brief summary of the effects of harvesting is given for each Commonwealth fishery (where data exists) by Caton et al. (1997) and we have covered the same issues here in greater or lesser detail. However, their interpretation may be somewhat inconsistent as they acknowledge the possible impact of baitfish removals in pole-and-line tuna fisheries, but conclude that "the environmental effects of purse-seine fishing for jack mackerel are relatively small. Bycatch consists mainly of low catch rates (less than 5% by weight) of other commercial fish species". Jack mackerel are an important forage species for seals and other large predators in the fishing area.

The lack of literature on wider trophic effects of species removals may, therefore, reflect a lack of recognition of this effect of fishing. Bycatch issues and disturbance to benthic communities are of higher immediate priority and dominate the literature.

Table 4.1.1. Summary of Australian studies relevant to "Effects of Harvesting on Ecosystems and Biodiversity"

Fishery/Issue	*Bycatch documentation*	*Bycatch reduction devices/practices*	*Substratum/benthos/ecosystem disturbance*
Northern Prawn	*Anon. (1993d), Eager and Campbell (1996), Harris and Poiner (1990), Hill and Wassenberg (1990), Limpus (1997), Marsh et al. (1997), Michaelis (1996), Pender et al. (1993a), Pender and Willing (1993a,b), Poiner et al. (1990), Ramm et al. (1990), Stevens (1993), Wassenberg et al. (1994), Ward (1996a)*	*Brewer (1994), Eayrs and Rawlinson (1995), Mounsey et al. (1995),*	*Harris and Poiner (1991), Hutchings (1990), Long et al. (1995), Poiner and Harris (1986, 1988)*
West Coast/SA Prawn	*Carrick (1997a), Laurenson et al. (1993)*	*Carrick (1997a), Broadhurst et al. (subm. f)*	*Carrick (1997a)*
East Coast Prawn	*Andrew and Pepperell (1992), Broadhurst et al. (1996a,b), Jones and Derbyshire (1988), Kennelly et al. (1992b, In Press b), Liggins et al. (1996),Robins (1995), Watson et al. (1990), Wassenberg and Hill (1989,1990)*	*Andrew et al. (1991), Andrew et al. (1993), Broadhurst (1995), Broadhurst and Kennelly (1996a, 1997), Broadhurst et al. (1996b, subm. b), Robins-Troeger (1994), Robins-Troeger et al. (1995),*	*Blaber et al. (1994a,1995a), Wassenberg and Hill (1987a,1990), Broadhurst (subm.d), Blaber et al. (1989), Pitcher (1997)*
Estuarine Prawn	*Andrew et al. (1995), Gray et al. (1990), Kennelly et al. (1992a), Liggins and Kennelly (1996)*	*Broadhurst and Kennelly (1994), Broadhurst and Kennelly (1995b, 1996b), Broadhurst et al. (1996a, 1997a, In Press c)*	*Gibbs et al. (1980)*
Northern Fish	*Moran et al. (1995), Ward (1996b)*	*Brewer et al. (In Press), Mounsey and Ramm (1991), Ramm et al. (1993),*	*Moran et al. (1995), Sainsbury (1982, 1987), Sainsbury et al. (1993, 1997), Thresher et al. (1986)*
SE Fish Trawl	*Tilzey et al. (1990), Tilzey (1994)*	*Broadhurst and Kennelly (1995a),*	
Longline	*Ross (1996), Stevens (1992)*	*Anon. (1991b), Chapman (1995), Dalziell and Poorter (1993)*	
Scallop		*Cover and Sterling (1994) , McLoughlin et al. (undated FRDC #91/49),*	*Black and Parry (1994), Currie and Parry (1994, 1995), Dredge (1989), Parry and Currie (1992),*

Fishery/Issue	*Bycatch documentation*	*Bycatch reduction devices/practices*	*Substratum/benthos/ecosystem disturbance*
Gillnet	*Beumer et al. (1981), Grant (1993), Harwood and Hembree (1987), Marsh et al. (1995,1996), Marsh and Corkeron (1997), Paterson (1990), Russell (1988), Schaap and Green (1988), Williams and Schaap (1992),*	*Hembree and Harwood (1987)*	
Handline		*Otway and Craig (1993)*	*Ayling et al. (1992)*
Abalone/Rock Lobster			*Andrew (1993a), Andrew and McDiarmid (1991)*
Shoreline Harvesting/Angling	*Kingsford et al. (1991a)*	*Winwood (1994)*	*Catterall and Poiner (1987), Forbes (1984), Keough et al. (1993), Luck (1990), Povey and Keough (1991), Quinn et al. (1996), Underwood (1993), Underwood and Kennelly (1990)*

4.1.3 FRDC action

The FRDC plays the lead role in investing in R&D on the effects of harvesting on the environment and ways to reduce them. The outcome should be achieving sustainable fisheries, but there are not yet clear guidelines, goals and performance indicators for such an outcome in Australia - even for "biological reference points" in the fished stocks themselves (see Staples 1997).

The fundamental priority for the FRDC should be to help develop frameworks for defining and evaluating progress towards achieving this outcome. Staples (1997) recommends four key points:

- *specifying what is to be achieved in terms of the resource, the environment, the economic and social benefits*
- *defining what is meant by "success" in meeting these objectives*
- *developing performance indicators against these objectives*
- *implementing a management system that has actions "triggered" by pre-defined changes in these indicators.*

Priority R&D gaps and issues for the FRDC Ecosystem Protection Program will automatically arise from consideration of these needs by Management Advisory Committees, Fisheries Research Advisory Bodies and other organisations. The status reports for Commonwealth fisheries (see Caton et al. 1997) provide a good example of how environmental issues (and thus R&D needs) can be incorporated in State fishery reports - we found a general lack of reporting of the existing or potential effects of Australia's many fisheries. There is a particular need for the FRDC to show initiative and responsibility in the prevailing climate of rapid expansion of fisheries into deeper waters of the EEZ, usually ahead of any understanding of the habitat involved or its importance, and fishers there are almost the only users of the resource.

In the meantime, there does exist a clear desire amongst both the public and industry to reduce the unpopular effects of fishing as an outcome in itself. This has been acknowledged in the July 1997 release of the draft Commonwealth Bycatch Policy, convened by the Australian Fisheries Management Authority. The primary goal is to develop "Bycatch Action Plans".

In addressing this outcome our review has listed and described briefly the known and potential effects of harvesting from the Australian literature, and we suggest a general range of R&D opportunities based on assessing and reducing these effects that may complement the existing

FRDC "Effects of Trawling" sub-program.

We conclude that there have been very high returns on the investments being made by the FRDC in cooperative design and testing of more selective fishing gears, and that this should be expanded to a wider suite of fisheries. Kennelly (1997) has identified and demonstrated a very successful approach involving observer programs to first identify the bycatch issues and opportunities and then use close R&D partnerships with the commercial fleets to build, test and publicise the performance of bycatch reduction devices.

Less publicised is the need for development of R&D approaches to assess the short and long-term survival of bycatch or target species that escape, are discarded or pass through bycatch reduction devices.

There still remain large gaps in knowledge about just what the bycatch issues are in many sectors of the Australian fisheries. These gaps range from lack of knowledge of bycatch composition in specific fisheries (especially recreational fisheries) to need for spatial and temporal refinement of data on bycatch occurrence. Underlying the bycatch issue is a need for a "short-list" of species that should be avoided - a need for R&D on the "sustainability of bycatch" that is being piloted by FRDC #96/257 for the northern prawn fishery.

Studies of megabenthos destruction indicate that the North West Shelf may be an extreme example and that this threat needs to be assessed separately by close study of trawl paths in other fisheries, such as the SE Trawl fishery and the Arafura and Timor Seas. The key to understanding the effects of habitat damage in these fisheries is knowledge of the precise locations of trawling intensity, and of megabenthos growth, mortality and recruitment rates. Study of some of these factors is underway now in FRDC#97/205 and FRDC #96/257.

Ultimately this research will lead to consideration of untrawled megabenthos corridors that could serve both as harvest refugia and sources of replenishment as well as conserving benthic biodiversity. The evolution of differential GPS and vessel tracking technology (eg. Vessel Monitoring Systems VMS) offers great potential for collecting precise information on the spatial nature of fishing, its bycatch and its potential for destruction of megabenthos.

There is a need for the FRDC to become more proactive in recognising the threats and opportunities posed by the current focus on implementation of a National System of Marine Protected Areas (NRSMPA) by the year 2000. The Interim Marine and Coastal Regionalisation *of Australia (IMCRA) and other initiatives under "Ocean Rescue 2000" - a Dept of Environment, Sport and Territories responsibility – form the basis for the planning of Marine Protected Areas (see Chapter 2).*

If the appropriate knowledge of fisheries habitats is available (eg. inventories of fisheries habitat values, landings and effects of harvesting) and is part of the planning process, the NRSMPA could potentially provide a strong basis for a Fisheries Habitat Protection strategy. If the data are not included and the research not available, it will be difficult to optimise the fisheries value of marine park areas in cases where there is conflict with the goals of conservation of biological diversity.

Trawling is already covered under multiple-use provisions for management of the Great Barrier Reef Marine Park so the impact of NRSMPA may not be so severe in the north-east of Australia. In contrast, the biodiversity of the south has been vastly under-represented in the current Australian provision of Marine Protected Areas (Edyvane 1997) and such closures may not be part of normal fishing culture there.

Consequently, the greatest cause for concern may lie in the rock lobster, abalone and southern shark fisheries of the temperate reefs and the rocky-shore recreational fisheries. These fisheries lie in centres of biodiversity and "nests of endemicity" and their ecological effects have been hinted at (eg. Stoddart and Simpson 1996, Edyvane 1996a) - but not fully studied. Determination of the effects of rock lobster pot fishing on kelp, and abalone diving on species interactions, are amenable to powerful observation and experimental approaches.

"Baitfishes" such as jack mackerel, pilchards and anchovies are known to support populations of cetaceans, seals, sea lions, seabirds and predatory sportfish and gamefish. They are also widely fished for growing markets for human consumption, mariculture feed and angling bait. There is however no knowledge of the levels of competition for baitfish between these predators and the expanding commercial fisheries. The overseas literature shows that extensive dietary analyses and construction of food webs are needed to predict the paths of such impacts (eg. Bax 1991). Further complexities are introduced by fishing of the predators themselves – for example the populations of southern bluefin tuna reduced by fishing in the Great Australian Bight presumably ate much larger quantities of pilchards before both the tuna and pilchard fisheries began there.

There is a need to develop R&D techniques for studying such interactions. The larger *predators (eg. dusky sharks in WA, seals) are also the major victims of entrapment in bait-box bands and other fishing debris. Development of "environmentally friendly" bait packaging (eg. biodegradable pilchard bags) could be a valuable expansion of the FRDC's investments.*

Finally, the deployment of artificial reefs (Branden et al. 1994) poses many R&D questions. They may be Australia's earliest response to concerns about habitat destruction, but they could equally be viewed as mainly another fishing practice to aggregate fish and fishing effort (see McGlennon and Branden 1994). Their role as "sources" or "sinks" of fisheries production remains unknown and poorly studied (see Pickering and Whitmarsh 1997 for international review), but perceived benefits and demand for them is high (eg. Gorman 1995a,b). With a current focus on habitat restoration there may be a role for artificial reefs in areas where seagrass has been removed (eg. Cockburn Sound shell-sand mining), but basic questions about materials and design are not sufficiently known (Branden and Reimers 1994). Rubber tyres may exude sulphur-based compounds that actually discourage overgrowth by epifauna. Artificial reefs may, theoretically, comprise a habitat disturbance and pose a risk as a haven for introduced marine pests (see Chapter 5).

Table 4.1.2. Summary of Major Opportunities for FRDC investment in addressing R&D Gaps in knowledge of "Effects of Harvesting on Ecosystems and Biodiversity"

R&D Gaps	*Main Habitats*	*Main Fisheries*	*Key Reference*	*Initiatives*
understanding of the habitat and implications for ecosystem disturbances in the rapid expansion of new fisheries into deeper waters of the EEZ, and of existing fisheries on shelves where fishing is the major human impact	*EEZ deeper than 20 m (national)*	*new seamount fisheries, demersal trawl, pelagic longline*	*Koslow (1997)*	*CSIRO FRDC#94/040, CTC/IMCRA*
Lack of sufficiently comprehensive documentation of spatial fishing intensity, bycatch, and resilience of bycatch populations - what are the issues and which bycatch should be avoided?	*Shelf, Gulfs, Bays (national)*	*Prawn Trawl, Finfish Trawl, Tropical Gillnet*	*Andrew and Pepperell (1992), Kennelly (1997), Pitcher et al. (1997), Robins (1995), Poiner and Harris (1996)*	*AFMA C'wlth Bycatch Taskforce*
Untrawled Megabenthos corridors on trawl grounds - opportunities for fishery enhancement and biodiversity conservation - what are megabenthos recovery rates?	*GBRMP, Moreton Bay*	*Prawn Trawl*		*FRDC "Effects of Trawling" sub-program, and FRDC#97/205*
Need for further development and extension of "environmentally-friendly" fishing gear, techniques and codes of practice	*Shelf, Gulfs and Bays (national) and estuaries (NSW)*	*Prawn Trawl, Finfish Trawl, sthn shark Gillnet; Tropical Gillnet*	*Brewer et al. (1997), Eayrs et al. (1997)*	*AFMA C'wlth Bycatch Taskforce*
Effects of fishing on stocks, biodiversity, food chains and the substratum -- Insufficient knowledge-base to integrate fishing with plans for a National System of Marine Protected Areas?	*Major gaps for rocky and coral reef fisheries (also shelves, see above)*	*Rock Lobster, Abalone, Recreational Line (esp. NSW) and Net (Tas.), GBR Line*		*CRC Reef "Effects of Line Fishing" experiment, CTC/IMCRA*
Effects of Baitfish Removals on predators - how can it be assessed?	*Shelf and Bays (WA, SA, Tas, Vic, Qld)*	*Pilchard, Jack Mackerel, Anchovy*	*Glaister and Diplock (1993)*	
"Environmentally Friendly" Bait packaging - bait-box bands, plastic bait bags	*Sub-tropical/Temperate inshore (WA, SA, Tas)*	*Rock Lobster, Recreational surf and rock-fishing*	*Wace et al. (1996)*	
Artificial reefs – sources or sinks of fisheries production?	*Temperate inshore*	*Recreational Line*	*Pickering and Whitmarsh (1997)*	

4.2 Bycatch and incidental take

The ESD Working Group on Fisheries (1991) defined bycatch as "The part of the catch which has no commercial value and is returned to the sea, usually dead or dying". The draft Commonwealth Policy on Fisheries Bycatch further defines by-product as the commercially valuable portion of the catch that was not the target, and bycatch as that portion of the catch that is discarded.

A review of the SOMER reports (Jones and Kaly 1996) and the bycatch literature in Table 4.1.1 (eg. Andrew and Pepperell 1992, Dayton et al. 1995, Limpus 1997, Hulsman et al. 1997a,b) shows that perhaps the most sensitive bycatch or target species are those with all, or combinations, of the following life-history traits:

- *natural rarity - less than 10 breeding pairs of wandering albatrosses (Macquarie Island sub-species) are now present in Australian territories;*
- *restricted ranges - flatback turtles are endemic to NE Australia*
- *low populations, but with aggregative behaviour - small cetacean species*
- *low reproductive rates and live-bearing- - many sharks, sawfishes (Pristis spp) and rays; seasnakes; dugongs; (eg. loggerhead turtles average only 5 breeding seasons in a lifetime with 128 eggs per clutch, and 4 clutches, per breeding season)*
- *old age at first maturity and slow growth rates*
- *longevity – adult turtles most vulnerable to fishing are several hundred times more valuable than juveniles in terms of population replacement potential; albatross pair to mate for life; North West Shelf sponges may be centuries old*
- *association and aggregation with target species – juvenile mulloway (and perhaps loggerhead turtles) associate with prawns to prey on them; seabirds and dolphins associate with yellowfin tuna schools*
- *prolonged recruitment failure - ENSO events depress green turtle nesting and can cause starvation of penguin chicks; species at the edges of their range may have episodic recruitment*
- *large size, wide body shapes and/or slow movements - turtles and seals are entrapped or entangled in gears, ropes and litter; sawfishes and rays are herded by trawls*
- *poor survival when released - ram-jet ventilators (eg. queenfish, great white sharks) die very quickly in gillnets; air-breathers drown; soft-bodied species are crushed or embolised; species with swimbladders are embolised*

These species may need decades (whales) to centuries (sponges) to recover from serious depletions of their populations. They include "charismatic megafauna", such as sea mammals, *turtles, albatrosses and large sharks and rays. Less popular, but vulnerable nonetheless, are many benthic or deep-sea species of invertebrate and fish that share the characteristics of much delayed reproduction and low fecundity. Adult survivorship is extremely important to sustain populations of these two groups of organisms. Jones and Kaly (1996) have outlined some of these population concepts in the context of conservation. These patterns emphasise the importance of obtaining demographic data for bycatch as well as target species.*

Apart from direct effects of depletion on the bycatch species, some popular ecological theories predict cascading effects on ecosystems of removals of "keystone" species. For example, Dayton et al. (1995) correlated a longline catch over 1 million large sharks with a rise in grey seal population from 3000 to 45 000, a rise in the infestation of cod with seal-worm parasites, and later stress and mortality in the high density seal population. Clear evidence of such indirect effects, not confounded by other factors, is lacking throughout the world - but "species-shifts" have been documented in Australia and elsewhere (see Section 4.5 below).

There have been a variety of responses to the bycatch issue in Australia, but the most thorough is perhaps demonstrated for the South East fishery (the Integrated Scientific Monitoring Program ISMP), the NSW prawn fisheries and the fisheries managed by the Commonwealth. These have involved:

- *observer programs and monitoring of fleet dynamics, catch, bycatch and discards*
- *R&D response to nominations for particular fisheries as "key threatening processes" under the Endangered Species Protection Act 1992*
- *R&D response in developing "Threat Abatement Plans" (TAPs) in the case of successful nominations*
- *R&D in development of bycatch reduction devices and monitoring and extension of their performance.*

4.2.1 Gillnetting - interactions with "charismatic megafauna" and bycatch issues

Australia lacks the pelagic drift-net fisheries notorious in other fishing zones for bycatch of cetaceans, seals and seabirds. Those effects have been reviewed by Dayton et al. (1995) and FAO. Taiwanese drift-netting for shark, tuna and mackerel became un-economical in the northern AFZ after modifications to reduce dolphin bycatch failed (Hembree and Harwood 1987) and net lengths were restricted under license conditions downward from 10-20 km to 1.5 km.

However, inshore gillnetting north of the tropic of Capricorn for the purposes of both commercial fishing and government shark control is now known to have caused large bycatch of dugongs, dolphins, turtles, rays and sharks. Even Humpbacked whales have been captured occasionally in the anti-shark nets (McPherson 1997). With the exception of dugong declines (see Box 4.2.1 below) there has been assessment of only the effects of such gillnetting on shark catch rates.

For example, in the Queensland shark meshing program Paterson (1990) reported capture between 1962 and 1988 of 520 "dolphins", 576 dugong, 3656 turtles and 13765 rays, aside from target sharks. For the target, "dangerous" sharks Simpfendorfer (1992) concluded that near Townsville Tiger Sharks had not been depleted, but populations of large Whaler sharks (Carcharhinus spp) had declined.

The issues surrounding inshore and estuarine gillnet fishing concern bycatch of threatened species and angling targets, waste through discarding practices and mesh selection on target species. These issues are important mainly in the tropics and fall into 4 categories :

- *bycatch of dugong - and (very rarely) turtles, Irrawaddy and Indo-Pacific Humpbacked dolphins (see Marsh et al. 1997) and crocodiles*
- *bycatch and ethics of the anti-shark meshing program*
- *byproduct or bycatch of species popular with anglers - mainly Queenfish (Scomberoides commersonianus)*
- *discarding and/or poor quality of catch in times of large catch in hot climes*
- *mesh selection for large, female barramundi (eg. Russell 1988).*
-

Voluntary cessation of indigenous hunting of dugong, and the recent ban on some forms of gillnetting, in a series of 9 (possibly extended to 12) large (>= 200 km) tracts of coastline in the Southern and Central GBR reflects the most pressing issue other than trawling - dugong bycatch – and is summarised in Box 4.2.1 to show the overlap with other habitat issues.

In 1997 a nomination was received to list gillnetting in tropical and sub-tropical waters (Moreton Bay around to Shark Bay) as a key threatening process under the Endangered Species Act 1992.

BOX 4.2.1. THE DUGONG DECLINE

Dugongs are listed as vulnerable to extinction -- a contributing factor in listing of the GBRMP under World Heritage. Their life-history traits -- aggravated by seagrass loss -- make the "tolerance" for bycatch in fishing or shark meshing very low:

- an age at first maturity of 10-17 years

- an average calving interval of 3-7 years
- a single calf per calving
- a longevity of 70 years

A sustainable rate of harvest has been estimated at only about 1-2% of females every year. Given the known applications for indigenous harvest, the tolerance for incidental death by other causes has been estimated at only 1 per 200 females per year.

There has undoubtedly been a significant decline in the southern GBR region. Aerial surveys showed a dramatic decline between Cooktown and Bundaberg of

- 3479 +- 459 dugong in 1986/87
- 1857 +- 292 in 1992
- 1682 +- 236 in 1994

This compares to Northern GBR counts of 10,471 +- 1073 and Hervey Bay 1971 +- 359 in 1988.

The Reasons

1. *Gillnet Bycatch*. There was a known kill of 4 dugong in one month in Shoalwater Bay commercial operations, but logbook data is lacking. In Townsville the anti-shark meshing killed about 80 animals in its first year of operation and between 1963 and 1983 there were about 249 deaths. More recently 25 dugong were reported killed in the Townsville shark nets during 1988-92.
2. *Traditional Indigenous Hunting.* Data on CPUE or even Catch per permit is not collected -- but there has been an increase in the number of permit applications to take dugong
3. *Loss of seagrass*. Of the meadows known to support dugong 27% are within 5 km of a waste outlet. Seagrass loss was a huge problem in Hervey Bay. In 1988 there were about 200 dugong in the Bay. In 1992 two floods and a cyclone in quick succession killed about 1000 km^2 of seagrass (Preen *et al.* 1995). There were more than 100 dead dugong washed ashore. However, there has been inadequate monitoring of seagrass change in the GBRMP - a major flood in the Burdekin River had an unknown impact on seagrass and dugong in “pristine” bays near Townsville during the period of decline.

The calving rate has not risen in Hervey bay with subsequent seagrass recovery - the numbers have stabilised but the calves are not being born because the dugongs are still more or less starving. The calving rate has dropped from 22% to 1.5% in 1994. There has been a similar drop in Cleveland Bay calf sightings.

Some suggested Fisheries R&D was to urgently

- assess risk of dugong drowning in netting operations
- identify hot-spots where the activities of dugongs and gillnets overlap
- consult fishers to develop practices to avoid dugong capture and help rescue

Further Reading: Marsh *et al.* (1995, 1996, 1997), Marsh and Corkeron (1997)
Stop Press: Dugong Protection Areas (DPAs) declared, and arrangements in progress for buy-back of gillnet endorsements on licences by QFMA

Gillnetting on temperate reefs is conducted by both recreational and commercial fishermen in Tasmania - the latter for a growing live-fish trade in Banded Morwong (Cheilodactylus spectabilis) and Wrasses (Pseudolabrus sp). Fisheries-independent surveys by Schaap and Green (1988) showed significant differences between reefs subjected to different levels of fishing pressure in the relative abundances and the average size of some species, total fish abundance, and community diversity and species composition.

This result reflects the sensitivity of such reef faunas to disturbance predicted by a large number of New Zealand studies (eg. see Jones 1988b for review) that showed surprising longevities (odaciids live for up to 70 years p.c. J.H Choat; C. spectabilis for at least 50 years p.c. M. McCormick), high levels of site attachment (Barrett 1995) and complex sexual structures in populations (see Jones' papers in Appendix 5). The results of small-scale removals of individuals in these experimental studies have been characterised by significant effects on local populations.

4.2.2 Trawling and scallop dredging

Demersal trawling is the least selective of all fishing techniques in Australia, with the highest overall bycatch to target ratios in catch and possibly the highest public profile. It is also the largest producer of food fish for domestic markets (eg. SE trawl fishery, east coast otter trawl), a major source of high-value exports (northern prawn) and the single biggest commercial sector in Queensland.

There have been major reviews of this subject (eg. Andrew and Pepperell 1992, Kennelly 1995, 1996) and we will briefly cover here only the major points or new information. In general terms most studies show that bycatch is made up of small fish (<20 cm), and relatively few species predominate.

At the centre of concern for trawl bycatch is public perception of :

- *turtle drownings*
- *killing of juvenile, commercially and recreationally important species*
- *destruction of megabenthos (see Section 4.3 below)*
- *wastage of fish*

These concerns are present in one form or another wherever trawling occurs (eg. Hanley and Couriel 1992, Hanley 1996, Edyvane 1996a). Surprisingly, the sheer inefficiency of prawn *trawls in capture of most fish species (see Wassenberg et al. 1997) has not penetrated the public debate about the practise.*

At the time of writing this review, prawn trawling (nominated in 1995) was being considered for listing as a key threatening process under the Endangered Species Protection Act 1992 because of incidental catches of turtles, sea-snakes and two species of monacanthid leatherjackets (see Caton et al. 1997). It is ironic that the monacanthids were chosen. Apparently because they had declined the most, amongst only 18 taxa whose abundance had declined significantly, in a study of 82 species comparing survey results before and after 20 years of prawn trawling in the Gulf of Carpentaria (see Harris and Poiner 1991).

From an industry viewpoint bycatch is a problem (see Eayrs et al. 1997) because of:

- *reduced gear efficiency - trawls spread less as the cod-end loads up*
- *crabs, megabenthos and "monsters" crush or scale and devalue prawns and fish*
- *"monsters" are dangerous to handle and bycatch raises handling and sorting times with heavier cod-ends*
- *dead fish (particularly in inshore banana prawn fishing on the east coast) wash up and cause public outrage*
- *sharks scavenge discards and may eat more prawns (see Section 4.4 below)*
- *retention of the blue swimmer crab bycatch is illegal in SA and they must be discarded.*

Dayton et al. (1995) suggest that fisheries-related mortality may be the single biggest factor preventing recovery of sea turtle species - but this includes methods such as longlining and drift-netting as well as trawling.

Current and recent studies are addressing a significant gap in knowledge of the factors causing drowning and mortality of turtles in trawl fisheries. The green (Chelonia mydas), hawksbill (Eretmochelys imbricata), olive ridley (Lepidochelys olivacea), flatback (Natator depressa) and loggerhead (Caretta caretta) turtles are listed as being endangered, threatened or rare in the Commonwealth Endangered Species Protection Act 1992 and the Queensland Nature Conservation Act 1992.

From several data sets collected between 1979 and 1988 in the northern prawn fishery, Poiner et al. (1990) estimated that an average of 5,730 (+- 1,907) turtles were caught every year, of which an average of 344 (+-125). Though after the introduction in 1987 of management measures to reduce effort in the fishery, the number captured declined to about

4,114 (+-1369) turtles in 1988, of which an estimated 247 (+-90) turtles drowned. Notable factors were:

- *turtle bycatch was restricted to depths< 43 m and the highest bycatch rates were from trawls of about 90 minutes in water <= 25 m*
- *flatbacks were the main turtle caught, but there were regional differences - loggerheads were caught in similar numbers to flatbacks in the SE Gulf*
- *no mortality recorded in trawls of ~ 90 minutes, rising to 7% in trawls of 180 minutes.*

This study was then followed up, and refined, by Poiner and Harris (1996) who investigated the catch, mortality rates, size composition and injury rates for turtles at a species level in 1989 and 1990. Estimates were made of the sea turtles captured and killed in the fishery as well as the likely population sizes of turtles on the trawl ground.

From a monitoring program conducted by trained, volunteer fishermen and data analysis using elementary probability theory, Poiner and Harris (1996) found that:

- *of the five species captured, three comprised 81% of the catch - the flatback (59%), the loggerhead (10%) and the olive ridley (12%). Green turtles (8%) and the hawksbill (5%) were captured only occasionally*
- *the highest catch rates were in depths between 10 and 40m (a 233,100 km^2 portion of the fishery), with few turtles captured below 40m (comprising 549, 900 km^2 of the area of the fishery)*
- *the highest catch rates were in the winter months of June and August, shortly before nesting commences in the early summer months*
- *mortality rates of the flatback, olive ridley and green turtles were relatively low (~11%) but the rates for loggerhead and hawksbill turtles were high (>20%) which may reflect the relative abilities of the species to resist drowning*
- *between 5,000 and 6,000 turtles are captured each year and about 14% drown in the trawl nets, with another 25% injured or comatose when brought aboard*
- *mortality estimates are <2% of the trawl-ground population size for all species except loggerhead (2.39%) and hawksbill (2.99%)*
- *the indigenous harvest of the green turtle in the Torres Strait is of the order of 5,200 to 6,300 turtles per year, and the Indonesian commercial fishery for turtles is estimated to take >70,000 adult green and hawksbill turtles per year.*

Poiner et al. (1990) concluded that from the available data, however inadequate, the impact of trawl-induced drownings on the turtle populations was probably not of such proportions as *to create immediate concern. Poiner and Harris (1996) concluded that the data were again inadequate, but also that trawler-induced mortality in the northern prawn fishery has less impact upon turtle populations than other hazards in northern Australia.*

However, these contentions have not met general agreement. For example, Kennelly (1996), Marsh and Corkeron (1997), and Limpus (1997) ranked fishing as a primary threat to flatback, loggerhead, green and olive ridley turtles. There is general agreement amongst the fishing industry with the recommendations by Poiner et al. (1990) and Poiner and Harris (1996) that any measures that reduce drowning and delayed mortalities of turtles would be desirable.

Poiner and Harris (1996) indicated that options the fishery may have to reduce turtle mortality include:

- *restrictions on fishing around seasonal nesting times (already done in the Gulf of Carpentaria)*
- *publicity on the importance of retaining comatose turtles until recovery*
- *shorter trawl tows (< 90 min)*
- *development of alternative trawl gear (see Section 4.8 below).*

The numbers of turtles caught and killed in the Queensland east coast otter trawl fishery were estimated by Robins (1995) from a 2-year monitoring program using 50 volunteers from the commercial fleet. The results were:

- *an average catch rate of 0.068 turtles per day fished - compared with the highest catch rates from Poiner and Harris (1996) of 0.098 turtles per trawl (we multiplied this by the usual 4 trawls per day to give a highest comparative estimate of 0.039 turtles per day fished in the northern prawn fishery)*
- *loggerhead (50.4%), green (30.1%) and flatback (10.9) turtles were the main species caught*
- *an estimated 5295 +- 1231 turtles were caught annually by the Queensland east coast otter trawl fishery, which had an annual fishing effort of 80,558 days*
- *about 1.1% of captured turtles were reported dead when landed. This mortality rate is lower than those reported for other trawl fisheries because in the Queensland east coast otter trawl fishery tow durations are short (<80 min) in the areas where turtles are commonly caught.*

Robins (1995) concluded that if all comatose turtles are assumed to die, the potential mortality rate of trawl caught turtles could be as high as 6.8%. However, the true mortality rate is probably somewhere between 1.1% and 6.8% of turtles landed, because some trawlermen resuscitate trawl-caught turtles.

Ward (1996a) compared the sea snake bycatch made by vessels that target different types of prawns in the northern prawn fishery:

- *in 1989-90, 5203 sea snakes of 14 species were sampled. Hydrophines (11 species) represented 86.7% of the total catch. Aipysurines (3 species) represented 15%of specimens from vessels that targeted tiger prawns or endeavour prawns, but comprised only 1.1% of specimens from vessels that targeted banana prawns*
- *it was estimated that prawn trawlers operating between Koolan Island and Cape York during 1990 caught approximately 81,080 +- 13,670 sea snakes*
- *vessels that targeted tiger and endeavour prawns caught approximately 69 260 +- 8750 sea snakes*
- *vessels that targeted banana prawns Penaeus merguiensis caught 7200 +- 3250 sea snakes*
- *vessels that targeted red-legged banana prawns P. indicus caught 4620 +- 1120 seasnakes.*

The results emphasised the advantages of interactions between fishers and scientists and the need to assess separately the impacts of the three fisheries that constitute the northern prawn fishery.

The turtle controversy and sea snake data illustrate our major gaps in knowledge of bycatch, its complexity and some solutions - bycatch is time, depth, area and gear specific, survival at release is species-specific (although most fish die), there are often other sources of fishing mortality and the "sustainability of bycatch" depends on the demographic parameters of the species in question. The units of effort used in reporting and estimating bycatch rates also cause problems when trying to make regional comparisons - emphasising again the need to improve the gathering of "logbook" information from fleets, using innovations such as Vessel Monitoring Systems.

In the absence of such data, public perception has been dominated by simple figures of prawn trawl bycatch : target ratios of 9 : 1 or even 20 : 1, yet in some fisheries the opposite trend is true -- eastern king prawns are fished down to 300m with 50-60% or less bycatch and discards and bycatch are usually much higher in water <30 m deep. Also overlooked is the *rapid, growing trend to find markets for bycatch, that should best be classified now as "byproduct". In the deep-water , eastern king prawn fishery the cuttlefish, octopus, flounder, angel sharks (Squatina spp), goatfishes (Upeneus) and even shovelnose ray (Aptychotrema rostrata) tails are now sold for domestic consumption. Elsewhere on the east coast bugs (Ibacus and Thenus), scallops and sand crabs (Portunus pelagicus) are important byproduct.*

In Southern Australia, too, the bycatch : target ratios are generally much lower than those publicised in the tropics. Carrick (1997a) recorded an average ratio of 3.5 : 1 for the Spencer Gulf prawn fishery, and Laurenson et al. (1993) reported that 130 tonnes was retained for sale of an estimated total catch of 354 tonnes of marine fauna off south-western Australia.

Allegations that prawn trawling destroys juveniles or competes for stocks of important species are widespread in Australia, but particularly so for:

- *juvenile mulloway in NSW estuaries*
- *juvenile Spanish mackerels (Scomberomorus commerson) (eg. McPherson 1981) and "reds" (Lutjanus sebae, L. erythropterus and L. malabaricus) in localised regions of north Qld*
- *juvenile snapper (Pagrus auratus) in SA and parts of NSW and Qld*
- *adult King George whiting and juvenile squid (Sepioteuthis australis) in SA*
- *adult sand (blue swimmer) crabs (Portunus pelagicus) in WA, SA and sthn Qld*
- *adult school whiting (Sillago bassensis) in sthn WA.*

The vulnerability of these animals to trawling is known to vary greatly with season and substratum type. For example, Lutjanus erythropterus and L. malabaricus move offshore from shallow nurseries through trawl grounds, but mainly in muddy channels, and Spanish mackerel are found on the trawl grounds inshore of their major spawning ground for only a short part of their life-history (p.c. #90 G. McPherson).

Carrick (1997a,b) showed significant bycatch of juvenile snapper only during good recruitment years when juveniles were caught outside their normal habitats in Spencer Gulf. There was no significant influence of trawl bycatch-rates of King George whiting on the commercial catch rates for this species in a statistical analysis using 20 years of logbook data and lags in effect times of trawl effort. There have been claims (eg. Edyvane 1996a) of an interaction between trawling and declining catch rates of this species in south-eastern Spencer Gulf.

Trawl fisheries are by nature very complex in Australia, with marked variation in targets and gears on the basis of cross-shelf depth and sediment types (Watson et al. 1990, Gribble 1997), latitudinal region (see Williams 1997), season and market price (eg. Gribble 1997). For example, more than 80 species are exploited in the multispecies South East fishery, with 17 species managed under quotas (Caton et al. 1997). As a result there are very different bycatch issues and effects on the benthic habitats.

For example, a major issue in the SE Trawl has been a lack of gear and mesh selectivity studies and the large-scale (up to 50% on occasion) discarding of redfish (Centroberyx spp) and up to 20-30 % of tiger flathead because of size and price (p.c. #1000 D. Smith). Caton et al. (1997) list discard rates as 50% by weight for the total catch off NSW and eastern Victoria to 14-26% in the southern orange roughy fishery.

Assessing the selectivity of a range of gear types, including demersal trawls, in different habitats of the SE fishery is one of the objectives of a current project (FRDC#96/275 and FRDC#94/040).

Australian bycatch research, as a consequence, is active on three main fronts that vary in development or importance from region to region and fishery to fishery. These are summarised in Table 4.1.1 , under the headings:

- *bycatch documentation - by fishery type, depth, region and season, and by partitioning into discards that float or sink, and are eaten by different types of scavengers; Volume 41(1) of the Australian Journal of Marine and Freshwater Research titled "Effects of Fishing" was concerned mainly with this issue. A broad, first focus of the Integrated Scientific Monitoring program (ISMP) in the SE Fishery was documentation of bycatch and discards through observer programs (see Caton et al. 1997)*
- *adaptation, design and testing of bycatch-reduction devices (BRDs) - "monster" excluder-bars, square-mesh panels; semi-pelagic trawls; mesh-selectivity studies - cooperation of science and industry in R&D with high returns for investment. Kennelly (1997) and Brewer et al. (1997) provide informative reviews on the state of knowledge and R&D directions, while Eayrs et al. (1997) give technical descriptions of all devices used in Australian prawn trawl fisheries*
- *ecosystem effects of habitat damage, species removals and discard additions - includes studies of the fate of discards and scavenging routes; species shifts on fishing grounds and in seabird populations. Reviews on the topic are rare (eg Sainsbury et al. 1997) and a number of major studies are underway (see Section 4.8 below). For example, a new*

initiative (FRDC#96/257) aims to elucidate "sustainability" of bycatch groups by summarising their demography and vulnerability.

4.2.3 Bycatch in other fisheries -- estuarine angling, trawling and pocket-netting -- bycatch of juveniles of important species

West (1993) noted that a marked lack of juvenile mulloway in the Clarence River (NSW) in sampling during March and June was a result of the prawn trawling season there. In earlier months the biggest samples of mulloway had come from the main river channel where prawn catches were often the highest. Both Oyster Channel and the Broadwater on the Clarence River were deemed especially important as sub-tidal nursery habitats and these areas were subsequently closed to prawn trawling. This particular fishery has also received attention in fully documenting the bycatch issues (Liggins and Kennelly 1996) and developing devices to and net designs to reduce the bycatch (see eg. Broadhurst and Kennelly 1994, 1995b). Similar issues exist for mulloway bycatch in the Hawkesbury (Gray et al. 1990).

The angling media has been vocal in criticising the level of mortality of juvenile fish in the bycatch of commercial fishing operations, yet creel surveys in several States are uncovering large proportions of "under-size" fish being kept by anglers. These fisheries can be larger than their commercial counterparts. For example, West (1993) found that about half the mulloway and sand whiting, 28% of the yellowfin bream and 16% of the dusky flathead kept by anglers were undersize in NSW northern rivers. Similar surveys in Gulf St Vincent found large proportions of undersize King George Whiting retained by anglers in the nursery areas at the mouth of the Port River estuary. This problem is widespread, but poorly acknowledged, in Australia where there is a prevalence of overlap of angling areas with inshore nursery areas in bays and estuaries.

Other issues that have not been studied in Australian recreational fisheries concern:

- *survival of hooked and released fish (sometimes embolised) with or without gear attached*
- *bycatch and discards in the non-selective gillnets, bait seines and cast-nets permitted for recreational use in various States.*

There is generally a poor recognition of the effects of recreational fishing on the environment and fish stocks in Australia. The present R&D focus is aimed at first determining the magnitude and composition of the recreational catch (eg. see Hancock (ed.) 1995), and there are very few papers on the other effects of such activities (eg. Diggles and Ernst 1997). This is surprising, given the perceived value of individual sportfish such as great white sharks, billfish and barramundi, the interest in catching and releasing them and the overseas concern for hooking mortality (see Muoneke and Childress 1994 for review).

Estuaries are dynamic environments and both regular and irregular events could be expected to have major influence on bycatch composition - appropriate and extensive observer coverage will be needed to document bycatch issues properly. For example, Kennelly et al. (subm. a) showed effects of moon phase on catch composition and Andrew et al. (1995) showed that bycatch in an estuarine pocket-net fishery was both variable and driven largely by freshwater flow events:

- *overall the bycatch to prawn catch ratio was 1:2 by weight in the Clarence River fishery, compared with commonly reported ratios of 20 : 1 in the trawl fisheries elsewhere. It is a relatively "clean" passive fishing method*
- *generally there was a small bycatch of about 35 kg per night per dig, however flood events saw great rises in bycatch up to about 125 kg per night*
- *fish (and prawns) moved downstream during high flow events and there is potential for much larger bycatches at these times. The whole fleet caught about 2 tonnes of bycatch per lunar month normally, but this went up to 7 tonnes after a flow event*
- *yellowfin bream, tailor, tarwhine, river garfish and snub-nosed garfish were species of angling/commercial importance in the bycatch. These were nearly all undersize, and only bream were considered to have much chance of survival after release*
- *over 96% of the bream observed were caught on just 7 out of 211 dig-nights. They were thought to be moving rapidly downstream to seek saltier water after a "fresh"*
- *best estimates of numbers caught are imprecise because of the flow influence. The "best" estimates for the entire fleet were :*

	4 months (91/92)	*8 months (92/93)*

yellowfin bream	*64, 079*	*3,152*
tailor	*24,777*	*13,307*
tarwhine	*13,085*	*298*
river garfish	*5,625*	*17,199*
snub-nosed gar	*5,070*	*11,775*
non-commercial (mostly herring and perchlets)	*1,864,331*	*784,182*

- *not all these fish would have reached "legal" size if they had not been caught. Estimating that number requires knowledge of natural mortality rates. Current knowledge does not enable any prediction of the ecological effects of removing these fish, or of returning their carcases to the food-chain*
- *NSW FRI have developed with industry the "Nordmore Grid" and other devices to reduce entry of bycatch, weed and logs into set-pocket and estuarine trawl nets (see papers by Broadhurst and Kennelly 1995b, 1996b, Broadhurst et al. 1996a, 1997a) .*

4.2.4 Shoreline harvesting

Australian advances in development and application of ecological sampling designs and analysis (eg. Underwood 1991a, 1992, 1994) occurred with a foundation in studies of intertidal organisms. These studies have recently shifted from small-scale manipulative experiments to larger scales associated with shoreline harvesting.

Shoreline harvesting of intertidal animals for food and bait, and trampling of algal beds has been reviewed by Quinn et al. (1996). There are both direct and indirect effects of species removals that are measurable and may lead to "alternative stable states" where, for example, grazing snails become established and suppress recruitment of other molluscs (p.c. #970 M. Keough). In this regard poaching of abalone on reefs closed to fishing may aggravate the appearance of urchin "barrens" habitat by altering the level of interaction between sea urchins and abalone.

The effects of angling removals of key rocky reef fishes is much harder to study and virtually unknown - despite the significant effects of small-scale removals of such fishes in New Zealand experiments (see Appendix 5). Data on the recreational catch is lacking in Australia, but Kingsford et al. (1991a) found 37 species of fish in the catch along the NSW coast. Herbivorous luderick and black drummer, yellowfin bream (benthic macro-carnivores) and tailor (pelagic piscivores), were the most important components – but there was a diverse bycatch of reef-associated species including herbivores, wrasses and leatherjackets as well as significant removals of shellfish and crabs for bait.

Creel surveys in WA indicate that the proximity of limestone reefs to the "bread and butter" angling fishery for herring (Arripis georgianus) with small hooks means that a wide variety of "reef resident" wrasses and other unwanted species are caught too. This may result in localised depletion and reduced species diversity (p.c. #1410 S. Ayvazian).

4.2.5 Bycatch in other fisheries - longlining

In pelagic longlining the major issues have concerned the capture of albatross species and other seabirds (skuas, shearwaters) on the hooks as they sink during gear setting in southern longlining, the alleged "finning" and discards of blue sharks on the east coast and the bycatch of billfishes, especially black marlin in "Area E" off north Queensland. There are also some localised concerns with seals and turtles. Current research initiatives include observer programs to document the occurrence, composition and fate of bycatch in the pelagic longline fisheries, and use of sonic transmitters and archival tags to assess interactions between billfish and tuna on longlines (FRDC #97/113).

Oceanic longlining was listed under the Endangered Species Protection Act 1992 as a key threatening process in 1995. A threat abatement plan for the effects of oceanic longlining on seabirds has now been drafted and can be downloaded at http://www.biodiversity.environment.gov.au/plants/threaten/longline/index.htm

There are also growing markets for some of the longline bycatch species, including Albacore, Rudderfish (Lepidocybium flavobrunneum), Ray's Bream (Brama spp) and shark.

Large sharks are becoming increasingly popular amongst the public and interactions between great white sharks (with shark nets and snapper longlines in SA) and grey nurse (with wobbegong set-lines in NSW) with commercial fishing gear have been the subject of recent inquiry (eg. Bruce 1992). The grey nurse shark is a protected species under the NSW Fisheries Act, and similar protection was being drafted for the great white shark in several States at the time of writing this review (see Caton et al. 1997 for review).

4.3 Habitat damage

From our review it is clear that the major anthropogenic threat to demersal fisheries habitats on the continental shelf is fishing - trawling in particular. Overall there is vast lack of knowledge of the macrobenthic communities on Australian shelves. In a review of the effects *of trawling on macrobenthic epifaunal communities, Hutchings (1990) documented the neglect of study of these communities and their roles - in contrast especially to interspersed coral reefs in the tropics. In the intervening years, there have been some major initiatives to redress this imbalance on the North West Shelf (see Sainsbury et al. 1993, 1997, Moran et al. 1995); the Great Barrier Reef Marine Park (GBRMP) (Pitcher 1997, Pitcher et al. 1997); the Gulf of Carpentaria (Long et al. 1995); Torres Strait (Long et al. 1997b,c); and on the SE trawl grounds and southern sea-mounts (see FRDC#94/040, Koslow 1997).*

In the Gulf of Carpentaria and North West Shelf the dominant macrobenthos are sponges, ascidians (colonial and solitary), alcyonarians, gorgonians, echinoderms molluscs and encrusting organisms such as bryozoans and serpulid worm tubes that settle on the larger organisms. Often these animals occur together in clumps, forming small patch reefs on otherwise bare muddy or sandy substrata. Hutchings (1990) suggested that there is an overlap in the species composition of macrobenthos in the North West Shelf, Gulf of Carpentaria and GBRMP. Long et al. (1997b) showed that seabed current stress determines distribution and abundance of sessile epibenthos in Torres Strait and that large areas are devoid of megabenthos cover.

Long et al. (1995) studied the distribution, biomass and community structure of megabenthos of the Gulf of Carpentaria, noting that this study was the first description of non-reefal megabenthos from tropical northern Australia and a rare opportunity to study intact benthic communities in the central Gulf that had been effectively closed to fishing for 14 years. Only the information on decapod crustaceans (Ward and Rainer 1988) has been published from the CSIRO studies in the North West Shelf megabenthos communities. Classification and ordination by Long et al. (1995) showed two main groups - a community of mainly suspension-feeders located in predominantly sandy sediments along the eastern and south-eastern margins and a community of predominantly deposit-feeders in the muddier sediments of the central and western Gulf. However, sessile suspension feeders (eg. sponges, zoantharians, pennatulaceans, bivalve molluscs and ascidians) were also found in the muddy central Gulf wherever suitable substrata for attachment were found.

Recent video surveys by NTDPIF of the trawl grounds in the Arafura Sea found very sparse, small epibenthos with indications that they have rapid turnover. It is possible that the North West Shelf benthos is atypical of trawl grounds in Australia - being big and probably old – whereas the Arafura and Timor ground benthos is evidently low density and very small in the areas surveyed. The epibenthos of the Torres Straits and Gulf of Carpentaria may have different resilience and regeneration time too, after disturbance by trawling, and this is presently under study by CSIRO Division of Marine Research (p.c. #20 D. Ramm, p.c. #1190 K. Sainsbury, also see Long et al. 1997c).

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

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

The association between shelf megabenthos and fisheries and other motile fauna has received scant direct attention relative to similar work on coral and rocky reefs, seagrasses and mangroves. The use of video cameras mounted on traps, trawls and fishery-independent sleds has been very useful in such study (eg. Sainsbury et al. 1993, Moran and Jenke 1989, Moran et al. 1995). Snappers (mostly Lutjanus vitta) and Emperors (Lethrinus spp.) associate with large epibenthos on the North West Shelf, whereas Butterfly-breams (Nemipterus) and Lizardfish (Saurida) occur in areas of open sand devoid of such assemblages (Sainsbury 1987). The distribution of decapod crustacea in that region is also associated with biomass of a large sedentary fauna (Ward and Rainer 1988).

Study of the epibenthos themselves is hampered mainly by the depths below the limits of safe SCUBA operation on trawl grounds and the taxonomic difficulties associated with these invertebrate groups. Studies of the biology and taxonomy of these groups, especially sponges, have been facilitated by the development of the bioprospecting industry in marine *pharmaceuticals and fisheries R&D is now providing an additional impetus to research on their biodiversity (eg. FRDC #97/205).*

A variety of innovative technologies has been developed to overcome the problems posed by depth, including side-scan sonar, video sleds, remotely-operated video and "ROXANN" software that interrogates "hardness" and "rugosity" from echosounder traces (se Pitcher et al. 1997).

One of the greatest challenges in assessing the effects of fishing on epibenthos is the lack of knowledge of potential for recovery, succession and resilience to trawling. There have been detailed studies on the community dynamics of pier-piling epifauna (see Keough et al. 1990 and Butler 1996), but it is unclear from the literature whether species in the same genus or family of epibenthos share the same reproductive modes, and even less is known of recruitment. There is also a lack of information on patch stability and turnover, on the need for pieces of hard substrata for attachment - and especially on growth rates and longevity. Currie and Parry (1995) suggest that studies of benthic "recovery" in experimental designs should have a duration at least as long as the longevity of component species - but frequently this is unknown. A new FRDC initiative (Pitcher et al. FRDC #97/205) will be addressing directly the dynamics of megabenthos patches and individuals, as well as determine the associations between shelter and diet of fishes inside and away from megabenthos patches.

The studies of depletion of tropical megabenthos by trawling have generally shown alarming rates of mortality of benthos >20 cm in maximum dimensions, especially after repeated trawls over the same track. Moran et al. (1995) used videos and trawls to estimate that a demersal trawl destroys about 16 % of such benthos in its path in a single pass, and they expressed concern that some previous studies of cod-end contents were under-estimating the effects of a trawl by not considering the damage by bridles and sweeps. Sainsbury et al. (1993) reported that the average catch per unit of trawl effort of sponges on the North West Shelf fell from 500kg hr^{-1} to only a few kg hr^{-1} as trawling developed. Video footage showed that as little as 10% of dislodged epibenthos ended up in trawl cod-ends and the probability of destruction in the trawl path was 0.43-0.95 depending on best/worst scenarios for mortality after disturbance.

Recovery of megabenthos communities on the North West Shelf after cessation of trawling has occurred (rapidly for benthos < 20 cm; slowly for large megabenthos) after 10 years to a level that bears an unknown relationship to "untrawled" conditions, but Lutjanus and

Lethrinus populations have also built up in these areas - so some fisheries function, at least, may be restored in such a time frame (Sainsbury et al. 1993).

Concern over the effects of fishing on benthic communities has a long history and has provided the impetus for a number of overseas research programs over the past 20-30 years. Collie et al. (1997) classify such disturbances as scraping or ploughing, sediment resuspension, physical destruction of bedforms and removal or scattering of non-target benthos. Most of these studies have detected significant effects on both infauna and epifauna (eg., Collie et al. 1997, Hall et al. 1993, Kaiser and Spencer 1996, Thrush et al. 1995). However, the persistence of these impacts depends on the rate of natural and fishing disturbance, the type of fishing gear, and sediment and epibenthos type.

For example, overseas studies of the scraping and ploughing associated with scallop dredging showed that dredges can crush scallops or push them into the sediment, as well as causing resuspension and loss of fine organic muds and silty sands and consequent coarsening of sediments to sandy gravel with shell hash. This turbidity was suspected to kill scallop larvae (Dayton et al. 1995)

Scallop dredging in Port Phillip Bay has been banned for political reasons, but a series of BACI studies there showed that interannual and inter-seasonal changes to community structure of epibenthos and infauna were greater than those due to the "grader-like" effect of the dredges (see Currie and Parry 1994,1995 for review). Callianassa mounds (but not the crustaceans themselves) were removed and there were significant effects on the dredging, but recovery took place within 14 months. However, the "recovered" community had an uncertain relationship to the "never dredged" community of 30 years previously and the flow-on effects of benthic changes were unknown. Analysis of spatial patterns of benthic bycatch back to 1963 showed consistency in landings of epibenthos in "rubbish bins" measures, and the direct effects of the dredges depend on substratum hardness. Higher, tine-induced mortalities occurred in "harder" sediment areas, whereas the molluscan fauna and smaller scallops are pushed into softer sediments by the dredge tines.

Hauling of seine nets by hand, by hydraulic winch and by boat power (power-hauling in SA) occurs through seagrass beds in most States. Underwater video footage of haul-netting in SA Gulfs showed that the movement of the footrope flattens Posidonia ahead of it in a bow-wave effect and only removes some epiphytes and dead blades (p.c. #1560 K.Jones). Concern over the practice in Jervis Bay is under study by NSW FRI (FRDC #96/286). Live and dead blades *will be tagged in situ and their presence in nets hauled over them will enable inferences to be made about the fate of live seagrass (Posidonia and Zostera) in hauling grounds.*

There is also trawling in deeper north Qld seagrass beds and the implications are not yet clear. The rate of disturbance is most important, as many of the seagrass are naturally dynamic, and many meadows are avoided by trawlermen because of the nuisance algal load that is brought up (Lee Long and Coles 1997).

4.4 Secondary effects of discards

Crabs, fish, sharks, seabirds and mammals are known to aggregate to feed on discards (eg. Blaber and Wassenberg 1989, Wassenberg and Hill 1990). Some of these scavengers may change foraging behaviour from day to night (eg. seabirds, fish) and diet. In the Gulf of Carpentaria the crested and roseate terns and brown boobies are foraging on discards of floating, demersal, fish species and CSIRO are investigating the implications for nesting success (see Blaber et al. 1995 for review). Seabirds follow trawlers everywhere, and in South Australian Gulfs cormorants have learned to enter the seine nets of power-haulers in flocks of tens to hundreds to feed on the concentrated catch. In the case of some seabirds (cormorants, crested terns and others), nesting populations have increased as a result of foraging on trawl discards. This may, in turn, cause depletion of other bird species - the rapid increase (10-13% annually) in silver gull populations due to a variety of anthropogenic causes has caused competition for nesting sites (Ross 1996).

In the absence of any density-dependent effects of predation or competition the ability of any species to capitalise on discards introduced into the system will depend on its reproductive capacity.

Sharks are visibly associated with prawn trawling in the tropics and there are anecdotal suggestions that they have benefited from trawl discards. Stevens and McLoughlin (1991) recognised four broad reproductive strategies among tropical sharks that will determine their potential to increase in abundance. It is especially important to note that one group had an annual cycle but breeding was continuous throughout the year, these were mostly small bottom- associated sharks. It is likely that these small species should be the focus of early attention to the impacts of discards. Diets ranged from omnivorous to highly selective and fish was an important component of the diet in all but one species.

One of the highest R&D priorities for NORMAC is shark predation on prawns. A series of studies on prawn predators (eg. Salini et al. 1990,1992,1994) and rates of consumption has shown that sharks are major predators of prawns in the Gulf of Carpentaria. Studies of discards in Albatross Bay alone showed that about 10-20,000 tonnes of discards were being distributed per year – to feed mainly sharks, which then possibly ate more prawns due to population expansion (p.c. #280 S.Blaber and D.Brewer).

4.5 Indirect effects of the reduction of target species and habitat damage

Overseas studies have shown that very heavy fishing can result in a rise in squid populations in the tropics, and by deposit feeders and invertebrates in the temperate zones. Indeed Dayton et al. (1995) report some observations that such fishing is "causing a rebirth of the Mesozoic-like system dominated by echinoderms and crustacea because overfishing has removed the evolutionarily-new teleost predators". Release from predation, herbivory and interspecific competition are some of the mechanisms that could govern these interactions.

4.5.1 Species shifts on reefs

One of the most commonly predicted - but poorly documented – problems with fishing concerns "cascading" effects on coral reefs of predator removals (Dayton et al. 1995) such as:

- *an "undocumented increase" in herbivorous fish numbers by removal of large groupers and other serranids (eg. coral trout)*
- *a "release from predation" of sea urchins, crown-of-thorns (COT) starfish and corallivorous Drupella snails, with subsequent effects of grazing and corallivory on coral reef structures*

Overseas studies of the urchin outbreaks on some reefs have shown support for these predictions, and many small-scale experiments have shown predation to be a major factor limiting community and population composition. However, studies at larger scales have repeatedly failed to find any effect of predator removals on other prey or non-target species, although there are usually differences in predator abundance between reefs "open" and "closed" to fishing (see Russ and Alcala 1989, Jennings and Polunin 1997 for review).

In the GBRMP surveys of gut contents of likely predators (Lethrinus miniatus and L. atkinsoni) and well controlled caging experiments inferred that line-fishing of such predators was unlikely to have had important influence of the outbreaks of COT starfish (see Mapstone et al. 1997 *for review). Comprehensive studies of the effects of fishing in the GBRMP are underway now (see Box 4.9.1 below).*

Marine herbivores, such as sea urchins, can have profound effects on the abundance and composition of algal assemblages on tropical, sub-tropical and temperate reefs. A series of papers by Andrew (1988, 1989, 1991, 1993b, 1994) has explored the experiments needed to test hypotheses concerning these effects - including the effects of fishing. For example, there has been an overseas debate over "urchin-lobster" interactions and the consequences of lobster fishing on urchin outbreaks. In our region, Andrew and McDiarmid (1991) studied the inter-relation between the sea urchin Evechinus chloroticus and rock lobster Jasus edwardsii in northern New Zealand. Both species were found in large numbers in the "Shallow Broken Rock" habitat - but rock lobsters were scarce in the "Barrens" habitat where urchins are mostly found, and urchins were largely absent from the kelp forests and deeper reef where rock lobsters were most abundant. During the day rock lobsters and sea urchins were spatially segregated on a small scale, but sea urchins were accessible to nocturnally foraging lobsters. Laboratory experiments demonstrated that large lobsters ate all sizes of sea urchins - with a preference for smaller urchins. The experimental removal of large brown algae or sea urchins and gastropods from areas of reef did not cause significant reductions in the daytime density of J. edwardsi. The authors argued that the changes in abundance of one species (for whatever reason) would not lead to changes in the local abundance of the other, mainly because of different microhabitat requirements.

Increases in abundance of sea urchins (Prionocidaris) have occurred (with seagrass dieback) in northern Torres Strait (see Long et al. 1997a), but the implications for the tropical spiny lobster fishery there are unknown (see Caton et al. 1997).

Small-scale manipulations and surveys at 7 mile beach and Dongara in WA (Joll and Phillips 1984, Jernakoff et al. 1994) have shown that western rock lobster (Panulirus cygnus) have a broad diet and high densities, and could be expected to have a predatory effect on molluscs such as the gastropod Cantharides spp. A corollary is that intensive rock lobster fishing could have effects on prey populations and indirectly on algal assemblages through herbivore removal. However, these findings have not been followed up with experiments at any scale.

There is an urgent need for studies on the effects of rock lobster fishing on sub-tropical and temperate reefs, as many of the southern fisheries are located in "nests of endemicity" that will probably feature highly in the NRSMPA. There have been suggestions that rock lobster *fishing is a threatening process in some areas (Edyvane 1996a, Stoddart and Simpson 1996). The short-term effects of closure to fishing in such areas suggest that fishing (of all types) could have a measurable effect. For example, Edgar and Barrett (in press) found that densities of rock lobster Jasus and urchins, and the mean size of wrasse, leatherjackets, abalone and Jasus, all increased within the reserves relative to outside, over the first year of closure.*

The authors conclude that large scale (1-2 km stretches of coastline), replicated, experimental closures to fishing are needed to define the effects of fishing on temperate reefs. These fisheries include angling, abalone diving, rock lobster potting and gillnetting (p.c. #1260 G. Edgar). At smaller scales reef fisheries within the limits of SCUBA diving are amenable to manipulations of prey, predator, shelter and algal assemblages and the clear waters would enable direct or video monitoring of the action of rock lobster pots to ascertain the damage they cause to the substrata (if any). Such work has been done for the Shark Bay trap fishery for snapper (Moran and Jenke 1989).

However, the Australian sea urchin studies have outlined a unique R&D opportunity to exploit urchin-abalone interactions and enhance both abalone yields and algal biodiversity by developing a small urchin fishery for Centrostephanus rodgersii (see Box 4.5.1 and FRDC #93/102).

BOX 4.5.1. MANIPULATION OF URCHIN-ABALONE INTERACTIONS - R&D OPPORTUNITIES FOR ABALONE ENHANCEMENT

The urchin *Centrostephanus rodgersii* creates and maintains "Barrens" habitat by herbivory. At the larger, among-habitat scale abalone are almost absent from the "Barrens " or "White Rock" habitat where sea urchins are most abundant. At a smaller within-habitat scale densities of urchins and abalone are negatively correlated at a scale of $10m^2$. At an even smaller, nearest-neighbour, scale within crevices both abalone and urchins are most likely to be found next to a conspecific (Andrew and Underwood 1992). It is also known that abalone eat drift algae and that coralline algae are critical for abalone spatfall and settlement, and it is suspected that there is a role for kelp in maintaining biofilms on these coralline algal surfaces - urchin grazing removes the kelp and possibly destroys abalone spat.

To increase the productivity of the southern NSW abalone fishery the study by NSW FRI involved :

- manipulating urchins by removal in pulse/press fishing
- abalone input by seeding with adults.

The results were that urchin removal caused an increase in abalone recruitment and numbers and NSW FRI will be developing a co-managed urchin roe fishery to supplement abalone harvesting in that area. Opportunities exist for seeding abalone brood stock into the algal habitats encouraged by urchin removal, and the ongoing experimental work will help define the mechanisms causing the interactions.

Contact: Dr Neil Andrew, NSW FRI see FRDC#93/102

4.5.2 Indirect effects of the reduction of target species and habitat damage -- species shifts on trawl grounds

The best-known Australian examples come from the CSIRO studies on the North West Shelf, reviewed by Sainsbury et al. (1993, 1997). Large fish with high domestic market value, especially Emperors and Snappers (Lethrinus and Lutjanus), were replaced by low value, small Lizardfish and Butterfly breams (Saurida and Nemipterus) after several eras of heavy trawling. The major mechanisms examined by CSIRO in experimental and modelling studies on the North West Shelf exemplify most of the routes by which species shifts can occur. They were:

- *an intraspecific mechanism, under which the observed changes are regarded as independent single-species responses*
- *an interspecific mechanism in which there is a negative influence of Lethrinus and Lutjanus on the population growth rate of Nemipterus and Saurida so that Nemipterus and Saurida experience a competitive release as the abundance of Lethrinus and Lutjanus is reduced by fishing*
- *an interspecific mechanism in which there is a negative influence of Saurida and Nemipterus on the growth rate of Lethrinus and Lethrinus so that Lethrinus and Lethrinus are inhibited as the abundance of Saurida and Nemipterus increases for other reasons*

- *habitat determination of the carrying capacity of each genus separately, so that trawl-induced modification of the abundance of the habitat types alters the carrying capacity of the different genera.*

In an analytic framework for evaluating adaptive management regimes the probability placed on the habitat limitation mechanism was about double that of the closest other contender after 5 years of experimental closures and surveys (see Sainsbury et al. 1997 and Section 4.9)

The need for life-history information in predicting species shifts and sustainability of bycatch species is best exemplified in the work by Thresher et al. (1986) on the four Saurida species that are found on the North West Shelf. One of the small-bodied species (Saurida sp. 2) lives for less than a year and has a very short generation time of only 60 days from settlement to sexual maturation. Its population had been doubling every year for over 5 years during the study and Thresher et al. (1986) suggest that the extremely short generation times would make Saurida sp. 2 an eminently pre-adapted "weed" species capable of rapid population expansion in the face of opportunities – such as new sandy habitat or release from predation -- caused by trawling. They also warned that the Saurida are voracious predators of juvenile fishes and crustacea and that they may have long-term predatory and competitive effects on the community composition on the North West Shelf even if fishing pressure declines.

We also suggest that knowledge of the survival of discards is essential in understanding the effects of fishing – as a further mechanism producing species shifts may be the differences amongst fish families in their ability to survive the rigours of being trawled, sorted and discarded. For example, Greenstreet and Hall (1996) found that the non-target species assemblage in the north-western North Sea had remained relatively unchanged despite a century of trawling - in stark contrast to the Georges bank where gadoid finfish have been replaced by dogfish (Squalus spp) and skates in an alternative stable state. These elasmobranchs are exploited in the North Sea, but not the Georges Bank, and this may have suppressed their rise, but the elasmobranchs discarded on the Georges Bank may also survive the capture by trawl better than other species, giving them a competitive advantage.

In this regard triggerfishes (Balistidae) may well have some advantage over other fishes in the tropics, as they have bony, carapace-like body armour and an ability to avoid embolism of the swimbladder through the mouth. Anecdotal reports suggest that Abalistes stellarus is a feature in tropical Australia of grounds disturbed by trawling (p.c. S. Newman) but data on their *biology and survival after discarding is not available. A "balistid rise" has been reported in overseas trawl grounds by Longhurst and Pauly (1987).*

Tank studies of the survival of discards have generally shown low survival of fish in the tropics (20% after 8 hrs ; Wassenberg and Hill 1989), but Carrick (1997a) found "much higher" rates of survival amongst King George Whiting (no data supplied) and Snapper (50% after 2 hrs) in South Australia. There are a multitude of factors governing survival, including trawl duration and depth, bycatch composition and cod-end weight, air temperature and handling methods.

Blaber et al. (1994b) found a species composition in the Gulf of Carpentaria trawl grounds that may be related to intensive prawn trawling. The catch rates and biomass estimates were directly comparable to a study done with the same gear previously (Blaber et al. 1990a) that suggest some temporal stability in the patterns of fish abundance and shows no evidence of decline. In fact, the biomasses of the top 25 species were approximately double on the prawn trawl grounds compared to the rest of the Gulf, even though the commonest prawn ground species included some of the most abundant species in the Gulf as a whole. These included Pomadasys, Upeneus, Pentaprion, Saurida and various leiognathids, and these species form the bulk of prawn trawl discards (Harris and Poiner 1990, 1991, Ramm et al. 1990).

The distribution of larger, commercially important species of lutjanids and lethrinids was centred on a series of stations across the northern Gulf outside the areas of prawn trawling. However, further analyses of relationships between benthic structure, benthos and fish distributions are required before inferences can be made about the role of megabenthos disturbance cited by Sainsbury (1987) in species replacements.

On a longer time-scale Harris and Poiner (1991) compared catches and sediments in the Gulf of Carpentaria after 20 years of trawling to conclude that the abundance of 63% of 82 taxa had not changed, although there had been an overall decline in fish abundance. The declines were mostly with 18 benthic and offshore taxa (eg. Paramonacanthus, scorpionfish and soles) but increases occurred in 12 bentho-pelagic and nearshore taxa - including sharks, anchovies, sardines and trevallies. There was also an unexplained decrease in mud content of offshore sediments in the study area, which has been associated overseas with both the ploughing effects of trawling and a lowering of fish diversity and production (Dayton et al. 1995). The results of Harris and Poiner (1991) emphasise the need to account for environmental variability in interpreting such long-term comparisons - including river outflow and temperature in shallow waters and sediments offshore.

The trawling practices by foreign fleets in the tropics may have intentionally removed megabenthos to "encourage" small fishes of high value on their domestic markets. For example, "butterfish" of the families Centrolophidae (Psenopsis anomala) and Ariommatidae (Ariomma indica) were the mostly highly-prized target of Taiwanese pair-trawlers in the Arafura sea and greatest catches were taken where the seabed had been damaged by trawling or over flattened substrata (Kailola et al. 1993).

Species shifts have been evident in the SE Fishery too, but interpretation of the data are difficult. In the early 1900s the gurnard Pteridotrigla (low now) and chinaman leatherjacket Nelusetta ayraudi (negligible now) were in the top 3-4 of species list in the SE Trawl (p.c. # 100 P.Last). Tiger flathead have been fished in Eastern Bass Strait since 1915 and are still a major species, but with lower catches. Current work by Bax et al. (FRDC #96/275 and FRDC#94/040) is designed to understand the use of different habitats by different species in the SE fishery as a first step to understanding the effects of fishing.

4.5.3 Indirect effects of the reduction of target species - competition with predators for food fishes

Aggregated prey such as schooling pilchards, squid and other "baitfish" are important as prey sources for the high food consumption of small cetaceans and seabirds, so dispersal of the aggregates by purse-seine fishing or other means is considered likely to be a problem by Dayton et al. (1995). Dispersal could cause predators to move elsewhere or to have difficulty in finding sufficient food. This issue has not been recognised or studied in Australia, yet it may be a significant problem at certain times and places because:

- *our low nutrient shelf waters support relatively minor clupeid production*
- *our planktivorous, schooling jack mackerel and clupeids are known to undergo major shifts in recruitment, schooling behaviour and spatial location due to ENSO and other oceanographic factors*
- *there is a concentration of charismatic megafauna such as Tasmanian fur seals, cetaceans, seabirds and billfish in the areas where these "baitfish" predominate and it is known that some or all of these species rely heavily on these as a prey source*
- *there is widespread knowledge that baitfish form the major diet of other fished species such as Australian salmon, tunas, billfish, sharks, tropical mackerels and other sport and gamefish*
- *to feed, some seabirds need actively feeding predators to drive baitfish upward to the surface (eg. Blaber and Milton 1994).*

In late winter/spring 1984 and 1985, adult little penguins in Port Phillip Bay died of starvation, apparently directly resulting from food deprivation (Harrigan 1992) and it was suggested at first that fishing had depleted their prey. Later study by Hoedt et al. (1995) indicated that baitfish (anchovies and pilchards) distributions may shift in Victoria during ENSO events, making foraging by adult penguins insufficient to meet demands of both body maintenance and chicks.

There are no well-defined protocols to study such effects of prey scatter and competition between fishing and predators, although it will be an issue of growing concern as a new pilchard fishery in SE Qld begins amidst much opposition from gamefishing and sportfishing interests. Studies of predator diets is a first step. Historical data on the diet of Australian salmon is available from factory sampling (p.c. # 1360 R.Lenanton) for periods before and after a major pilchard fishery began on the south coast of WA, but there has been no comparison of the pilchard composition in the diet.

4.6 Changes in demography under fishing pressure

Our focus here is on the environmental effects of fishing, but some mention should be made of the potential for changes within the fished stocks themselves because these, in turn, may affect Australian ecosystems. Genetic resources come under the definition of "biodiversity".

There have been some recorded incidences of changes in demography of fished species. For example, Cockrum and Jones (1992) studied the reproduction of King George whiting in the period 1980 to 1988, in comparison with studies undertaken in 1953 and 1966. The length at first maturity decreased for both sexes since 1953 – from 36cm to 31cm for females and from 32cm to 27cm for males. This was attributed to heavy commercial and recreational fishing and "knife-edge recruitment" in the nursery areas. Similar changes have been mentioned for barramundi in Queensland (Williams 1997).

Abalone life-history makes them both easy to study and vulnerable to the genetic effects of local depletion. Shepherd (1990) has long-term, fishery independent data on demography for 3 sites spread throughout the South Australian fishery. All sites have shown subtle, slow declines in density and recruitment over 15 years. There has also been a decline in growth rate due to selection by divers for fast growing individuals and on the West Coast of SA (Elliston) the age-at-first-maturity has decreased by one year.

It has been proposed that the abalone there are putting more energy into egg production than somatic growth in response to size-selective harvest, and "slot" size limits are being tried to restore earlier demographic patterns (p.c.# 1540 S. Shepherd).

4.7 Generation of litter and the environmental consequences

The Australian problems of fishing debris, lost gear and litter is reviewed by Jones (1995), Coxon (1995) and Wace et al. (1996). Such debris includes scraps of netting, fibreglass strapping bands from bait boxes, tangles of monofilament fishing line and other plastics that concentrate along slicks and other hydrodynamic features before appearing on beaches and causing public alarm. The debris is often cast ashore far from their source (eg. Slip and Burton 1991), and studies have recently commenced to distinguish the foreign or domestic, commercial or recreational sources from one another in litter collections.

There are frequent reports of marine animals becoming entangled and suffering from the effects of net webbing, monofilament fishing line and fibreglass bait bands. The publicity and implications surrounding these events are particularly bad when the conservation status of the animal has been declared as "threatened" or "endangered" under the Endangered Species Protection Act 1992. Sea lions, southern fur seals, cetaceans, sea turtles, sea birds and sharks figure most prominently in these reports (eg. Slater 1991), and rates of seal entanglement as high as 1 - 2% have been reported by Caton et al. (1997). The wounds from bait bands are particularly alarming, and emaciated, "banded" whaler sharks have menaced spearfishermen in WA.

There have been no studies in Australia of the rate of loss of gear or occurrence of ghost-fishing by lost gill and trawl nets and rock lobster pots. Caton et al. (1997) suggest that the high levels of fishing debris found in litter surveys were partly because of the intense burst of orange roughy fishing prevailing at the time, and the littering and lost nets that occurred in this period. Anecdotal reports suggest that rock lobster pots are lost in significant numbers in some areas when they become snagged or the buoy lines are dragged under by strong currents.

Recreational fishing is known to cause chronic littering - particularly at popular locations – and this contributes to the debris documented by Wace et al. (1996). Brown's Beach in Innes National Park on Yorke Peninsular, SA, was temporarily closed to surf anglers for this reason, *and similar problems have occurred on the rock-fishing platforms of Jervis Bay National Park, NSW. The use of 4 wheel drive vehicles has been found to cause egg destruction for some plovers and terns on beaches at surf-fishing locations (p.c. D. Paton, University of Adelaide) and destruction of terrestrial plants for firewood and vehicle access occurs in national parks throughout coastal Australia.*

4.8 Reducing the effects of fishing

The term "environmentally friendly" fishing gear has been used recently in Australia to encompass a variety of attempts to reduce bycatch, to reduce contact of the gear with sessile benthic communities and to reduce littering with fishing debris (eg. see Brewer et al. 1997). The perspective of such a term has not been defined, and advances in "environmentally friendly" trawls that fly over benthic communities may actually increase effects of fishing on ecosystems by allowing fishing to occur in areas that previously could not be trawled without fear of gear loss. This again reinforces the lack of definition of objectives, outcomes and performance measures in pursuing ecologically sustainable development of fisheries in Australia (Staples 1997).

However, in pursuing an outcome of a reduction in bycatch, Australian fishermen have not lagged behind northern hemisphere adoption of appropriate technology. For example, Spencer Gulf prawn fishermen developed "crab bags" to prevent Portunus entering cod-ends and estuarine fishermen in NSW and Qld have used inclined panels or "blubber chutes" to avoid swarms of Catostylus jellyfish for over 20 years.

In the late 1980's there began an intense and rewarding R&D effort between industry and science in developing or adapting devices for Australian conditions and testing them (see Kennelly 1997, Eayrs et al. 1997 for reviews).

The major designs use inclined grids ("hard TEDs") or inclined mesh panels ("soft TEDs") to guide animals out of escape openings, or panels of mesh that allow fish to escape but not prawns. These rely on clever interpretation of water flow and pressure gradients and different behaviours of organisms in trawls. They have included:

- *semi-pelagic fish trawls to avoid megabenthos and sea-bed dwellers (eg. Ramm et al. 1993)*
- *the AusTED, Super Shooter and Nordmore grid to exclude turtles, rays and other "monsters", jellyfish and megabenthos (eg. Mounsey et al. 1995, Broadhurst et al. 1997a)*

- *square mesh windows, fisheyes, square mesh cod-ends and radial escape sections to allow small fish to escape without loss of prawns (eg. Broadhurst et al. 1996b, Broadhurst and Kennelly 1996a, 1997)*

The design and operation of all bycatch reduction devices for Australian prawn fisheries is reviewed by Eayrs et al. (1997) who recommend that a sound understanding of the bycatch issues at hand are necessary for selection and adaptation of devices which will vary amongst regions and fisheries. For example, Moran et al. (1995) do not believe that semi-pelagic trawls are a solution to megabenthos destruction on the North West Shelf as they are in the Arafura Sea where schools of large lutjanids occur. They argue that, even if such gear is legislated for use in the NW fishery, the fishermen will fish them hard on the bottom - as trials showed significantly smaller catches than a standard demersal trawl.

In 1995 prawn trawling was nominated as a key threatening process under the Endangered Species Act 1992 and the nomination was still under consideration at the time of writing this review. If the formal listing goes ahead, then the industry will have to develop a threat abatement plan to mitigate threats to the survival of endangered species, such as turtles. Market forces may also hasten the voluntary adoption of bycatch reduction devices, as in May 1996 the USA placed bans on the import of any prawns caught in trawls not fitted with turtle-excluder devices.

The FRDC "Effects of Trawling" sub-program aims to set time frames and objectives for the adoption of bycatch reduction devices and to measure the performance of these measures, in terms of both bycatch reduction and achievement of "sustainability" in trawl fisheries. However, we could not find references to programs designed to measure the success of the reduction in bycatch and abatement of threat to endangered species.

The profit margin in the Queensland East Coast trawl fishery is much smaller than that in the Gulf of Carpentaria, and this will have implications for the voluntary or enforced use of TEDs. Targets given in the "Trawl Proposed Management Arrangements 1998-2005" by the QFMA are :

- *compulsory use of Turtle Exclusion Devices in defined areas upon the implementation of the East-Coast-Moreton Bay Trawl Fishery Management Plan*
- *develop a process for minimising impacts upon threatened and endangered species which meets the requirements of conservation agencies including Environment Australia, by December 1998*
- *level of trawl-induced turtle kill to be negligible by (year) 2000 for the east coast and Moreton Bay.*

Many other laws under State and Commonwealth Fisheries Acts have been designed to increase selectivity of fishing gear and reduce various effects of fishing – such as discards of fishing debris (see Caton et al. 1997 for review), bycatch of threatened or endangered fauna, damage to benthic communities and mortality of "undersize" animals. They are too numerous to mention here, but notable examples from other fisheries are :

- *development of semi-pelagic fish trawls is being pursued to reduce destruction and capture of megabenthos, improve catch quality and reduce bycatch of unwanted species (see Brewer et al. 1996,1997; this is now a requirement to participate in the Northern Fish Trawl)*
- *"Tori poles", night setting, bait thawing and bait-throwing devices have been successful in reducing hooking of albatross and other seabirds on longlines, and there is mandatory use of these devices south of 30° South*
- *spikes inside rock lobster pot entrances have been developed by SA fishermen to dissuade entry and bait stealing by sealions on Kangaroo Island*
- *selective mesh sizes and breaking strains, and attendance rules, have been implemented in the Queensland gillnet fisheries to reduce bycatch and entanglement of large marine animals*
- *funnels in Queensland eel traps have reduced freshwater tortoise bycatch*
- *the early efforts of the Australian National Sportfishing Association and gamefishing movement has instigated a shift of the angling culture toward catch-and-release and conservation (a code of practice for angling is being drafted as part of development of a National Policy on Recreational Fishing)*

- *the use of less harmful and more selective fishing gear (single hooks, barbless treble hooks, line classes) has been ruled or encouraged for certain locations and competitions in recreational fisheries.*

The use of Marine Protected Areas to reduce effects of fishing is discussed in section 1.2.3.

4.9 Assessing the effects of fishing

Our review revealed that scientific assessment of the effects of fishing, particularly on shelf macrobenthos and habitats, is made difficult or confounded by the facts that:

- *much of the mainland shelf <50 m deep has been trawled already - some heavily for very long periods - and differential GPS is enabling new areas to be trawled safely*
- *early data does not exist or the existing research and logbook data often are of little use in robust assessments due to lack of replication or standardisation, lack of metadata, bias and errors*
- *early fishery-independent surveys were not designed with statistical power in mind - failure to assess precision of old survey data may result in weak and uninformative test for change*
- *zoning of MEPAs are seldom designed with inherent models in mind for setting up contrasts in later assessments of effects of fishing*
- *trawling is a very low power way of sampling, because habitat patches are at the 10's of metres scale, and trawling integrates along a long path*
- *research surveys are much more reduced in time and space than the actual fishing effort - to obtain more replicates, reduce spatial variation of density estimates and evaluate patchiness. This may increase sampling power, but dilute the knowledge of actual, local impact on megabenthos and on bycatch species that aggregate*
- *short-term, low spatial scale work seldom shows any correlations between effects of fishing and habitat loss, and abundance of fished species*
- *there is little knowledge of the demography of non-target species*
- *changes in fishing gear efficiency, discarding and reporting practices and environmental forcing (eg. zonal winds, El Nino, river outflow) cannot be accounted for in historical comparisons*
- *a public backlash against manipulative science threatens future study in MEPAs where contrasts do exist for powerful experiments.*

Sceptics suggest that ALL studies of effects of fishing are too late because there are few if any meaningful "controls" - most sensitive species have long been fished or removed (eg. Dayton *et al. 1995). However, it should be argued that while such controls are desirable they are not necessary to understand the effects of fishing. Powerful experiments such as the CRC Reef "Effects of Line Fishing", FRDC "Effects of Trawling" sub-program and the CSIRO North West Shelf studies have relied instead on maintenance of spatial and temporal contrast in effort and stock size.*

Indeed, the question of sustainability on Australian fishing grounds should now remain centred on maintaining present, productive, fishing grounds in a manner to safeguard "representative" habitats - not winding back the clock to pristine, pre-fished habitats and assemblages everywhere (p.c. # 720 D. Staples). The appropriate design and implementation of marine protected areas under the NRSMPA, scheduled for implementation by the year 2000, could enable both fishing and maintenance or recovery of biodiversity.

Assessments of the effects of fishing have been conducted at increasingly larger spatial and temporal scales:

- *long-term (>15 yr) zoning was used to produce large scale manipulations of trawling to infer effects on fisheries and recovery rates of fish communities and benthos (see Sainsbury et al. 1993 for review and Section 4.9)*
- *over 5 years the CSIRO/QDPI "Effects of Trawling" and CRC "Effects of Line Fishing" programs in the GBRMP are using depletions, comparisons of "open" and "closed" zones and other manipulated contrasts to achieve similar goals (eg. Ferreira and Russ 1995, and See Boxes 4.9.1 and 4.9.2)*
- *replicated pairs of fished and unfished grounds in Spencer Gulf have been trawled repeatedly to measure depletion rates of bycatch species and infer effects of prawn trawling (Carrick 1997a,b)*
- *repeated trawling of marked areas has allowed depletion rates of megabenthos and fish, and trawl selectivity for juveniles to be determined (eg. Moran et al. 1995)*
- *abalone and urchin densities have been manipulated at within-reef scales to infer mechanisms governing interactions (FRDC #93/102).*

Study of the secondary effects of discards has been limited to video observations of underwater scavengers and stomach content analyses (eg. Wassenberg and Hill 1987), and to surveys of seabird nesting success and crop contents (eg. Blaber and Wassenberg 1989, Blaber et al. 1995). Use of dyed discards inside and outside of Gulf trawling seasons could aid gut content analyses of sharks to determine how much discards sharks are eating. Models could then be used to link consumption rates with size and age at first maturity and fecundity *of sharks to estimate enhancement of shark populations. This work may be considered in a new project being conducted by CSIRO (p.c.# 280 S.Blaber; FRDC #96/257).*

BOX 4.9.1. THE "EFFECTS OF LINE-FISHING" EXPERIMENT ON THE GBR -- STATE, PRESSURE AND RESPONSES IN THE FLEET, PREDATORS AND PREY POPULATIONS

The subject of a major multi-institutional experiment run through the Reef CRC in pursuit of a suite of harvest and management strategies with associated risks, for ultimate decisions on the Reef Line Fishery by QFMA/GBRMPA.

Background
Coral trout are valuable commercial, charterboat and recreational species with landings up to 1000 tonnes p.a. and the prospect of value-adding in the live-fish trade. They are also a top predator, whose removal may change other fish populations. An experiment was planned to refine both fisheries management and to test the way that multiple-use is zoned in the GBRMP. Coral Trout can be accurately and precisely counted independent of the fishery by Underwater Visual Survey.

Components
1) Document history of fishing and stocks (CPUE logs, oral history, fleet dynamics, prior research review)
2) Describe status of fishery and stocks from year to year (CPUE logs, catch and fishery-independent visual and biological surveys) and fisher attitudes and motivations
3) Measure directly the responses of fishery and stocks to changes in fishing pressure
- a) Monitoring before, during and after the Bramble reef (closed for 4 years) re-opening and
- b) pulse and press fishing in reefs zoned closed and open to detect response of coral trout and their prey

Design
24 reefs in the 4 major sectors of the GBRMP;
within each cluster of six reefs

- 2 control reefs that will remain closed for the duration of the experiment - to monitor and account for natural variation
- 2 "Green" experimental reefs - now protected, will be opened for line and spear fishing for **one year each**; will determine how effective seasonal or area closures are; will measure flow-on effects of fishing on prey and non-target fishes
- 2 "Blue" reefs - raising the level of fishing activity beyond present levels will enable study of response of stocks - closing them afterwards will provide information on recovery

Responses
Coral Trout are a high-level predator, therefore the experiment will be looking for response in abundance of prey species (such as Pomacentrids) and non-target species, as well as size/age and numbers of coral trout, through visual surveys. Close attention will be paid to the inverse relationships previously observed between adult coral trout abundance and juvenile (0+) abundance. This could be some evidence that fishing either
a) enhances recruitment from plankton, or
b) enhances survival of juveniles

Further Reading : Mapstone *et al.* (1997)

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BOX 4.9.2. THE CSIRO/QDPI "EFFECTS OF PRAWN TRAWLING" PROGRAM

This study in the northern Green Zone of the GBRMP focuses on Mid-Shelf Red-Spot King (*Penaeus longistylus*) trawl grounds, because the choice of "open" vs "closed" comparisons in the inshore part of the zone were confounded by illegal fishing. The sponge gardens in this area were found to exceed the area of hard coral reef.
The manipulations gained extreme accuracy (+- 5 m) using differential GPS. Prawn trawl effort is very aggregated -- 60% of the catch comes out of 10% of the area trawled in the Gulf of Carpentaria - so the experiment will incorporate much finer scale effects of aggregation of prawning effort.

- **year 1** most intensive set of inter-reefal benthos data for GBRMP
- **year 2** comparison of open/closed, bycatch, trawl gear comparisons
- **year 3 & 4** experimental simulations of impacts of prawn trawling on benthos, fish, prawns and bycatch
- **year 5** depletion experiment - different levels of trawl effort to assess rate of depletion of benthos by the trawl

1) Describe the area

- 10,000 square nautical miles inside the largest cross-shelf closure zone on the GBR
- at 100 random sites use fish trawl, prawn trawl, Church Dredge, video, diver and sediment grab samples.

One of the aims of this part was to find areas of commercial quantities of prawns that had never been trawled. Primarily red-spot kings, a very difficult task because with modern GPS trawlers can now shoot gear as little as 100 m away from reef.

2) Compare Blue and Green Zones (fish, prawns, megabenthos)

3) In areas found never to have been trawled, employ a BACI manipulation in 12 plots
- 6 controls + 6 treatment - 1nm by 2 nm, shallow and deep, by 2 seasons.
Used chaining or nets with differential GPS. Hit once in one season, repeated 6 months after, then 6 months after that, then 12 months after.

4) Monitoring, plus Depletion study

- *a) recovery of plots*.. depletion along one precisely defined track in 12 plots, repeated until significant decline in benthos; video before, monitor net catch during, then video after to monitor recovery
- *b) run video before/after*
- *c) use ROV over hard substrata*

Preliminary findings (March 1997):

- For many fish and sea bottom taxa the abundance is greater in the "closed" area than the adjacent "open" area, however the heterogeneity of species occurrence over the whole study area overshadows the detection of any major latitudinal patterns in species abundance
- the bycatch:marketed species ratio ranged from 9:1 to 12:1
- bycatch was dominated by small fish (50-70%), crustaceans and bivalves. The majority of fish are dead at the time of discarding and are taken by surface scavengers including some species of seabirds. Trawling has undoubtable, significant impact on bottom fish communities and potential flow on effects to scavenging populations
- a single pass of a trawl net can remove 5-20% of the sea bottom community and complete denuding of the sea bottom structure occurs after 10-13 trawl passes over the same area. In many areas of GBRMP where the frequency of trawling is at a relatively low frequency the 9mpacts of trawling may not be significant. However, there are many high intensity trawling areas where impacts would be extensive
- In prawn trawls, NO commercially or recreationally important species of reef fish were caught, which "confirms" previous work in the GBRMP

A new task has commenced to examine the rates and dynamics of sea bottom community recovery in an area where trawling had an effect but has now ceased.

Further Reading : Pitcher *et al.* (1997)

ISSUE 5:
Introduced and Translocated Pests and Diseases

5.1 Overview and FRDC role

5.1.1 The issues

The invasion of the Asian clam Potamocorbula amurensis in San Francisco Bay, the zebra mussel Dreissena polymorpha in the Laurentian Great Lakes and the comb jelly Mnemiopsis leidyi in the Black Sea are dramatic overseas examples of the catastrophic impact of ship-vectored introductions of marine pests. Fisheries and mariculture have collapsed in some instances and there seems little hope of eradication in some locations.

Introduced pests and diseases may pose the most important long-term threat to coastal ecosystems, and to the harvest industries located there. This is because they differ from all the other issues and impacts discussed in this review in three main ways:

- *the other human impacts are more or less localised and can generally be rehabilitated by removal of the source of a stressor, but pests and diseases spread widely to the limits of their physiological tolerances - often a very wide geographic range*
- *prospects for complete eradication appear to very poor, although R&D has been insufficient to explore all possibilities*
- *the ecological roles and impacts of invading species can only be partially predicted from knowledge of their biology and ecology in donor regions.*

A large number and wide variety of plants, animals and pathogens have been introduced into, or translocated amongst, Australian aquatic environments. Best-recognised are the spread of weeds and fishes in freshwaters, but of more immediate concern for the FRDC - in view of the relatively high value of coastal mariculture and fisheries - are the recently recognised ship-vectored introductions to temperate bays. These include toxic dinoflagellates (Gymnodinium and Alexandrium spp), Japanese kelp (Undaria pinnatifolia), Northern Pacific seastar (Asterias amurensis) and Mediterranean fanworms (Sabella spallanzani).

The European shore crab (Carcinus maenas) has a much lower profile in the popular media, perhaps because of the length of time it has been here (since the late 1800s) and its inconspicuous nature, yet some authorities (see Thresher 1997) suggest that this species could very well be Australia's most environmentally-destructive introduced marine pest. This exemplifies both the lack of knowledge of relative impacts and the control by the media of the discussion on risks, hazards and control opportunities. Ship-vectored introductions of ballast water or hull-fouling organisms are also present in the tropics, but have less of a media profile, and there will no doubt be further discoveries as port surveys progress in Australia.

Recurrent, toxic and nuisance algal blooms, and the potential for introduction of water-borne pathogens, have resulted in a public health hazard and millions of dollars in lost revenue for shellfish mariculture. Biotoxins causing paralytic shellfish poisoning (PSP), and to a much rarer extent amnesic shellfish poisoning (ASP) and diarrhetic shellfish poisoning (DSP), have been reported in Tasmania and Victoria when cultured shellfish are exposed to recurrent dinoflagellate blooms. Closures and loss of revenue have occurred at these times, and fish kills have resulted during the "red tides" in the Port River estuary of South Australia.

At the time of writing further algal and dinoflagellate blooms have occurred in Coffin Bay and Boston Bay near mariculture enterprises, but the general lack of knowledge of phytoplankton dynamics in Australia makes it difficult to distinguish natural and artificial "triggers". The poorly-known taxonomy of some dinoflagellates has also hampered separation of native and introduced taxa.

The human health risks associated with blooms and pathogens (see Chapter 3) produces a "halo effect" (p.c. #1300 G. Hallegraeff) that can depress all seafood sales. Disease in mariculture is a constant threat and a recent review concluded that the pathogens Aeromonas salmonicida (which causes furunculosis), infectious pancreatic necrosis virus (which causes infectious pancreatic necrosis), Myxosoma cerebralius (which causes whirling disease) and Renibacterium salmonarum (which causes bacterial kidney disease) are the greatest threat to Australia. The salmonids, prawns and oysters that comprise the majority of estuarine mariculture industry are the fisheries that would be most affected by such introductions.

A review of Australia's "disease preparedness" by Crane and Rawlin (1997) for the FRDC (FRDC#95/087) showed that

- *most of the States and Territories are now addressing legislative deficiencies*

- *there is a severe lack of resources at the levels of both policy development and operations in relation to aquatic animal health.*

Diseases and other pathogens may "cross over" into wild stocks and habitats. The most likely cause of the massive mortalities of pilchards in 1995 was from a novel Herpesvirus to which the Australian pilchard population was naive and whose origin was, therefore, most likely to be exotic (see Fletcher et al. 1997). Our informants mentioned the possibility of an introduction of the Rhabdovirus that has caused "right-eye" and "red spot" disease in barramundi and other NT fish since 1986. There is also an opinion that the Aphanomyces fungus associated with epizootic ulcerative syndrome (EUS) was introduced with aquarium fish before the 1970's (see section 2.2.1).

The Northern Pacific seastar has consumed cultured oysters and mussels and poses a threat to Tasmanian mariculture. The European shore crab is a voracious predator that poses a similar threat, particularly in its recent invasion of Tasmania, and there is concern that rack and line shellfish culture will be hampered by overgrowth with Japanese kelp and fanworms.

The Northern Pacific seastar and Japanese kelp have visibly altered the structure of soft-bottom and temperate reef habitats in some localised areas. Nearby are some of Australia's most valuable shellfisheries for abalone and rock lobster. These reefs lie in southern "nests of endemicity", and the starfish has been implicated in the decline of the spotted handfish - possibly the first extinction of a marine fish species (p.c.#1180 B.Bruce).

The fanworm competes for phytoplankton food with Port Phillip Bay scallops and other bivalves, is not eaten by fish - because of its very high vanadium content – and locally modifies water circulation, and possibly benthic denitrification processes and seagrass beds. It is known to use dead rhizomes from Posidonia dieback as a holdfast. Changes to the Port Phillip Bay habitat by fanworms have included depression of food consumption by fish in fanworm beds and enhancement of populations of the little rock whiting Neoodax balteatus.

In the Swan River the Asian mussel Musculista senhousii may displace Halophila seagrass, as overseas studies show that this mussel overgrows, out-competes and may displace seagrasses. The toxic alga Caulerpa scapelliformes may have a similar effect in Botany Bay. There has been spectacular overgrowth of Posidonia seagrasses in the Mediterranean by a hybrid of Caulerpa taxifolia and there is still a risk that this popular aquarium plant will be introduced to Australia.

The effects of other introduced marine taxa may be less visible, but no less profound—Officer and Parry (1996) found that the bivalve Corbula gibba and the crab Pyromaia tuberculata are now included in the 20 most important linkages in the Port Phillip Bay food web. This may have encouraged an expansion of the spiky globefish population in the Bay.

The New Zealand screwshell (Maoriculpus rosaceous) is now considered to dominate the shellfish biomass on parts of the Australian shelf, and has been implicated in declines of native shellfish, but studies and evidence are lacking. Food webs and sediment type may have been altered by the sheer abundance of this species.

Some of the marine pests are characterised now by relatively restricted ranges but have the potential, under known temperature and salinity tolerances, to invade vast areas of southern Australia. Others, such as the fanworm and European shore crab are widespread. There is obviously a clear need to reduce the risks of translocation of these pests amongst ports, particularly by the fishing industry. The New Zealand screwshell is present from the Great Australian Bight to southern Queensland.

The challenge for the FRDC is to invest in ways of identifying and managing the threats posed by these pests to mariculture and fisheries, in the context of broader endeavours by the Australian Ballast Water Management Advisory Committee (ABWMAC) and Centre for Research on Introduced Marine Pests (CRIMP). These other initiatives have focussed first on risk assessment and reduction of introductions and broad scale monitoring of invasions. Indeed, protocols must also be developed by the FRDC's stakeholders to help:

- *prevent their own industries introducing and spreading diseases and pests*
- *following best practises and developing secure procedures in translocating species across faunal provinces for aquaculture and preventing their escape*
- *following genetic best practises in translocating native freshwater fishes amongst drainages*
- *preventing and containing diseases arising in mariculture.*

There is also an existing or potential role for the fishing industry in reducing the abundance of some introduced and translocated pests, such as European carp (Cyprinus carpio), by harvesting and expanding markets. However, once an industry becomes reliant on pest stocks there is the risk that deliberate spread will occur and that there will be resistance to its eradication or depletion.

There is clear evidence that invasions by pests and diseases in freshwater are facilitated by habitat disturbance, but similar evidence is lacking for marine waters. The potential synergies between the issues of pest invasions and changes to drainage and habitat modification, nutrient and contaminant inputs, and possibly effects of harvesting and mariculture, should be considered by the FRDC in assessing the priorities for the "Ecosystem Protection Program".

In summing up the Australian Society for Fish Biology (ASFB) Workshop on effects of introduced and translocated fishes in Australia, Courtenay (1990) identified that:

- *there is a paucity of information on interactions between non-native and native fishes and their food webs and habitats*
- *there were often earlier or simultaneous alterations to habitats or other anthropogenic disturbances that may have facilitated the establishment of alien species*
- *introductions and translocations are primary or secondary forces in declines or other perturbations to native fish populations, in synergy with other disturbances*
- *molecular genetics shows that there are measurable differences between populations within species and translocations can alter the natural course of evolution, through hybridisation*
- *habitat modifications such as impoundments often result in demand for introductions of species that can tolerate these modifications*
- *Australia's impoverished and depauperate inland fish fauna makes it particularly vulnerable to aquarium fish introductions*
- *allowing for any non-native aquatic species into a nation under legislation is, in effect, approving its possibility of becoming a part of the biota of that nation.*

Our interviews indicated that these freshwater aspects have much relevance to the recent invasions of marine pests. For example, tannin loads in the Derwent River are suppressing dinoflagellate blooms through light attenuation, and periodic freshwater flushing gives tolerant natives a competitive "edge" over introduced species - yet proposed damming of such rivers will probably release the marine pests from such natural control mechanisms and allow further establishment.

Prospects for complete eradication of pests seem to be low but the research base has been inadequate. Similarly the lack of evidence of the impacts of many pests has been due to a lack of study of Australian aquatic ecosystems, particularly before and after pests become established. This weakness in the evidence, not the impacts, should not discourage investment *in R&D - research into the biology, ecology and spread of the pests is the major route by which techniques for managing and minimising the risks and hazards can be developed.*

The freshwater research has identified the need for integrated control and management methods based on knowledge of "weak" points in the invader's life-history. Narrow attempts at control , such as poisoning, may produce "weed by weed" replacements of invaders, but holistic manipulations of water regime, stocked predators and riparian vegetation may enhance native predators at the same time as reducing invaders. Weed and insect invasions are sometimes met by "fast-tracking" of approvals of new herbicides and pesticides, with unknown implications for receiving waters.

Yet not all introductions are perceived as bad - in a fisheries context they can be classified according to their "desirability" in this review as:
desirable

- *economically important and popular sportfish and mariculture species (eg. salmonids such as trout and Atlantic salmon)*
- *intentional introductions that have become locally important to mariculture or fishing, and are benign (eg. Pacific oysters in SA)*
- *intentional or unintentional translocations of native, freshwater, sportfish species outside of normal habitats or genetic ranges (eg. golden perch, silver perch, barramundi strains, murray cod, redclaw, marron).*

undesirable

- *ship-vectored introductions or species introduced unintentionally in the live-fish trade that have potential to dramatically alter ecosystem function and production from fisheries and mariculture (eg. cyst-forming dinoflagellates such as Gymnodinium catenatum, Northern Pacific Seastar, Japanese kelp, fanworms, Corbula, Maoriculpus)*
- *pasture grasses that are economically valuable to graziers but are serious weed pests when spread to aquatic systems (eg. para grass, Hymenachne)*
- *intentional introductions by the aquarium fish industry that can profoundly alter wetland processes (aquatic weeds eg Salvinia, Eichornia, Pistia) or have become established with unknown effects (eg. weather loach, tilapia, Oreochromis, poeciliids)*
- *introductions of woody weeds that profoundly alter riparian or floodplain structure and presumably function (eg. willows, Mimosa pigra, rubber vine, blackberries)*
- *intentional introductions that were perceived to have some economic benefit (eg. European carp, goldfish, redfin perch, tench, mosquito-fish)*

- *escaped, feral populations from mariculture (eg. Pacific oysters in northern Tasmania, Victoria and NSW).*

In this chapter we briefly summarise the "undesirable" marine and freshwater pests that threaten fisheries production and fisheries habitats, with recommendations for FRDC investment in Table 5.1.2 and a summary of the literature in Table 5.1.1.

The few early reviews of the subject (eg. Lehane et al. 1996, SOER 1996) highlight the following gaps in knowledge:

- *poor taxonomy and lack of baseline data of endemic and introduced biota*
- *lack of knowledge of range and rate of spread of invaders*
- *lack of knowledge of effects on fisheries and mariculture*
- *poor development of management options for existing pests*
- *"weak" monitoring and testing protocols for disease introduction*
- *a need to start exclusion of pests at the overseas source ports where ballasting occurs.*

Artificial spawning, rearing and stocking techniques have been refined in the last decade for major sportfish such as golden perch, Australian bass and barramundi. These advances and a rapid growth in impoundment sportfisheries have resulted in an increasing demand for restocking that has spread recently into "open" estuarine systems. Research on the stocking of open systems has expanded to include whiting (Sillago sp), dusky flathead (Platycephalus fuscus), mangrove jacks (Lutjanus argentimaculatus), grunter (Pomadasys kakaan) and mulloway (Argyrosomus hololepidotus).

Whilst there are certainly R&D opportunities to enhance impoundment fisheries there is a consensus of concern for the possibility of "genetic pollution" if best-practice is not developed and applied to stocking of open systems. The same concerns also apply to escape of large numbers of barramundi and other native species from aquaculture facilities during floods and other mishaps.

5.1.2 The literature

For the FRDC to gain the full knowledge of the threat of introduced pests and diseases it would be necessary to conduct a review of the growing body of international literature on overseas pests and diseases (see Carlton and Geller 1993 for general review). However, our brief was to examine only Australian information and literature in Table 5.1.1 has been selected from the (sparse) results of our searches in this area, on the basis of its relevance to *fisheries and mariculture harvests and habitats. It broadly reflects the way that research has fallen out into risk assessment and surveys to grapple with the scope of the threats, with lower initial emphasis on identifying and managing the impacts of the marine pests existing here now. The freshwater research is thin - but more evenly spread across sub-issues.*

This may be because of the relatively recent focus of attention on the coastal issues. Our literature searches found very few Australian studies of the effects of the main marine pests on ecosystems and harvests - especially compared to the issues outlined in other chapters. However, since the searches were completed there have been eleven technical reports from the Centre for Research on Introduced Marine Pests.

The literature in this area is sparse and new, including a handbook (Furlani 1996) and bibliography of introduced marine species (Furlani 1997) and a variety of studies pitched at different levels in the survey and sampling (eg. Hayes 1997), biology and dispersal (eg. Rainer 1995), impact and control areas of R&D opportunity. Comprehensive reviews of biology, demography and potential for control and eradication exist only for the European shore crab (see Thresher 1997). There have been studies of the early life-history critical for dispersal of the Northern Pacific seastar (eg. Bruce et al. 1995a) and some studies of control options for carp (eg. Grewe 1996).

Freshwater R&D on pests is moving toward "tweaking the system" through provision of environmental flows and restoration of riparian vegetation in integrated programs to reduce pests. A fishery for European carp and stocking of barramundi to eat tilapia are regional parts of this integrated approach that have benefits for the fishing industry.

University-based research is focussing on understanding the environmental processes producing monospecific algal blooms and on the survey methods for, and life-histories of, some pests at specific locations (eg. fanworm studies in WA, SA and Port Phillip Bay). Results and reviews are consequently not yet available. Research progress and overviews of priorities for R&D on Ballast Water Imports were summarised in Manning et al. (in press), Herfort and Kerr (in press), and Kerr (in press) supplied during a visit to Bureau of Resource Sciences in 1995, but we have not been able to update the sources of these references.

The value of studying natural dynamics, trophodynamics and life-histories at large scales and long terms - in contrast to single-species stock assessments - has been realised in studies of Port Phillip Bay food webs and fish communities (eg. Officer and Parry 1996, Hobday et al.

1996). A major spin-off has been the ability to detect effects of introduced fanworms, bivalves and crabs and thereby derive testable hypotheses for future experiments.

Definitive reviews of the biology, threats, control measures and R&D needs for weeds and other pests in freshwaters have been prepared by Finlayson et al. (1996) in the Scoping Review for the LWRRDC "Wetlands R&D Program". Despite the importance to fisheries of coastal tropical wetlands we found a surprising lack of research on the environmental effects of aquatic weeds and pasture grasses. In a review of the topic Lukacs and Pearson (1996) concluded that even basic information such as distribution, abundance or basic control options are non-existent. They report that major weeds such as water hyacinth, Salvinia and alligator weed have had only incidental study of their impact upon habitat. The ASFB published workshop proceedings on the issue of "introduced and translocated fishes and their ecological effects" in Australia (Pollard 1990). The dearth of marine literature in that document may reflect that not many fish species are transported in ballast water or on hulls, but it may also illustrate the recent nature of concern for, and rapid rate of spread of ship-vectored introductions.

Table 5.1.1. Summary of Australian literature on effects of introduced and translocated pests on fisheries and mariculture.

Pest/Issue	Effects on mariculture	Effects on fisheries habitats	Taxonomy, biology and ecology	Surveys of introduction and spread	Management Methods
Dinoflagellate blooms	Hallegraeff et al. (1988), Hallegraeff (1992a), Shumway and Cembella (1994), Parry et al. (1989b)		Cannon (1993), Furlani (1996), Hallegraeff (1987, 1992a,b, 1993, 1995, 1996), Hallegraeff et al. (1989, 1991)	Anon. (1992b), Hallegraeff and Bolch (1991), Hosja et al. (1994)	Arnott (1990a, b), Arnott et al. (1991), Reichelt et al. (1994), Rigby et al. (1993),
Seastars, molluscs, fanworm, crabs	Clapin and Evans (1995), Davenport and McLoughlin (1993), McLoughlin and Thresher (1994, 1997), Rees (1996), Winstanley (1996)	Clapin and Evans (1995), Hobday et al. (1996), Lewis et al. (1994), Officer and Parry (1996), Parry et al. (1995), Peterson (1994), Thresher (1997)	Bruce et al. (1995a), Clapin and Evans (1995), Furlani (1996), Oshima et al. (1989,1993), Thresher (1997)	Clapin and Evans (1995), Davenport and McLoughlin (1993), Rainer (1995), Thresher (1997)	Clapin and Evans (1995), Hutchings (1992), Thresher (1994b, 1997),
Algae	Rees (1996),		Furlani (1996)	Pollard and Hutchings (1990), Rainer (1995), Sanderson (1990), Sanderson and Barrett (1989)	
Weeds		Finlayson et al. (1996), Lukacs and Pearson (1996)	Finlayson et al. (1996), Furlani (1996)	Cowie et al. (1988), Finlayson et al. (1996)	Finlayson et al. (1996)
Introduced Fish		Arthington (Undated), Ault and White (1994), Finlayson et al. (1996), King et al. (1997), Lake (1994), Robertson et al. (1997)	Finlayson et al. (1996), Furlani (1996), Lloyd (1984, 1986, 1990a), Lloyd and Tomasov (1985),	Burchmore et al. (1990), Cadwallader et al. (1980), Pollard (1990),	Bluhdorn et al. (1990), Grewe (1996)
Diseases		Langdon (1990)	Wolf (1977)	Furlani (1996), Gibson et al. (1991), Herfort and Kerr (in press)	Crane and Rawlin (1997)
Translocated fish		Bell (1992a), Beumer et al. (1996), Sheridan (1995),	Keenan (1996), Russell (1996)	Hogan (1996), Russell (1996)	Cadwallader (1996), Rimmer (1996)

5.1.3 FRDC action

There have been a large number of peak bodies and Task Forces recently set up to organise R&D on the avoidance, study and management of pest and disease invasions. We have not been able to draw together their recommendations, but there is clearly a key role for the FRDC in filling R&D gaps in the areas of both reducing the role of industry in causing pest and disease spread, and reducing the effects of pests and diseases on industry, by:

- *determining the role of the fishing and aquaculture industries as a vector and source of exotic marine pests (eg. by vessel movements, intentional spread, live seafood shipments, bait and feed imports, escape of feral aquaculture species)*
- *developing codes of practice, technologies, education programs and other activities to reduce this role and avoid translocation and introduction of pests and pathogens*
- *liaising with international fleets and joint venture partners to ensure research is undertaken to reduce the risk of them introducing pests and diseases*
- *for new introductions deemed beneficial for aquaculture, encourage and if necessary support assessment of impacts on fisheries and aquaculture, in order to prepare impact mitigation strategies*
- *identifying the effects of existing pests on "wild" fisheries habitats and mariculture - a short-list of designated pests has been prepared by the Australian Ballast Water Management Advisory Committee (ABWMAC)*
- *developing cost-effective techniques (including industry "best practise") to minimise impacts of all introduced species assessed to pose threats to harvesting*
- *developing mariculture surveillance protocols and technologies to avoid hazards caused by toxic algal blooms and introduction and spread of pathogens (eg. continuous-recording water quality buoys, disease test kits).*

Close coordination with the national initiatives such as CRIMP, ABWMAC, LWRRDC and Environment Australia would serve the FRDC best in refining R&D priorities in this area, in ensuring that fisheries issues are included in their considerations and to facilitate effective use of FRDC funds. Further R&D on the aggravation of algal blooms by nutrients and effects of mariculture on the environment is outlined in Chapter 3.

The need to watch and prepare for disease introduction is crucial, but somewhat outside the scope of our review. Reviews of the subject are available in Crane and Rawlin (1997), Herfort and Kerr (in press), Humphrey (1995), Langdon (1990) and Munday et al. (1994)

The Land and Water R&D Corporation has prioritised the R&D needed to address the threats posed by aquatic weeds, woody weeds, pasture grasses, noxious fish and feral animals in its scoping review for the LWRRDC Wetlands R&D Program. These pests pose major threats to freshwater fisheries, Australian bass and barramundi in large parts of their range. Integration of the FRDC and the LWRRDC activities for these issues is essential to rehabilitate these fisheries.

We believe that there are R&D opportunities to expand and develop sportfisheries in impoundments based on stocked fishes. There is also demand to stock open estuaries and coastal lagoons (eg. mulloway in NSW, sand whiting and dusky flathead in Qld), but in all cases there is need to provide R&D on " best practice" in restocking and translocations to :

- *safeguard local genetic biodiversity*
- *develop genetic and physical tags to distinguish stocked fish*
- *develop appropriate brood-stock turnover rates*
- *assess appropriate stocking levels*
- *assess the risks and hazards of disease dispersal.*

Table 5.1.2. Summary of major opportunities for FRDC investment in addressing R&D gaps in knowledge of "Introduced and Translocated Pests"

R&D Gaps	*Key Threat*	*Main Habitats*	*Main Fisheries*	*Key Australian Reference*	*Initiatives*
Toxic dinoflagellate blooms and shellfish poisoning – the need for development of national biotoxin surveillance and bloom management protocols for mariculture	*Toxic and nuisance species of cyst-forming dinoflagellates*	*temperate bays and estuaries*	*Mariculture of shellfish and finfish in all States*	*Arnott (1990a,b), Arnott et al. (1991), Hallegraeff (1992a,b, 993,1995,1996)*	*Port Phillip Bay Shellfish. Sanitation Program., Tas, Shellf.Qual. Assur. Progr.*
Need for development of genetic and ecological "best-practice" in restocking impoundments and open systems	*inbreeding and genetic pollution*	*impoundments, disturbed freshwaters; SE Qld estuaries*	*east coast sportfisheries for translocated species (eg. catadromous bass and barramundi) ; estuarine barramundi, whiting, flathead*	*Benzie (1994), Rimmer (1996), Russell and Rimmer (1997), overseas references eg. Blankenship and Leber (1997)*	
Effects of introduced pests on fisheries — Assessment of threatening processes of key existing and potential introduced pests - strategic biological research for integrated management of the threat and tactical R&D to minimise impacts	*ABWMAC designated pests; aquatic weeds and pasture grasses; carp and tilapia*	*sheltered temperate coastal waters; disturbed freshwaters;*	*Tas., SA and Vic. shellfish culture; Tas. Abalone and Rock Lobster; Tas. Salmon culture; east coast freshwater sport and commercial fisheries*	*Bunn et al. (1996), Finlayson et al. (1996), Kerr (in press)*	*CRIMP, Environment Aust., LWRRDC Wetlands R&D Program, AQIS*
Potential for new, harmful introductions of pests and disease that endanger fisheries elsewhere (eg. Mnemiopsis, Pfisteria, Sargassum, Caulerpa)– what are the risks and hazards for Australia?	*Sheltered waters, diverse overseas taxa*	*All States; all waters, mainly enclosed waters near ports, freshwaters now*	*Shellfish mariculture; fish translocations for mariculture; big threat posed by aquarium industry imports*	*Herfort and Kerr (in press), Munday et al. (1994), overseas references eg Carlton and Geller (1993), Bellan-Santini et al. (1996)*	*ABWMAC, AQIS Ports and Diseases Study*

5.2 Ballast water and hull-fouling organisms -- ship-vectored threats to mariculture and temperate fisheries habitats

Recent recognition of the threats posed by dinoflagellate blooms and changes to ecosystem structure by introduced pests has sparked alarm over ship-vectored imports of fauna, flora and pathogens in ballast water or fouled on hulls.

The Australian Quarantine and Inspection Service (AQIS) is now the lead Commonwealth agency for the management of ballast water issues, including policy development, implementation of a strategic research plan, and quarantine operations.
A full summary of their activities can be found on the Internet at
http://www.dpie.gov.au/aqis/homepage/imadvice/bprogram.html

The Ballast Water Program which includes the Australian Ballast Water Management Advisory Council (ABWMAC) and Research Advisory Group (RAG) is administered by AQIS in Canberra. The Strategic Ballast Water Research Program has been developed and is being implemented by ABWMAC on advice from its Research Advisory Group. AQIS provides administrative support for the implementation of the
Research Program. The outcomes of the Strategic Ballast Water Research Program are central to the development of effective ballast water management policies. The Program is focused on the development of a risk assessment based Decision Support
System (DSS) as an effective ballast water management tool for AQIS and other relevant government agencies and port authorities.

The DSS will provide a sophisticated risk assessment tool for application to each vessel voyage, and will allow authorities to more effectively manage ballast water discharges from international and coastal vessels. The Research Program also examines the issue of hull and sea-chest fouling as a vector for harmful marine pests.

The Coastal Zone Inquiry (RAC 1993) focussed early attention on the problems and costs associated with marine pests and the Centre for Research on Introduced Marine Pests (CRIMP) was established in the CSIRO Division of Marine Research in 1994. The objectives of CRIMP are to:

- *develop and promote the application of techniques for earlier detection, more accurate prediction of impacts, and effective assessment of risks and costs associated with marine pest species introduced into Australian waters*

- *develop new methods or improve existing measures to control the spread and minimise the impacts of introduced marine pest species (CSIRO unpubl.)*

There is, however, less emphasis within the early priorities of both ABWMAC and CRIMP on management of the impacts of existing pests on fisheries and mariculture and these beneficiaries of such R&D will have to contribute an investment (p.c.# 1110 R.Thresher). We recommend a major role for the FRDC in this field – Kerr (in press) reports that economic costs due to toxic dinoflagellates alone may be around 200 million dollars over the next decade.

There have been a multitude of Australian initiatives and peak bodies with core business, or recently formed, to combat the threat of introductions. These include:

- *Biodiversity Group in Environment Australia (formerly ANCA) - live imports and management of aquarium fish trade*
- *AQIS - risk assessments for pathogen and live/dead imports of seafood products*
- *Harmful Algal Bloom Task Force*
- *National Seastar Task Force*
- *Australian Shellfish Sanitation Advisory Committee*
- *National Taskforce on Imported Fish and Fish Products*
- *the Task Force on Managing Incursions of Exotic Pests, Weeds and Diseases*
- *Working Party on Aquatic Disease Preparedness Assessment.*

The International Council for the Exploration of the Sea (ICES) has an international focus of several working groups on the threat of pest and disease introductions.

It was beyond our resources to identify and compile the R&D recommendations of all these bodies for the purpose of this scoping review. A first step for the FRDC in investing in this area would be to align its priorities with the activities of these groups.

5.2.1 Toxic and nuisance dinoflagellate blooms - a threat to mariculture

The problems associated with algal blooms have been reviewed in detail by Hallegraeff (1993, 1995) and are discussed in section 3.3. The major pest is the toxic dinoflagellate Gymnodinium catenatum, but several other species of Alexandrium may also have been introduced.

5.2.2 Marine pests that alter ecosystem structure

The reviews of information on marine pests by Furlani (1996, 1997) show serious gaps in knowledge of pest ecology, dynamics of invasion and effects on fisheries and mariculture, and with the sparse literature at hand for the Australian situation we could not rank pests relative to one another. In the SOMER reports Lehane et al. (1996) indicated that fanworms, Northern Pacific seastars, and Japanese kelp pose the greatest long-term threat to benthic communities, but this is disputed by CRIMP and may reflect more their media profile than their impacts.

Information from CRIMP suggested that the main pests threatening benthic communities in Australia are the European shore crab, the New Zealand screwshell, the Japanese kelp, and a hybrid of Caulerpa taxifolia that may not yet have reached Australia.

Freshwater studies of "invasion ecology" suggest that habitat disturbance is the key to allowing invaders to become established at a site. However, some marine pests such as Japanese kelp and European shore crabs are known to become well established and spread in apparently healthy benthic communities. Once pests become established, there is a high risk that the fishing industry itself may transport them to new locations (p.c.#1110 R.Thresher), for example:

- *fanworms are known to foul hulls in ports*
- *at least 12 species of phytoplankton can survive inside the valves of closed shells (eg. oysters) in the "live water" fish trade*
- *Japanese kelp may have been transported on gillnets and anchor lines amongst Tasmanian rocky shores, perhaps by abalone fishermen in the case of a recent outbreak*
- *seawater used in live fish shipments could potentially contain seastar larvae.*

The Fanworm Sabella spallanzani

Sabella spallanzani is a native of the Mediterranean. The worms are about 20 cm long and live in flexible tubes up to 50 cm long. They settle on hard substrata, such as pilings, but can anchor onto shells and rocks in sand and soft sediments. New recruits then settle on these colonisers to form very large, dense colonies. High vanadium (350ppm) levels in their tissues make the worms inedible to fish (p.c.#1050 A. Longmore), and there is evidence that they have a well-developed capacity to regenerate damaged body parts, so dredging is not a control option (Clapin and Evans 1995).

Fanworms are very fecund broadcast spawners. Spawning occurs annually and the larvae are lecithotrophic with a duration of less than 2 weeks. Settlers die after exposure in the intertidal – the fanworms prefer sheltered, subtidal environments. They have a wide depth distribution, governed by wave energy, and they are found in depths below about 1 m in calm conditions and below about 3-4 m in exposed conditions in WA (p.c.# 1350 R.Lavery), to at least 18 m (Clapin and Evans 1995).

Seagrass dieback in Cockburn Sound and Port Phillip Bay may have helped fanworms to become established as they are known to use the remnant rhizome mat as a holdfast. The fanworms then overgrow the former habitat of seagrass in some areas and the standing stock of epiphytes and epifauna is actually greater than on seagrass (p.c.# 1350 R.Lavery).

Fanworms were first recorded in Port Phillip Bay (in Corio Bay) in 1988, then spread rapidly to a patchy distribution throughout 30% of the bay waters. They are altering the epifaunal substratum and the levels of turbulence there. Only the weedy "whiting" Neoodax balteatus settles in Sabella as a juvenile, and there are indications that this species has become more abundant in Port Phillip Bay. There is good evidence that fish feeding success is significantly lower in regions of the bay colonised by worm beds (see Hobday et al. 1996).

There are also serious concerns for the effect of the fanworms on the benthic bioturbation and denitrification cycles (see Bird 1994) that are critical in the assimilative capacity of the bay for sewage nutrient inputs. Bioturbation extends down to at least 50 cm within the sediments there, and there is a very high risk that overgrowth by dense, monospecific stands of fanworms could disrupt the processing of nutrients within this oxic layer. This hazard is unknown, but presently under study (p.c. #1050 A. Longmore), and was identified as the greatest threat to the health of the bay by the Port Phillip Bay Environmental Study. The fanworms also filter out thousands of tonnes of phytoplankton and are thought to be competing with scallops and cultured mussels for food (p.c.# 960 M. Holloway).

In Western Australia the fanworm is well established throughout Cockburn Sound and in the harbours of Fremantle, Bunbury and Albany. In Cockburn Sound patches of the fanworm attached to shell fragments covered approximately 20 Ha of shallow sandbank (3-6m depth) and are clearly visible in aerial photographs, having existed there for at least 10 years. Elsewhere in the Sound the fanworm apparently prefers to attach to artificial substrata in the form of pier pilings, breakwaters, wrecks and navigation markers. The fanworm has been *translocated on the hulls of dredges and other vessels within and amongst locations in WA (Clapin and Evans 1995).*

A preliminary study found little evidence of direct impact of the fanworm on the fishing and mariculture in Cockburn Sound. This may be partly because most of the important commercial fisheries there are offshore and rely on pelagic planktivores. There is obviously a more severe threat to the Victorian and South Australian bay fisheries that employ haul-seines to catch King George whiting, sea garfish, southern calamari and other species amongst the shallow, patchy seagrass areas to which the fanworm may ultimately spread.

The Northern Pacific seastar - Asterias amurensis

This seastar poses serious threats to mariculture and wild mollusc fisheries in Tasmania (and perhaps Victoria) because of its local density and predatory habits. There is an intensive research effort at CRIMP on predicting and measuring its potential distribution, its dietary preferences and rates of consumption and developing management methods for shellfish farms (see Davenport and McLoughlin 1993, Furlani 1996).

At the time of writing, Asterias was restricted in its distribution and had not yet seriously affected shellfish farms. There are very high densities in the Derwent estuaries (estimated at about 27 million by CRIMP), and their rate of spread has not matched predictions from hydrodynamic transport models. The larval biology has been investigated by Bruce et al. (1995) and future modelling of dispersal will incorporate different scenarios in larval behaviour, such as diurnal migration, and preferential distribution near the surface and seabed (p.c. #1170 S.Walker).

The larvae are certainly dispersed widely -- Asterias benthic recruits are being found in scallop spat collector bags in Mercury Passage -- but no post-larval stages have been seen on the seabed in that region. The roles of settlement cues, competition and predation are unknown, but are being studied by CRIMP and at the University of Tasmania (p.c. #1260 G. Edgar).

A single individual of Asterias amurensis was found in Port Phillip Bay in 1994, and there is concern that this pest and the introduced Astrostole scabra starfish (up to 1 m wide) from New Zealand will prey on abalone (p.c. #1080 H. Gorfine).

Introduced algae - Undaria, Codium and Caulerpa

The Japanese kelp Undaria is an annual species that grows very rapidly and shades other native algae. In only ten years, Japanese Kelp has spread four kilometres along Tasmania's east coast. Thousands of plants up to two metres tall grow on bare rock to a water depth of eight metres. It may be impossible to eradicate this weed once it is established. It needs open spaces or a substratum of coralline algae to recruit and grow. It provides a good food source for abalone – but only in summer - and dies back in winter. Other macroalgal species have been displaced in the meantime. There is consequently great potential for such forcing to modify interactions amongst herbivores and algae that produce urchin "barrens" habitat (see section 4.5.1). The distribution of the Japanese kelp has been documented by Sanderson (1990) and Sanderson and Barrett (1989) and studies of some of the ecological effects of this pest are underway at CRIMP, the University of Tasmania and the Victorian Institute of Technology. It spread to Victoria from Tasmania during the drafting of this review.

Beds and "gardens" of Caulerpa scapelliformes occur in Botany Bay and throughout the Sydney region and there is concern that this alga will displace seagrass - it is inedible to fish and was translocated from South Australia (p.c. #610 A. Larkum). Introduced species include Caulerpa racemosa and C. filiformis. Green algae in the genera Caulerpa and Codium pose major threats to Australian ecosystems (especially those supporting the rock lobster and abalone fisheries), and a very high priority for the FRDC and its stakeholders should be to keep them out of our waters.

In the Mediterranean a hybrid of Caulerpa taxifolia has invaded from an initial patch of 1m^2 to over 3000 Ha and there has been extensive overgrowth of the seagrass Posidonia oceanica by chemical and physical competition. Chisholm and Jaubert (1997) attribute its spread in less than a decade to:

- *abnormal size and growth rate*
- *strong chemical defence against herbivory and epiphytic overgrowth*
- *efficient vegetative propagation*
- *enhance tolerance of winter minimum seawater temperatures*
- *an ability to colonise widely varying substrata*
- *efficient absorption, conservation and internal recycling of nutrients*
- *peak frond length and productivity in autumn when the biomass of native species is at a minimum.*

These properties allow it to grow in depths of at least 99m, in densities of 350 m of fronds and 14,000 leaves m^{-2} and to out-compete seagrass and shallow-water macroalgae. No doubt these same properties also endear it to marine aquarists, as this hybrid (reportedly bred as Caulerpa "prolifera") is sold widely in the international marine aquarium trade, and we believe there are high risks that it will reach Australia by this route (if it has not already). Vigilance is essential and CRIMP has advised AQIS of the problem.

Bellan-Santini et al. (1996) reported that it was still too early to formulate relevant conclusions about the impact of the alga on Mediterranean benthic faunal communities, although abundance of molluscs and crustacea (important fish food) were lower at infested sites when compared with reference sites. Monitoring is being continued to determine if the observed patterns of species richness represented stable or regressing benthic communities of invertebrates amongst the algae.

There is also potential for introduction of Sargassum nudicum – an invasive self-fertilising hermaphrodite that forms large rafts of drift algae in Europe and the Mediterranean (p.c. #530 N. Andrew). This spread first by escape from mariculture enterprises.

Other introduced marine species

The predatory activities of the European shore crab Carcinus maenas have destroyed mussel fisheries in parts of the USA and threaten Tasmanian shellfish farms. This pest is the focus of research on demography, impacts and possibilities for biological control by CRIMP. The workshop on these issues held by CRIMP (see Thresher 1997) provides some important messages that may apply more generally to the pests in Australia:

- *surprisingly little was known about the ecology of the species in its native range*
- *even in areas where the species is perceived to have had a large impact, data supporting this conclusion are sparse*
- *the spread of the species and the decline in some overseas bivalve fisheries has been simultaneous, but climatic changes, overfishing and other environmental disturbances have also occurred and confound historic comparisons*
- *range may not be readily explained by physiological tolerances and dispersal ability*
- *rapid and recent changes in distribution may be due to climatic change (eg. to Tasmania in a general response to a climate-induced shift in biogeographic provinces)*
- *regional differences in impacts, demography and behaviour - eg. major impacts perceived on bivalve and crab populations in Tasmania , but only slight impact (and lower densities) in Victoria and Tasmania*

- *the prospect for physical removal of the pest is attractive, but depends on a trade-off between effort and effectiveness*
- *establishing a fishery for the crab is superficially attractive, but once an industry forms its reliance on viable populations may cause resistance to eradication attempts or decimation of the population*
- *there are several options for biological control, but discussion of their prospects focussed on safety, effectiveness and the information needs to assess both.*

The workshop also defined a number of priorities and opportunities for R&D, including study of the range expansion of the crab to construct "before-after" contrasts to assess and identify impacts.

Mention is also made here of other pests identified by our informants. The brevity does not reflect their threat to fisheries, but rather the lack of study and evidence of impacts.

On the shelf grounds of the SE fishery the New Zealand screwshell Maoriculpis rosaceous is rapidly spreading and occurs in densities over 1000 per m^2 in depths down to at least 50 m. It reportedly appeared first in the Derwent River and spread north to southern Queensland and west across the Great Australian Bight. It reportedly came from the live trade in oysters across the Tasman (as did the seastar Patiriella), and is a nuisance for scallop fishermen. It has been implicate by CRIMP in the demise of native shellfish and is routinely washed off the decks of scallop vessels and some trawlers in port. It has risen in abundance over the same 50 year time frame in which several species (see section 4.5.2) have declined in the SE fishery, but there is no knowledge of the links between these events.

Introduced crabs Pyromaia tuberculata and the bivalve Corbula gibba now form important parts of the diet of fishes in Port Phillip Bay, and may have encouraged a rise in the population of the spiky globefish (see Officer and Parry 1996). In San Francisco Bay a related bivalve Potamocorbula invaded and evidently suppressed the spring bloom by filter-feeding, causing larval fish to starve and local fisheries to collapse (p.c.#1110 R. Thresher).

5.2.3 Disease

A review of the threat to fisheries habitats by introduced diseases was somewhat beyond the expertise and resources of the review team. However, the mass mortality of pilchards in autumn 1995 demonstrated that the threat of disease to fisheries ecosystems is a major one, not necessarily confined to monospecific, high-density culture of aquatic organisms. This event *also focussed attention on the very large volumes of frozen feed and bait that are imported for the fishing and tuna-ranching industry. For this reason we have made an attempt to review some of the current issues here.*

Herfort and Kerr (in press) developed a simple methodology – based on the rationale that high impact and high risk implies high threat - that took the "seriousness" rating from previous studies of pathogens, and the number of vessel visits, to rank the threat posed by various fish pathogens presently unidentified in Australia. This was based also on the premise that the amount of contact by ships between ports is a crude indicator of the relative risk of organism introduction by this means, but not necessarily establishment.

Japan had a 2 in 3 chance of being the source of any exotic fish pathogen introduced during 1991, as 41% of all shipping came from there and 16 fish pathogens are known to inhabit the region. The Asian region in general had a chance 9 times that of the rest of the world combined due to the origin of ships and the number of endemic pathogens.

The study concluded that the pathogens Aeromonas salmonicida (which causes furunculosis), infectious pancreatic necrosis virus (which causes infectious pancreatic necrosis), Myxosoma cerebralius (which causes whirling disease) and Renibacterium salmonarum (which causes bacterial kidney disease) are the pathogens of greatest threat to Australia (see DPIE 1996). The salmonids, prawns and oysters that comprise the majority of estuarine mariculture industry are the fisheries that would be most affected by such introductions, but a third group of small baitfish that contribute to food chains are also at risk.

The major recommendations were to:

- *develop a testing protocol to detect pathogens at an agreed level*
- *apply this protocol to ports under risk of introduction*
- *conduct studies of the environments of "infected" overseas ports with the Australian ports at risk of receiving infected ballast water*
- *quantify the risk of translocations between domestic ports*
- *establish a system to link high-risk source ports with high-susceptibility points of discharge - eg bays near mariculture facilities*
- *establish biological sampling of high-risk ports overseas to confirm the presence of the suspected pathogens*
- *establish ship-board ballast water/sludge monitoring of pathogen presence form high-risk ports*

- *encourage ballasting overseas at points far from sources of pathogens, such as fish processing or mariculture facilities*

Further research was recommended to better understand the factors involved in the introduction/establishment process, and to develop comprehensive inventories of existing and planned mariculture facilities in Australia to be pro-active in assessing risks. Hayes (1997) has provided a review of ecological risk assessment methodologies.

The threat of cholera (Vibrio cholerae) introduction is also a real threat to mariculture, as spores have been recorded in ballast-water sediments transported from South America to the USA. The ABWMAC has commissioned a study of this threat (see http://www.dpie.gov.au/aqis/homepage/imadvice/b9697rsch.html) to :

- *conduct a literature review (including a review of the North American evidence) to assess the potential for Vibrio cholerae to survive translocation in ships' ballast water, examining the effect of factors such as temperature and salinity tolerances, voyage duration, association with copepod skeletons, phytoplankton and other hosts*
- *evaluate possible ballast water treatments and their impacts on cholera, with reference to lethal temperatures and biocide concentrations (eg. hydrogen peroxide, chlorine, heat treatment of ships' ballast water*
- *describe existing methodologies available and their effectiveness for monitoring cholera in ballast water and seafood products, including the distinction between toxic and non-toxic serotypes.*
- *outline Vibrio cholerae's global and Australian distribution to identify its potential for both domestic and international translocation and for the establishment of cholera in Australian waters. Review the lessons learned from the history of past pandemic outbreaks*
- *determine to what extent the principles relating to cholera apply to other exotic bacteria of public concern such as those responsible for fish farm diseases and botulism*
- *undertake scientific trials (laboratory, simulated or on board) to determine the lethal temperature and incubation conditions of V. cholerae.*

This range of objectives shows the focus of ABWMAC research projects on risk assessment and management. There are opportunities for the FRDC to aid ABWMAC in developing these measures, as well as taking a lead role in identifying impacts of existing pests and diseases on industry and ways to reduce them.

In 1995 there was an unprecedented, mass mortality of pilchards (Sardinops sagax) spanning the entire 6000 km range of the species. Griffin et al. (1997) have reviewed the physical an biological factors associated with the mortality and quite confidently rejected environmental stress as a causative agent. They could not reject the hypothesis that an introduced pathogen was responsible, and discounted the likelihood that fish-to-fish contact, ocean currents or ballast water were vectors - leaving predators (eg. seabirds, dolphins, predatory fish) as remaining candidates for vectors.

Fletcher et al. (1997) were stronger in their conclusions - "the most likely cause of the massive mortalities of pilchards in 1995 was from a novel Herpesvirus to which the Australian pilchard population was naive and whose origin was, therefore, most likely to be exotic".

There was an early suspicion that the Herpes-like virus that was the aeteological agent was introduced in imported, frozen Californian pilchards fed to southern bluefin tuna in fattening pens in Port Lincoln. Over 10,000 tonnes of pilchards were imported for this purpose in 1995. Humphrey (1995) warned that the importation of bait and feedfish "constitutes a high risk of introducing exotic pathogens" with the risk escalating when importing, and using in an untreated state, hosts (species) that are also present in Australia.

The issue highlights the possibility of future disease introduction in bait and mariculture pellet food. The sources and consumption of frozen bait from overseas are widespread – in the order of tens of thousands of tonnes annually. This ranges from regular use of Scomber japonicus by Japanese longliners in all waters of the EEZ where they are permitted to operate to imports of clupeids for rock lobster bait in WA and squid for the angling bait market in all States. Fish meal is imported for use in local pellet food manufacture, but imported pellets may carry viruses. The National Taskforce on Imported Fish and Fish Products is reviewing the protocols needed to manage these imports safely.

"Epizootic Ulcerative Syndrome" (EUS) first broke out amongst all age classes of Northern Territory barramundi in 1986. There were many fish killed from a variety of freshwater species and the syndrome was attributed not to water quality implications, but rather a Rhabdovirus. However, Pearce (1990) notes that that while Rhabdovirus-like particles have occasionally been found in lesions their role in EUS is unclear since they have never been isolated. We could find no record of whether the virus was introduced or endemic, and other informants suggested that the Aphanomyces fungus was also involved.

The EUS is now restricted to mainly barramundi. For example, in Corroboree billabong rates of ulceration were 54% in 1993 and 11% in 1994. In 1986 all age classes were dying but now 0+ juveniles are the only ones infected and the survivors grow to maturity. There is also variability in infection rates amongst billabongs. Quite a few of the older survivors have only one remaining eye - giving rise to a local name of "right eye disease" (p.c. # 1670 R. Griffin).

5.3 Translocated fishes and introduced pests in lower catchments

The R&D priorities for introduced pests in wetlands have been prioritised for the LWRRDC by Finlayson et al. (1996) and we have summarised their findings in Table 5.3.2.

5.3.1 The role of habitat disturbance

The culmination of decades of research on major freshwater pests has seen a recognition of the role of habitat disturbance in allowing pests and weeds to become established in catchments (see Arthington et al. 1983, 1990). A similar role is proposed for disturbances in our major ports and harbours (eg. dredging, pile driving) in allowing establishment of the newly recognised pests from ballast water introductions (p.c.# 1110 R. Thresher), but other scientists argue that "disturbance" is confounded with "shelter" in such comparisons.

Arthington et al. (1990) found that the reviews of effects of introduced fishes in Australia generally did not give sufficient attention the significance of habitat disturbance - and that significant R&D opportunities exist for pest management through integrated habitat restoration and enhancement. Habitat disturbances associated with successful establishment of introduced fishes most often occur in combination and lead to general degradation of habitat, loss of specific habitats or reduced habitat heterogeneity. These disturbances act also to threaten native species (see Pollard et al. 1990 for overview) and are listed in Table 5.3.1.

Table 5.3.1 Habitat Disturbances and their possible roles in establishment and transfer of introduced pests in freshwaters.

DISTURBANCE	POSSIBLE MECHANISM	EXAMPLES	REFERENCES
1. impoundment causes changes in the seasonal distribution of river discharge; flood amelioration; long-term trends towards reduction of average flows in the middle and lower reaches of rivers	• creates a more pool-like environment in and below dams that favours aquatic macrophyte growth and species preferring weedy, slow-flow, lentic habitats • removes the floods that periodically remove introduced species	European Carp, Redfin Perch, Tench, mosquito fish (Gambusia); Oreochromis mossambicus	Arthington et al. (1990), Bluhdorn et al. (1990), Lake (1994), Lloyd (1984), Pollard (1993a), Pollard and Burchmore (1986),
2. diversion and channelisation of rivers	• sudden changes in water level kills eggs of littoral spawners • inter-basin transfer spreads pests • loss of pools and habitat diversity	redclaw may have been spread by this means: Tilapia may reach Gulf drainages via new population in Lake Tinaroo	Davies et al. (1992), p.c. A. Webb
3. loss of riparian vegetation	• allows entry of C_4 plants that smother waterways, change food webs		Bunn et al. (1996, 1997),
4. bank erosion and sedimentation; desnagging	• niche compression may render native species unable to compete with introduced species		Ault and White (1994), Bales (1992), Burchmore et al. (1990),
5. thermal and chemical pollution	• heated waste-waters from power plants harbour warm-water • tolerance of low O_2 favours survival of Gambusia and Oreochromis in urban drains • pesticide resistance favours some populations of Gambusia	cichlids and poeciliids in temperate rivers	Cadwallader et al. (1980),
6. the presence of introduced plants (eg. Para Grass, Hymenachne, Salvinia, Eichornia, Pistia)	• shelter from Barramundi and other predators in Para Grass and amongst water hyacinth • introduced herbivores eat epiphytes or plants themselves • reduction of microhabitat diversity and niche compression of native fishes	Oreochromis and Tilapia mariae , poeciliids (eg. Poecilia reticulata and G.holbrooki)	Russell et al. (1996a,b), Beumer et al. (1996), Cowie et al. (1988), p.c. A. Hogan

5.3.2 Translocated fishes

In the past decade there has been a great advancement in development of techniques to artificially spawn and rear the young progeny of a variety of marine and catadromous species. The demand for this R&D may have come first from mariculture interests (eg barramundi, mangrove jack, snapper and mulloway), but more recently from recreational fishing interests for Australian bass, dusky flathead, sand whiting (Sillago ciliata), grunter (Pomadasys kakaan)to be stocked in "open" systems (see Palmer 1995 for review).

This translocation and restocking of fish is accompanied by a variety of risks and hazards associated with genetic "pollution" of local stocks, consumption of forage species, competition with other species, and spread of disease (eg Benzie 1994, Kearney and Andrew 1994, Langdon 1990).

The risk of inbreeding, or swamping of local gene pools with recessive alleles, is greatest when stocking occurs in small breeding populations with distinct genotypes. Such scenarios could easily occur with local strains of Australian bass and barramundi (see Sheridan 1995, Keenan 1996 for reviews). In the case of barramundi there are many difficulties for hatcheries to rotate brood stock - repeatedly obtaining permits to take brood fish in closed seasons presents problems, brood males quickly develop into females under the favourable conditions of captivity, and brood fish are large animals that require large facilities if they are to be kept in high numbers.

Aside from the genetic implications there are poorly known effects on the Australian environment of translocating large populations of "top" predators such as barramundi or burrowing benthic carnivores such as redclaw, yabbies and marron (eg. Kearney and Andrew 1994). The issue of disease dispersal with such translocations is also a considerable risk and hazard with recorded episodes in Australia (see Langdon 1990 for review). There is an opinion that the Aphanomyces fungus present in the lesions of fish suffering from epizootic ulcerative syndrome (EUS; see section 2.2.1) was introduced into Australia with goldfish in the aquarium trade during the 1970's (p.c. I. Anderson, QDPI Oonoonba Veterinary Laboratories, November 1997).

Harris and Battaglene (1990) indicated also that policy development and implementation was made difficult for translocations of freshwater native fish because of :

- *the many established precedents*
- *the economic significance and varied standards of our numerous fish farms and hatcheries*

- *the paucity of Australian studies identifying and extending knowledge of specific problems*
- *the ill-founded public popularity of fish stocking as a panacea for freshwater fisheries management problems in general.*

The last point is especially pertinent to the situation prevailing now in the face of increasing demand for stocking of open estuarine systems (see Tait 1996).

In reviews of the subject, Blankenship and Leber (1995, 1997) do not dwell on the risks and hazards, but instead provide the following ten points as a "responsible approach to marine stock enhancement":

1. *prioritise and select target species for enhancement*
2. *develop a species management plan that identifies harvest opportunity, stock rebuilding goals, and genetic objectives*
3. *define quantitative measures of success*
4. *use genetic resource management to avoid deleterious genetic effects*
5. *use disease and health management*
6. *consider ecological, biological and life-history patterns when forming enhancement objectives and tactics*
7. *identify released hatchery fish and assess stocking impacts*
8. *use an empirical process for defining optimum release strategies*
9. *identify economic and policy guidelines, and*
10. *use adaptive management.*

Whilst advances have been made in implementing many of these points (eg fish marking: Willett 1993,1994, Russell and Rimmer, 1997), we could find no studies of the effects on ecosystems of the restocking programs in Australian inland waters and estuaries. There is clearly a lead role for the FRDC to help develop various aspects of "best practice" in Australian restocking programs.

5.3.3 Noxious aquatic macrophytes, woody weeds and pasture grasses

There are major threats to the sub-tropical and tropical coastal wetlands by woody weeds (eg. Mimosa pigra and rubbervine Cryptostegia), aquatic weeds (eg. Salvinia molesta and Eichornia crassipes) and pasture grasses (eg. para grass, Hymenachne). There is surprisingly little knowledge of their effects of ecosystems (Finlayson et al. 1996) - despite their abundance and rate of spread.

For example, Mimosa pigra is an aggressive prickly shrub that can form dense monospecific stands on the floodplains of northern Australia. At present it is confined to the coastal floodplains of the Northern Territory in an arc extending from the Moyle River in the west to the Arafura Swamps in Arnhem Land. It covers an estimated 80 000 Ha. It is a prolific producer of seeds that are readily dispersed by water, vehicles and animal vectors. However there is no knowledge of its effects on barramundi nurseries.

The aquatic weeds Salvinia molesta, water hyacinth Eichornia crassipes and Pistia (water lettuce - translocated from natural populations in NT) form rafts that completely block light, heat and oxygen flux in north Queensland barramundi nurseries – and also form support for the horizontal extension of introduced pasture grasses (para grass Brachiaria muticum and Hymenachne spp).

This allows complete overgrowth of small wetlands and channels in the space of several seasons. Electrofishing surveys in Herbert River floodplain lagoons have found differences in the proportions of 0+ and 1+ barramundi juveniles. In some Cattle Creek wetlands where weeds are overgrowing lagoons each season the juveniles recruit but die within the year during cessation of flow. The dieback is caused by overgrowth of weeds and then anoxia as the weeds decompose after being overturned in flood events.

Salvinia molesta has invaded some billabongs in Kakadu National Park in the past decade. An attempt at control of this weed by the Australian Nature Conservation Agency pulled out several thousand tonnes of Salvinia from Island Billabong on the Magela Creek Floodplain. Barramundi existing there at the time were in poor condition (p.c.#1670 R. Griffin)

Para grass was introduced as "improved pastures" in 1880 and Hymenachne amplexicaullus was introduced in the early 1980's. Both can grow in >=2 metres of water and are replacing native sedges. Invasions of both pasture grasses have clear interactions with destruction of riparian vegetation. Para grass is now a major weed in disturbed stream channels in northern NSW, Qld and the wet-dry tropics - but is still being promoted as an improved pasture grass (see Bunn et al. 1997).

Bunn et al. (1997) were the first to examine the effects on aquatic food webs of invasions of para grass, in comparison to sugar cane and riparian trees. There is high primary production by para grass, but very little of this is transferred into the aquatic food web, either directly through herbivory or indirectly through a detrital pathway. Sugar cane was found not to be *contributing at all. These findings were consistent with previous studies that C_4[1] macrophytes play a relatively minor role in aquatic food webs despite their major contribution to primary productivity.*

The only contribution of para grass production was through terrestrial prey (eg. insects, frogs) to snakeheads (Ophieleotris aporos) and the eel Anguilla reinhardtii. In-stream primary production appears to form the basis of the food web supporting invertebrates in wet-tropics creeks. Highly productive, inconspicuous epiphytes (eg. on macrophyte stems) are probably most important.

Restoration of riparian vegetation would provide C_3 carbon for benthic detrital food webs and arthropod prey for fish—shading is seen as the only long-term solution to para grass spread rather than mechanical and chemical control. These temporary measures invariably result in re-invasion or weed-by-weed replacements in riparian zones.

Without control para grass will continue to contribute to water quality problems by :

- *high rates of respiration in detritus*
- *efficiently trapping sediments and destroying benthic habitats*
- *reducing channel capacity*
- *sheltering tilapia and making them unavailable to large fish predators such as barramundi and sooty grunter.*

Simple removal may also cause serious downstream problems. Bunn et al. (1997) estimated that for one creek alone sediments trapped in amounts of about 20 000 tonnes km^{-1} will be released when para grass is lost. However, cane-land streams cannot be viewed as a permanent store for sediments - as high-discharge events inevitably will lead to scouring of channels and associated discharge of sediment and high plant biomass. These conflicting issues emphasise the need for an integrated management of river systems and their receiving waters, and some of these needs are reflected in the R&D recommended to the LWRRDC in Table 5.3.2.

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[1] C_4 and C_3 refers to how plants fix carbon from the atmosphere into plant tissue. C_4 plants, like salt marsh grasses, utilise the c4 pathway in which oxaloacetic acid (OAA), a 4 carbon compound, is produced in the dark photosynthesis reactions. In contrast, mangroves and phytoplankton utilise C_3 photosynthetic biochemistry, in which phosphoglyceric acid (PGA), a 3 carbon compound, is produced in the dark reactions. C_4 plants have a specilized leaf anatomy that maximises internal CO_2 concentrations, thereby allowing the plant to maintain a higher rate of photosynthesis at higher temperatures and at stronger light intensities than C_3 plants. All woody plants are C_3 plants.

Table 5.3.2. Summary adapted from Finalyson et al. (1996) of priority pest species in the LWRRDC "Wetland R&D Program Scoping Review" and strategies for R&D.	
Priority plant species	*Mimosa - Mimosa pigra - NT Top End* *Para grass - Brachiaria mutica - north and NE Aust* *Alligator weed - Alternanthera philoxeroides- east Aust* *Lippia - Phyla canescens- Darling Basin* *Salvinia - Salvinia molesta- north, east and SW Aust.*
Priority animal species	*Feral pigs - Sus scrofa - ubiquitous* *Mosquito fish - Gambusia holbrooki - east, south and SW Aust* *European carp - Cyprinus carpio- south and SE Aust.* *Cane toad - Bufo marinus- north and NE Aust.*
R&D Strategies	• *Develop community awareness of and involvement in pest management and planning* • *Conduct risk assessments of introduced species and possible control techniques* • *Enhance biological control and genetic modification programs* • *Develop protocols for integrated pest management including Decision Support Systems* • *Economic incentives for land users to maintain the essential ecological features of wetland* • *Environmental pricing mechanisms to encourage the retention of wetland processes and functions* • *Inventory and survey of susceptible areas and potential pests*

Despite their relatively harsh physico-chemical environment, saltmarshes are highly susceptible to invasion by exotic species (Adam 1995, 1996). Cord grass, Spartina angelica, was introduced in the early 20th century and has spread vigorously in Victoria and Tasmania but populations in New South Wales and South Australia have remained small. In Victoria, Cord grass has become established to seaward of Avicennia marina fringes, but its effects on nutrient transfer, fish access and adjacent seagrasses are unknown.

Other weeds invading saltmarsh are most notable in southern Australia and include: Pampas grass Cortaderia selloana; the rush, Juncus acutus, replacing the native Juncus kraussii; and groundsel bush, Baccharis halimifolia, forming dense stands in disturbed saltmarshes.

Introduced species also occur in mangrove habitats, including the European shore crab in Victorian Avicennia and an unconfirmed proposal by Saenger (1988) that the microbial soil fungus Phytophora, introduced in landfill soils, caused extensive dieback of Avicennia marina around Gladstone. All other species including the dominant Rhizophora stylosa appeared unaffected. Saenger (1988) proposed that the fungus was introduced to the area with construction of roads and earthen bunds, and was possibly enriched by high organic nutrients *associated with sewage outfall. An alternative view suggested that the fungus might be latent and only affect trees already stressed for other reasons (Pegg and Foresberg 1982).*

Introduced fishes - a much higher profile, but less of a threat to ecosystems than habitat destruction and weeds?

Introduced and translocated fishes, and their ecological impacts in Australia, were reviewed in a workshop held by the ASFB in 1989 (see Pollard, 1990). In summing up, Courtenay (1990) identified that :

- *there is a paucity of information on interactions between non-native and native fishes and their food webs and habitats*
- *there were often earlier or simultaneous alterations to habitats or other anthropogenic disturbances that may have facilitated the establishment of alien species*
- *introductions and translocations are primary or secondary forces in declines or other perturbations to native fish populations, in synergy with other disturbances*
- *molecular genetics shows that there are measurable differences between populations within species and translocations can alter the natural course of evolution, through hybridisation*
- *habitat modifications such as impoundments often result in demand for introductions of species that can tolerate these modifications*
- *Australia's impoverished and depauperate inland fish fauna makes it particularly vulnerable to aquarium fish introductions*
- *allowing for any non-native aquatic species into a nation under legislation is, in effect, approving its possibility of becoming a part of the biota of that nation.*

Our review of the literature comes to the same conclusions for freshwater systems. For example, European carp have possibly the highest public profile of any aquatic pest in Australia, and there are continual calls for spending on eradication programs. Yet only recently has there been wider public reporting of the views of biologists that water resource management regimes have created ideal habitat for carp in the Murray-Darling.

Morison and Hume (1990) reported that attempts to look at differences between habitats with different densities of carp, and at habitats before and after carp became established, and to conduct experiments in ponds where densities of carp were controlled, could still not resolve major questions about the effects of carp on the environment. They concluded that prevailing hydrological changes were more important in determining turbidity and macrophyte *abundance during the period of a study which found strong circumstantial evidence that carp had reduced the density of shallow-rooted and soft-leaved macrophytes.*

However, they warned that such findings were a feature of all such studies on carp introduced elsewhere, and that unequivocal demonstrations of adverse effects should not be required before restrictions on the importation, sale or possession of a species are implemented.

Gehrke and Harris (1994) provided key possible mechanisms of a role for carp in enhancing algal blooms, and billabong-scale exclusion/enclosure experiments that manipulate carp densities are in progress to better understand the effects of this fish pest (p.c. #350 A. Robertson). For example, King et al. (1997) found that carp had a significant effect on turbidity (also see Roberts et al. 1995) and intensity of algal bloom but this varied with carp biomass and billabong sediment type, and factors other than carp usually contributed to most of the variation in measured water quality. Robertson et al. (1997) concluded that the impact of carp on benthic and surficial processes was significant but the mechanisms of change differed between billabongs. The parameters measured were rates of particle settlement, biofilm development, sediment respiration, macrophyte detritus and decomposition, sediment nutrient concentrations and benthic algal biomass.

Eradication attempts have been successful in very small impoundments, but have failed at larger scales (sometimes because of deliberate re-introduction) , and a fishery for the species (mainly as rock lobster bait) has not seriously depleted their populations (Morison and Hume 1990). However, new products and markets for human consumption of carp are now being developed and electrofishing for carp will provide a part of any integrated management program for the species.

Unfortunately there is evidence that anglers and commercially motivated fishermen have been spreading or re-introducing carp, for instance from the mainland to Tasmania as live-bait. Similarly, Townsville anglers have been seen transporting tilapia from impounded freshwaters of Ross River to nearby estuaries for use as live-bait, despite the risk of heavy penalties. There is concern that tilapia will reach the Gulf drainages, and hence the lucrative northern prawn fishery, via a recent introduction to Lake Tinaroo and through inter-basin transfers of water. Tilapia have spread to estuaries in Townsville, but there is no knowledge (and evidently no study) of their predation on prawns there, so the threat to the northern prawn fishery is unknown. The Japanese goby Acanthogobius flavimanus is established in some bays in the eastern States, but also has unknown impacts.

Grewe (1996) has modelled the possibilities for transgenic incorporation of an inducible fatality gene (IFG) into the carp genome. He concluded that a combination of intermittent culling by triggering the action of the gene (eg. by a dietary supplement) and re-stocking with transgenic fish appears likely to result in eventual eradication of the carp from target systems.

The value of detailed ecological studies of introduced pests is illustrated by the work of Bluhdorn et al. (1990) who have proposed a series of management strategies for new invasions of Oreochromis mossambicus based on the ecology and biology of the species and size of the habitat being invaded. These include complementary use of manipulations of water flow regimes, predator enhancement and direct poisoning.

Glossary of Acronyms

Our use of terms and jargon is defined in a separate glossary in Volume 1.

ABWMAC - Australian Ballast Water Management Advisory Committee
AEAM - Adaptive Environmental Assessment and Management
AFMA - Australian Fisheries Management Authority
AFZ - Australian Fishing Zone
ANCA - Australian Nature Conservation Agency
ANZECC - Australian and New Zealand Environment and Conservation Council
AQIS - Australian Quarantine Inspection Service
ASFB - Australian Society for Fish Biology
ASIC - Australian Seafood Industry Council
ASS - Acid Sulfate Soils
BRD - Bycatch Reduction Device
BRS - Bureau of Resource Sciences
CCAMLR - Commission for the Conservation of Antarctic Marine Living Resources
CHRIS - Coastal Habitat Resource Information System
CONCOM - Council of Conservation Ministers, 1985 (now ANZECC)
CPUE - Catch per unit of fishing effort
CRC - Cooperative Research Centre
CRIMP - Centre for Research on Introduced Marine Pests (CSIRO)
CSIRO - Commonwealth Scientific and Industrial Research Organisation
CTC - Commonwealth Trust Consortium
CYPLUS - Cape York Peninsula Land Use Study
DEST - Department of Environment, Sport and Territories
EAC - East Australian Current
EEZ - Exclusive Economic Zone
EFT - Environmentally Friendly Trawl
ENSO - El Nino- Southern Oscillation
ERIN - Environmental Resources Information Network
ESD - Ecologically Sustainable Development
FAO - Food and Agriculture Organisation of the United Nations

FEHC - Fisheries and Environment Health Committee
FEM - Fisheries Ecosystem Management
FHA - Fish Habitat Area
GAB - Great Australian Bight
GBR - Great Barrier Reef
GBRMPA - Great Barrier Reef Marine Park Authority
GIS - Geographical Information System
GoC - Gulf of Carpentaria
Ha - hectare
ICM - Integrated catchment Management
IMCRA - Interim Marine and Coastal Regionalisation of Australia
ISMP - Integrated Scientific Monitoring Program
IUCN - International Council for the Conservation of Nature
JCUNQ - James Cook University of North Queensland
LME - Large Marine Ecosystem
LTMP - Long-Term Monitoring Program
LWRRDC - Land and Water Resources Research and Development Corporation
M - natural mortality
MAFRI - Marine and Freshwater Research Institute
MEPA- Marine and Estuarine Protected Areas
MPA - Marine Protected Area
MPC - Maximum Permitted Concentration
NatMIS - National Marine Information System
NHMRC - National Health and Medical Research Council
NORMAC - Northern Prawn Fishery Management Advisory Committee
NRSMPA - National Representative System of Marine Protected Areas
NSWFRI - New South Wales Fisheries Research Institute
NTDPIF - Northern Territory Department of Primary Industries
OR2000 - Ocean Rescue 2000
PAH - residual petroleum hydrocarbons
PASS - Potential Acid Sulfate Soils
QDPI - Queensland Department of Primary Industries
R&D - Research and Development
ROV - Remotely Operated Video
SARDI - South Australian Research and Development Institute
SBT - Southern Bluefin Tuna

SCARM - Standing Committee on Agriculture and Resource Management
SCFA - Standing Committee on Fisheries and Aquaculture
SIIP - Sugar Industry Infrastructure Package
SOER - State of the Environment Report
SOMER - State of the Marine Environment Report
TAP - Threat Abatement Plan
TBT - tributyltin
TCM - Total Catchment Management
TED - Trawl Efficiency Device, and used for Turtle Exclusion Device also
UNCLOS - United Nations Convention on the Law of the Sea
WAMRL - Western Australian Marine Research Laboratories
WWW - World Wide Web

Appendix 1: Standing Committee on Fisheries and Aquaculture - Fisheries Environment and Health Committee Terms of Reference

(Hamdorf 1994)

To advise SCFA on environment and fish health matters by:

- *identifying current and emerging national issues relating to the aquatic environment, the protection of fisheries ecosystems and fish health including:*
- *chemical usage and/or contamination,*
- *marine pollution*
- *disease identification and preparedness,*
- *management of introduced pests,*
- *ballast water issues,*
- *translocation,*
- *endangered species,*
- *habitat degradation,*
- *import and export of live fish and fish products*
- *co-ordinating and developing policy advice and strategies for dealing with such key national issues*
- *overseeing SCFA's role in co-ordinating the implementation of agreed national policies and strategies relating to environment and fish health matters*
- *determining strategic research priorities for areas under the ambit of the Committee*
- *facilitating the co-ordination of research activities into environmental health matters including those relating to introduced pests and diseases.*
- *liaising with relevant committees of SCARM and ANZECC and the Interim Australian Ballast Water Management Advisory Council and other groups in the area*
- *undertaking specific tasks affecting environment and fish health matters as requested by SCFA.*

Appendix 2: Fisheries Environment and Health Committee Research Priorities Draft (June 1996)

see Hamdorf (1994)

CATEGORY	ISSUE	OBJECTIVE	OUTCOMES
1. Fish Diseases	1.1 Endemic diseases	1.1 Conduct adequate disease surveillance in fisheries (will also detect "exotics") Determine epidemiology of diseases Evaluate control strategies	Accessible information (database) of diseases, occurrence and effects
	1.2 Exotic diseases	1.2 Conduct disease surveillance Risk assessment for likely impacts Develop emergency response plans	Ability to rapidly quarantine areas, apply controls and prevent further spread of disease
	1.3 Infrastucture requirements	1.3 Maintain diagnostic/analytical capacity Develop/maintain disease preparedness plans	Maintain wild stocks free of exotic diseases
2. Habitats	2.1 Riverine health and status	2.1 Define requirement for water flows, fish passages and effects of salinisation, desnagging and increased nutrient loads	2.1 Improved management decisions regarding the habitat impacts of land use approvals
	2.2 Mapping/monitoring habitats	2.2 Defining the role of specific habitats for specific fisheries and benefits of buffer zones to the protection of fish habitats	2.2 Establishment of buffer zones to protect habitats from run-off, refuse and physical disturbance
	2.3 Habitat utilisation	2.3 Identification of critical habitat Define impacts of human developments Representative system of protected areas & monitor effectiveness of protected areas	2.3 Establishment of protected zones (MEPAs etc) and understanding of effects and benefits of these areas
	2.4 Rehabilitation	2.4 Develop restoration technology to allow enhancement of habitats for fisheries production	2.4 Ability to rehabilitate habitats to restore fisheries values
3. Effects of Fishing	3.1 Impacts of fishing - trawling (concern in all jurisdictions)	3.1 Document changes to benthic community and physical structure of substrates	3.1 Minimise habitat impacts through improved trawl design and reduce non-target bycatch
	3.2 Impacts of fishing - gillnetting (concern in most jurisdictions , and includes beach protection)	3.2 Document the impacts of netting and develop fishing gear/techniques to avoid or minimise the take of non-target species	3.2 Continued improvement of fishing techniques, access to overseas markets and reduced by-catch
	3.3. Impacts of other fishing methods - hauling, longlining, potting and trapping	3.3 Document the impacts of these fishing methods and develop techniques to avoid take of non-target species	3.3 Ditto

CATEGORY	*ISSUE*	*OBJECTIVE*	*OUTCOMES*
	3.4 Fishing gear and waste	*3.4 Study the effects of ghost fishing, fishing debris and waste. Improve practices and develop gear that biodegrades*	*3.4 Ditto*
4. Aquaculture	*4.1 Impact of farms* *4.2 Effects on farms* *4.3 Zoning/site assessment*	*4.1 Design effective monitoring methodology* *Reducing nutrient output* *Reducing other impacts (genetics, disease, aesthetic effects, etc)* *Study effects of stoking rates* *4.2 Design effective monitoring methodology* *4.3 Effective site assessment procedures*	*4.1 Sustainable aquaculture in fresh and marine waters with guidelines on farm density* *Community acceptance of aquaculture and reduction in impacts on adjacent habitats* *4.2/4.3 Improved siting and reduction of impacts from adjacent land uses with commercial benefits to farmers*
5. Introduced & Translocated Species	*5.1 Management of impacts of translocated species on habitat and endemic species* *5.2 Quantification of impacts* *5.3 Surveys of pest existence* *5.4 Control of organisms*	*5.1 Assess impacts of translocations from aspect of ecological, genetic, disease and endangered species effects.* *5.2 Define impacts caused by the release of species outside their natural range* *5.3 Conduct surveys of pest distributions* *Study biology/ecology of introduced spp.* *5.4 Develop control measures for exotics which cause least impact on non-target spp*	*5.1 Valid translocation policies and protocols. Prevention of exotic disease in cultured or wild stocks* *5.2 Recognition of risk involved with translocations* *5.3 Detailed distributions of pests, eg carp, fanworms, tilapia, barramundi* *5.4 Capacity to control exotic species while maintaining endemic species*
6. Pollution/Chemical Impacts	*6.1 Nutrient discharges* *6.2 Heavy metals, organics, biotoxins in seafood* *6.3 Algal blooms*	*6.1 Understanding impacts of nutrient sources such as sewage and agriculture.* *6.2 Analyse different seafood to quantify natural background levels and sources to assist with quality assurance, assessment of human health and ecosystem impacts* *6.3 Monitor bloom occurrence/effects*	*6.1 Minimise impacts by improved planning and further mitigation* *6.2 Maintenance of markets, base line data sets for monitoring and response to pollution, food standards issues, and understand uptake mechanisms* *6.3 Maintain seafood quality*

CATEGORY	ISSUE	OBJECTIVE	OUTCOMES
7. Management Tools	7.1 Ecological Risk Assessment	7.1 Document and apply risk assessment processes to fisheries issues such as translocations and resource management.	7.1 Application of risk assessment to protect fisheries habitat
	7.2 Design of research and monitoring methodology	7.2 Develop a suite of monitoring options to be considered and applied as appropriate for minimising the impacts of habitat losses	7.2 Implement/direct mitigation works, knowing likely benefits and costs, relative to impact of losses
	7.3 Adaptive management techniques	7.3 Develop techniques to assess and modify adaptive management tools	7.3 Assessment and updating of management approaches
	7.4 Protected areas, zoning and multiple use strategies	7.4 Assess the effectiveness of protected areas, zoning and multiple use strategies	7.4 Community involvement and awareness in habitat management
	7.5 Long-term change	7.5 Monitor likely impacts of long-term changes (eg. global warming, sea level, etc)	7.5 Longer-term plans and management strategies for fisheries

Appendix 3: A Collation of Investment by THE FRDC in Projects with some Focus on Issues covered in this Review

PROJECT CODE	*PROJECT NAME*	*ORGANISATION NAME*
97/222	*Development of continuous prawn cell lines for virus isolation and cultivation*	*CSIRO Australian Animal Health Laboratory*
97/220	*Seagrasses in southern NSW estuaries: their ecology, conservation, restoration and management*	*University of Wollongong*
97/217	*The development and evaluation of methods to assess the impact of chronic toxicity on ichthyoplankton - a pilot study*	*Marine and Freshwater Resources Institute*
97/214	*Development of generic contingency plans for disease emergencies of aquatic animals*	*CSIRO Australian Animal Health Laboratory*
97/212	*The impact of prawn farm effluent on coastal waterways.*	*Cooperative Research Centre for Aquaculture*
97/210	*The effects of haul seining in Victorian bays and inlets*	*Marine and Freshwater Resources Institute*
97/207	*Development of discard-reducing gears and practices in the estuarine prawn and fish haul fisheries of NSW*	*NSW Fisheries*
97/206	*The effects of net fishing: addressing biodiversity and bycatch issues in Queensland inshore waters.*	*QLD Department of Primary Industries*
97/205	*Effects of trawling subprogram - Dynamics of large sessile seabed fauna, important for structural fisheries habitat and biodiversity of marine ecosystems and use of these habitats by key finfish species*	*CSIRO Division of Marine Research*
97/204	*Fish in the shallows of NSW south coast estuaries - variability and diversity of fish communities and the development of biological indicators for sustainability and biodiversity*	*University of Wollongong*

Project Code	*Project Name*	*Organisation Name*
97/203	*Fish use of subtropical saltmarsh habitat*	*Griffith University*
97/201	*The impacts of ponded pastures on barramundi and other finfish populations in tropical coastal wetlands.*	*QLD Department of Primary Industries*
97/142	*Issues affecting the sustainability of Australia's freshwater fisheries resources and identification of research strategies*	*University of Canberra*
97/139	*Mesoscale oceanographic data analysis and data assimilative modelling with application to Western Australian fisheries*	*CSIRO Division of Marine Research*
97/133	*Fisheries biology and habitat ecology of the southern sea garfish (Hyporhamphus melanochir) in southern Australia.*	*SA Research and Development Institute*
97/128	*The fisheries biology of blue throat wrasse (Notolabrus tetricus) in Victorian waters*	*VIC Fishing Industry Federation*
97/124	*The effects of line fishing on the Great Barrier Reef and evaluation of alternative potential management strategies*	*James Cook University*
97/122	*Ecologically sustainable development of the fishery for patagonian toothfish (Dissostichus eleginoides) around Macquarie Island: population parameters, population assessment and ecological interactions*	*CSIRO Division of Marine Research*
97/114	*Synthesis of industry information on fishing patterns, technological change and the influence of oceanographic effects on SEF fish stocks*	*Biospherics Pty Ltd*
97/113	*Residence times, exchange rates, migration patterns and behaviour of black marlin in the NW Coral Sea; a pilot study to evaluate interaction between recreational and commercial fishing sectors in Area E*	*CSIRO Division of Marine Research*
97/108	*The definition of effective spawning stocks of commercial tiger prawns in the NPF and king prawns in the eastern king prawn fishery - behaviour of postlarval prawns*	*CSIRO Division of Marine Research*

Project Code	*Project Name*	*Organisation Name*
97/105	*The growth, mortality, movements and nursery habitats of red-legged banana prawns (Penaeus indicus) in the Joseph Bonaparte Gulf*	*CSIRO Division of Marine Research*
96/286	*The physical effects of hauling on seagrass beds - stage 2 (an extension to 95/149)*	*NSW Fisheries*
96/285	*Identification of environmental factors, with particular reference to acid sulfate soil runoff, causing production losses in Sydney rock oysters*	*University of NSW*
96/284	*Huon estuary study - environmental research for integrated catchment management and aquaculture*	*CSIRO Division of Marine Research*
96/280	*Baseline studies on the ecology of scavengers (mainly sea-lice) on the continental shelf and slope off eastern Australia*	*The Australian Museum*
96/275	*Development of a rapid-assessment technique to determine biological interactions between fish, and their environment, and their role in ecosystem functioning*	*CSIRO Division of Marine Research*
96/264	*Dynamics of harmful Rhizosolenia cf. chunii blooms in Port Phillip Bay.*	*Marine and Freshwater Resources Institute*
96/257	*Effects of trawling subprogram - Ecological sustainability of bycatch and biodiversity in prawn trawl fisheries*	*CSIRO Division of Marine Research*
96/255	*A study of the impact of fishing pressure on midwater ecosystems.*	*Biospherics Pty Ltd*
96/254	*Effects of trawling subprogram - Commercialisation of by-catch reduction strategies and devices in northern Australian prawn trawl fisheries.*	*QLD Department of Primary Industries*
96/149	*Climate and fisheries on the south east Australian continental shelf and slope*	*CSIRO Division of Marine Research*
96/140	*Evaluation of selectivity in the south-east fishery to determine its sustainable aggregate yield*	*CSIRO Division of Marine Research*

PROJECT CODE	PROJECT NAME	ORGANISATION NAME
96/139	Changes over 20 years in relative abundance of species and composition of catches from fishery independent surveys on SEF trawl grounds	NSW Fisheries
96/130	Biology and stock assessment of WA's commercially important sharks species	Fisheries Department of WA
96/118	Development of a fishery independent index of abundance for juvenile SBT	CSIRO Division of Marine Research
96/116	Spawning and larval recruitment processes of commercially important species in coastal waters off Victoria.	Marine and Freshwater Resources Institute
96/107	A synthesis of existing data on larval rock lobster distribution in southern Australia	CSIRO Division of Marine Research
96/102	Development of an environment-recruitment model for black bream as a case study for estuarine fisheries management	Marine and Freshwater Resources Institute
95/172	Improving the land and water management of coastal plains of NSW	Webbnet Land Resource Services Pty Ltd
95/167	Establishment of a Coastal Habitat Resources Information System for QLD (CHRIS)	QLD Department of Primary Industries
95/158	Recruitment, growth, mortality and habitat use of juvenile banded morwong Cheilodactylus spectabilis	University of TAS
95/150.02	An assessment of populations of commercially and recreationally important fish and invertebrates utilising large restored wetlands.	NSW Fisheries
95/150	An assessment of populations of commercially and recreationally important fish and invertebrates utilising large restored wetlands	NSW Fisheries
95/148	Enhancement of mulloway (Argyrosomus hololepidotus) in intermittently opening lagoons	NSW Fisheries
95/145	Impact of gillnet fishing on inshore temperate reef fishes, with particular reference to banded morwong	TAS Department of Primary Industry and Fisheries

Project Code	*Project Name*	*Organisation Name*
95/087	*Aquatic disease preparedness assessment*	*CSIRO Australian Animal Health Laboratory*
95/085	*Development of an algal bloom monitoring buoy for the Australian aquaculture industry - proof of concept*	*University of TAS*
95/083	*Immuno-staining of a ciliate protozoan causing significant mortality of farmed tuna: the development of a rapid identification technique which will enable improved farm management practices to be implemented to minimise fish mortality*	*SA Research and Development Institute*
95/060	*Diagnosis and identification of Aeromonas salmonicida and detection of latent infections in carrier fish*	*CSIRO Australian Animal Health Laboratory*
95/058	*The seamount fauna off southern Tasmania: impacts of trawling, conservation and role within the fishery ecosystem*	*CSIRO Division of Marine Research*
95/055	*Review and synthesis of Australian fisheries habitat research*	*Australian Institute of Marine Science*
95/048	*Cephalopod beak identification and biomass estimation techniques: tools for dietary studies of southern Australian finfishes.*	*Museum of VIC*
95/043	*A collaborative investigation on the usage and stock assessment of bait fishes in southern and eastern Australian waters, with special reference to pilchards (Sardinops sagax neopilchardus); extension into QLD and NSW*	*QLD Department of Primary Industries*
95/042	*The influence of the Dawesville Channel on the recruitment, distribution and emigration of crustaceans and the fish in the Peel-Harvey estuary*	*Murdoch University*
95/041	*Growth of pearl oysters in the southern and northern areas of the pearl oyster fishery and examination of environmental influences on recruitment to the pearl oyster stock.*	*Fisheries Department of WA*

Project Code	Project Name	Organisation Name
95/037	*The biology and stock assessment of the tropical sardine, Sardinella lemuru off the mid-west coast of Western Australia*	*Fisheries Department of WA*
95/025	*Biological and ecological research needed for the effective management of the bar-cheeked coral trout and the chinaman cod, including an investigation into the factors controlling sex-change in the serranids (cods, groupers and coral trout).*	*University of WA*
95/007	*Determination of spawning areas and prediction of recruitment locations for King George whiting in Victorian waters using hydrodynamic numerical modelling*	*Marine and Freshwater Resources Institute*
95/002	*Applications of molecular biology to management of the abalone fishery*	*Deakin University*
94/165	*DNA markers and genetic stock structure in commercial species of penaeid prawns in the east coast fishery*	*QLD Department of Primary Industries*
94/144	*Identification and mapping of barramundi nursery swamp habitat in the Chambers Bay/Finke Bay area.*	*NT Primary Industry and Fisheries*
94/135	*International environmental instruments and actions - Their effects on the fishing industry*	*University of Wollongong*
94/132	*The use of oysters as natural filters of aquaculture effluent*	*Moreton Bay Prawn Farm*
94/113	*Feasibility study for the establishment of a kelp processing industry on the west coast of Tasmania*	*TAS Department of Primary Industry and Fisheries*
94/079	*Pearl oyster aquaculture: health survey of NT, WA and QLD pearl oyster beds and farms*	*NT Department Primary Industry and Fisheries*
94/067	*Assessment of juvenile eel resources in south east Australia*	*Marine and Freshwater Resources Institute*
94/055	*Regional larval fish archives: Preservation of an important fisheries resource*	*The Australian Museum*

Project Code	*Project Name*	*Organisation Name*
94/045.02	*Development, application and evaluation of the use of remotely sensed data by Australian fisheries*	*CSIRO Division of Marine Research*
94/043	*Investigation of the characteristics & properties of mixed function oxidases (mfo) in commercially significant fish from SA waters and assessment of their induction as a potential early warning and hence biomarker of organic pollutant linked stress*	*University of Adelaide*
94/042	*Sampling estuarine fish species for stock assessments*	*NSW Fisheries*
94/041	*Restoration of estuarine fisheries habitat*	*NSW Fisheries*
94/040	*Habitat and fisheries production in the South east fishery ecosystem*	*CSIRO Division of Fisheries*
94/037	*Assessment of inshore habitats around Tasmania for life-history stages of commercial finfish species*	*Tas Department of Primary Industries and Fisheries*
94/032	*Effects of seasonal and interannual variability of the ocean environment on recruitment to the fisheries of Western Australia*	*CSIRO Division of Marine Research*
94/029	*A collaborative investigation on the usage and stock assessment of bait fishes in southern and eastern Australian waters, with special reference to pilchards (Sardinops sagax neopilchardus)*	*SA Research and Development Institute*
94/027	*NSW inland commercial fisheries analysis*	*NSW Fisheries*
94/024	*Assessment of stocks of sea mullet (Mugil cephalus) in NSW and QLD waters*	*NSW Fisheries*
94/022	*The origin of recruits to the east coast yellowfin tuna fishery and the delineation of the structure of yellowfin stocks in the western Pacific.*	*CSIRO Division of Marine Research*
94/014	*Effects of biological and environmental factors and of fishing practices on recruitment and abundance of scallops*	*Marine and Freshwater Resources Institute*

Project Code	*Project Name*	*Organisation Name*
94/005	*The feasibility of enhancing and rehabilitating abalone stocks by larval re-seeding*	*SA Research and Development Institute*
93/245.03	*Habitat Research/Management Workshop*	*NSW Commercial Fishing Advisory Council*
93/245.01	*Fisheries Ecosystem Management and the Coastal Environment*	*FRDC*
93/240	*A desk-top evaluation of the application of towed-body LIDAR to biomass assessment of demersal fish stocks - CSIRO TRUST FUND*	*CSIRO Division of Fisheries*
93/239	*Exchange and analysis of historical Soviet fishery data from the waters around Australia*	*CSIRO Division of Marine Research*
93/237	*Development of software for use in multi-frequency acoustic biomass assessments and ecological studies*	*CSIRO Division of Marine Research*
93/235	*Laboratory and field studies of the larval distribution and duration of the introduced Sea Star Asterias amurensis with updated and improved prediction of the species spread based on a larval dispersal model*	*CSIRO Division of Fisheries*
93/231.07	*Effects of trawling subprogram - Development and application of AUSTed in the Australian trawl industry*	*QLD Department of Primary Industries*
93/229	*Monitoring the impact of trawling on sea turtle populations of the Queensland East Coast - EFFECTS OF TRAWLING SUBPROGRAM*	*Queensland Department of Primary Industries*
93/180	*Development of by-catch reducing prawn trawl and fishing practices in NSW's prawn trawl fisheries - EFFECTS OF TRAWLING SUBPROGRAM*	*NSW Fisheries*
93/180	*Effects of trawling subprogram - Development of by-catch reducing prawn trawl and fishing practices in NSW's prawn trawl fisheries*	*NSW Fisheries*

PROJECT CODE	*PROJECT NAME*	*ORGANISATION NAME*
93/179	*The effects of trawl design on by-catch and benthos in prawn and fin-fish fisheries - EFFECTS OF TRAWLING SUBPROGRAM*	*CSIRO Division of Fisheries*
93/176	*Development and application of AUSTed in the Australian Trawl Industry REFER 93/231.07*	*Queensland Department of Primary Industries*
93/169	*Assessment of the carrying capacity of Boston Bay Port Lincoln with a view towards maximising the southern bluefin tuna resource*	*South Australian Marine Farm*
93/153	*Control of winter mortality and QX disease in Sydney rock oysters UniQld*	*University of Queensland*
93/130	*Development of vaccines and rapid diagnostic monoclonal antibodies against microorganisms associated with diseases of wild and cultured finfish and shellfish*	*Deakin University*
93/128	*Development of molecular probes for use in bacterial disease diagnosis and health monitoring of farmed and wild finfish in Australia*	*TAS Department of Primary Industry and Fisheries*
93/109	*Use of the bomb radiocarbon chronometer to validate fish age*	*Australian National University*
93/102	*Interactions between the abalone fishery and sea urchins in NSW*	*NSW Fisheries*
93/100	*Evaluation of methods to assess abalone abundance*	*Marine and Freshwater Resources Institute*
93/096	*Effects of trawling subprogram - The environmental effects of prawn trawling in the Far Northern Section of the Great Barrier Reef (Part of funding from CSIRO & Qld Trust Accounts)*	*QLD Department of Primary Industries*
93/083	*The impact of commercial hauling nets and recreational line fishing on the survival of undersize King George whiting (Sillaginodes punctata)*	*SA Research and Development Institute*
93/074	*Assessment of the fishery for snapper (Pagrus auratus) in QLD and NSW*	*QLD Department of Primary Industries*

PROJECT CODE	PROJECT NAME	ORGANISATION NAME
93/061	*Investigation of school and gummy shark nursery areas in southeastern Australia*	*CSIRO Division of Fisheries*
93/058	*Development of an acoustic system for remote sensing of benthic fisheries habitat for mapping, monitoring and impact assessment*	*CSIRO Division of Marine Research*
93/050	*Leeuwin environment index - pelagic recruitment strength relationship*	*SA Research and Development Institute*
92/155	*Preliminary assessment of the distribution and potential impact of the introduced seastar Asterias amurensis in Tasmanian waters*	*CSIRO Division of Fisheries*
92/145	*Biology and harvest of tropical fishes in Queensland's inshore gillnet fisheries*	*QLD Department of Primary Industries*
92/140	*Investigation of the potential distribution and fishery impact of the exotic seaweed Undaria pinnatifida*	*Tas Department of Primary Industries and Fisheries*
92/090	*Australian fisheries research publications database*	*CSIRO Division of Fisheries*
92/084	*National Fisheries Technical Workshop series - Sustainable fisheries through sustaining fish habitat*	*Australian Society for Fish Biology*
92/079	*The interaction between fish trawling and other commercial and recreational fisheries - EFFECTS OF TRAWLING SUBPROGRAM*	*NSW Fisheries*
92/045	*The role of coastal nursery habitats in determining the long-term productivity of prawn populations in the NPF*	*CSIRO Division of Fisheries*
92/044	*Importance of shallow water reef/algal habitats as nursery areas for commercial fish from temperate Australia*	*University of Melbourne*
92/019	*An Ichthyoplankton based analysis of the spawning distribution and stock structure of temperate Australian finfish species*	*CSIRO Division of Fisheries*
92/007	*Small prawn habitat and recruitment study*	*Queensland Department of Primary*

Project Code	Project Name	Organisation Name
		Industries
91/049	Development of improved and environmentally sensitive scallop harvesting gear	CSIRO Division of Fisheries
91/045	Cyclones and seagrass communities - recolonisation rates and the effects on penaeid prawn stocks	CSIRO Division of Fisheries
91/041	Effects of habitat disturbances on coastal fisheries resources in Tin Can Bay/ Great Sandy Strait	Queensland Department of Primary Industries
91/023	Investigation of school and gummy shark nursery areas in south eastern Tasmania	CSIRO Division of Fisheries
91/017	Trophodynamics of the south-east trawl deep-water stocks	CSIRO Division of Fisheries
91/004	Modelling prawn larvae dispersion and settlement in Spencer Gulf - Management Implications	University of Adelaide
91/003	Key factors which affect prawn recruitment and implications to harvesting prawn stocks	SA Research and Development Institute
90/114	Evaluation of the benefits and costs of research in Australia	Australian Bureau of Agricultural and Resource Economics
90/112	Pilot study to include fisheries is the National Residue Survey	Department of Primary Industry and Energy
90/104	Development of 'Australian Rural Research in Progress' database REFER 93/250	Bureau of Resource Sciences
90/019	The biology and population status of important trawl by-catch species and the impact of trawling in SW Australia	WA Department of Fisheries
90/018	Growth, movement, mortality and reproductive strategies of the dominant demersal food-fish species on the Great Barrier Reef	Queensland Department of Primary Industries

Project Code	*Project Name*	*Organisation Name*
90/017	*Monitoring the replenishment of the dominant demersal food-fish species on the Great barrier Reef*	*Queensland Department of Primary Industries*
90/007	*Assessment of spatial and temporal variation in puerulus settlement of the southern rock lobster*	*Tas Department of Primary Industries and Fisheries*
89/081	*Red spot disease of sea mullet (Mugil cephalus)*	*NSW Fisheries*
89/039	*Toxic dinoflagellate spores in ships' ballast water: a danger to aquaculture*	*CSIRO Division of Fisheries*
89/038	*Presence and persistence of the hazardous micro-organism Clostridium botulinum in ballast sediments*	*CSIRO Division of Food Science and Technology*
89/013	*Causes of decline in stocks of commercially important prawns in the Northern Prawn Fishery*	*CSIRO Division of Fisheries*
89/002	*Patterns of utilisation of seagrass (Heterozostera) dominated habitats as nursery areas by commercially important fish*	*Victorian Institute of Marine Science*
88/091	*Consequences for commercial fisheries of loss of seagrass beds in southern Australian waters*	*Victorian Institute of Marine Science*
88/090	*A workshop on recovery and restoration of seagrass habitat of significance to commercial fisheries*	*Victorian Institute of Marine Science*
88/077	*The fish resources of tropical north-eastern Australian waters*	*CSIRO Division of Fisheries*
88/071	*Distribution, seasonal abundance and dispersal patterns of larvae of commercially important finfish species from southern Australian continental shelf and slope waters*	*CSIRO Division of Fisheries*
88/018	*Assessment of trawl-induced incidental mortality on pre-recruit saucer scallops*	*Queensland Department of Primary Industries*
87/116	*Workshop to establish national protocol for monitoring loss of seagrass habit of significance to commercial*	*Victorian Institute of Marine Science*

Project Code	*Project Name*	*Organisation Name*
	fisheries	
87/016	*The effects of cyclones on the seagrass communities and penaeid prawn stocks of the Gulf of Carpentaria*	*CSIRO Division of Fisheries*
86/110	*Preparation of a set of guidelines on the procedures necessary to carry out baseline studies at any Australian coastal site*	*The Australian Museum*
86/108	*Surveys of seagrass beds and juvenile prawn populations along the Queensland coast - Bowen to Cairns and Karumba to Cape York*	*Queensland Department of Primary Industries*
86/100	*Investigations of the effect of water temperature on the growth, recruitment and breeding cycle of the western rock lobster*	*WA Department of Fisheries*
86/092	*Investigation of the impact of the seastar Coscinasterias calamaria on commercial mollusc fisheries*	*University of Melbourne*
86/084	*Occurrence of toxic dinoflagellates in southern Tasmanian waters and possible implications for shellfish farming.*	*CSIRO Division of Fisheries*
86/083	*An investigation of the habitat requirements of post-puerulus stocks of western rock lobster (Panulirus cygnus)*	*CSIRO Division of Fisheries*
86/078	*Productivity of tiger prawn nursery areas*	*CSIRO Division of Fisheries*
86/061	*Settlement and recruitment of greenlip abalone: their use in predicting stock abundance*	*SA Research and Development Institute*
86/053	*Red spot disease of sea mullet (Mugil cephalus)*	*NSW Fisheries*
86/038	*Scallop Recruitment Studies at Lakes Entrance*	*Department of Conservation and Natural Resources*
86/010	*Factors affecting the toxicity of the dinoflagellate, Gambierdiscus toxicus, and the development of ciguatera outbreaks*	*Queensland Department of Primary Industries*

Project Code	*Project Name*	*Organisation Name*
85/089	*Assessment of the potential for the sea urchin Heliocidaris erythrogramma to destroy seagrass (Posidonia) beds in Botany Bay, NSW*	*University of Melbourne*
85/085	*Recruitment processes in commercially important prawn species*	*CSIRO Division of Fisheries*
84/049	*Colonisation of New South Wales by non-indigenous marine species: baseline studies at Twofold Bay, NSW*	*The Australian Museum*
84/038	*Applicability of inexpensive hyrdroacoustic techniques for assessment in shallow water conditions*	*University of Adelaide*
84/022	*A study of seagrass prawn nursery grounds and juvenile prawn populations in north Queensland*	
84/020	*Studies on the biology of and the fishery for the red-spot king prawn, Penaeus longistylus*	
83/039	*A study of the distribution of post-larval and juvenile Western King prawn in Spencer Gulf, South Australia*	*SA Research and Development Institute*
83/032	*Port Phillip Bay and Bass Strait scallop research*	*Department of Conservation and Natural Resources*
82/070	*Role of submersibles in fisheries research*	*NSW Fisheries*
82/062	*A demersal fisheries resource survey of the Queensland continental shelf slope between10°S and 21°S*	*Queensland Department of Primary Industries*
82/060	*Studies on toxic dinoflagellates responsible for formation of ciguatoxin*	*Queensland Department of Primary Industries*
82/048	*Bacterial pathogens of oyster larvae and spat*	*University of Tasmania*

Project Code	*Project Name*	*Organisation Name*
82/043	*The biology and ecology of the blacklip abalone with reference to the juvenile stage between post-planktonic settlement and recruitment to the fishery*	*University of Tasmania*
82/033	*A survey of the incidence of ciguatoxin in "high risk" fish from the Cairns region*	*University of Queensland*
82/013	*Investigation of the biology of tiger prawns in the western Gulf of Carpentaria*	*CSIRO Division of Fisheries*
82/008	*The occurrence and significance of pathogenic vibrios in oysters*	*CSIRO Division of Fisheries*
81/035	*The oceanography of a continental shelf section*	*Flinders University*
81/024	*A study of ciguatera poisoning in Queensland*	*University of Queensland*
81/020	*Investigations into QX disease in oysters and other problems associated with marine parasites*	*University of Queensland*
81/002	*Mortality of the Sydney rock oyster in northern New South Wales and southern Queensland*	*NSW Fisheries*
80/033	*Squid ecology*	*Department of Conservation and Natural Resources*
80/028	*Publication of the report of the Working Group on Mercury in Fish and fish products*	*Department of Primary Industry and Energy*
79/005	*Dependence of commercially import fish on krill as a food source in south-east Tasmania*	*University of Tasmania*
78/039	*A study of the biology and ecology of juvenile prawns in the Noosa River/lakes system*	
78/036	*Tide and current analysis of the Gulf of Carpentaria and its relation to banana prawn larval dispersion [extended as "Circulation in ..."]*	*CSIRO Division of Fisheries*

PROJECT CODE	*PROJECT NAME*	*ORGANISATION NAME*
78/013	*North Queensland continental slope survey using the Tethered Rope Instrument Package (TRIP)*	*Queensland Department of Primary Industries*
77/005	*Survey of prawns and fish in Joseph Bonaparte Gulf [and the Kimberley Region] by trawling*	
76/020	*Ecology of coastal reefs: the nurseries of juvenile western rock lobsters*	*CSIRO Division of Fisheries*
76/018	*Ballast water investigations*	*NSW Fisheries*
76/015	*Marine resources survey*	*NSW Fisheries*
72/014	*Establishment of juvenile rock lobster sampling sites for prediction of catch fluctuations*	*Tas Department of Primary Industries and Fisheries*

Appendix 4: Summary of results of fisheries-habitat studies in inshore bays and estuaries, by region, location, habitat type, fisheries taxa, life-history stage and source

*GoC = Gulf of Carpentaria, NQ= North Qld, SEQ = South East Qld, sWA = South-western WA, *** = not identified*

Region	Location	habitat type	taxa	stage	type of study or results	reference
Aust. review	Tasmania, Victoria, NSW, SA, WA	shelf, beaches, estuaries, bays	Arripis truttaceus, A. trutta, A. georgianus	larvae, juv.-ad.	review of research needs/ role of Leeuwin-current/nursery/environmental-forcing/recruitment	Anon. (1996b)
Aust. review	Australia-wide examples	deep shelf, estuaries, freshwater	***	***	review of ecosystems /life-history/comparative-studies/ecological-distribution/migrations	Blaber, S. J. M. (1991)
Aust. review	14 localities, from Rottnest Is – Jervis Bay	bare and seagrass dominated	47 fish species examined	***	definitive regional study of the nearshore/seagrass/trophodynamics and production of fish/invertebrates in bare vs seagrass habitats.	Edgar, G. J. and Shaw, C. (1995c)
Aust. review	Western Port, and 14 regional sites from Rottnest Is. - Jervis Bay, inc. Tas.	seagrass, bare sand	Meuschenia freycineti and Haletta semifasciata, and 86 other species	***	The effects of seagrass-dieback were studied by sampling in vegetated and unvegetated habitats. A high correlation was found between production of small fishes and the production of epifaunal crustaceans, leading to a suggestion of food-limitation.	Edgar, G. J., Hammond, L. S., and Watson, G. F. (1993)
Aust. review	Port Phillip Bay vs other Vic. bays, Jervis Bay, Botany Bay, Cockburn Sound	bay	review	larvae-adults	Review of fisheries productivity in PPB ; 1) in relation to nutrient inputs, and 2) some empirical comparisons with other marine embayments ; 1) hampered by no info. available on fish production prior to sewage inputs. No evidence of impacts	Gwyther, D. (1990)
Aust. review	***	/temperate-zones	***	fish-larvae	life-history/literature-review	Miskiewicz, A. G. (1992)
Aust. review	review article	particularly Zostera, Posidonia, Thalassia, Halodule	***	***	autecology, trophic relationships, shelter requirements and temporal changes in these various seagrass–fish assemblages.	Pollard, D. A. (1984)
Aust. review	entire coast	mangrove	fish/prawns	***	review of structure, function and ecology of mangrove ecosystems, including synthesis of fisheries-nursery value.	Robertson A. I. and Alongi, D. (1996)
Aust. review	tropical coasts	mangrove	fish/prawns	***	selected review of tropical estuarine fish communities with comparisons of Alligator Ck, Embley Estuary, Leanyer Swamp	Robertson, A. I. and Blaber, S. J. M. (1992)

Region	Location	habitat type	taxa	stage	type of study or results	reference
GoC	Embley R. and Albatross Bay	1) open-water channels<5m; 2) intertidal sandy-mud beaches; 3) seagrass Enhalus; 4) intertidal mudflats; 5) small mangrove creeks; 6) bay prawn trawl grounds	197 spp in Embley estuary; 243 in bay trawl; 106 spp unique to estuary	juv.-adult	At least 33% of the Embley fauna is "estuarine-dependent" and make up half the biomass in all estuarine habitats. Six spp groups recognised. Consistent variation amongst habitat types emphasises the need to sample all estuarine habitats	Blaber et al. (1989)
GoC	Gulf of Carpentaria	bay trawl grounds	***	***	distribution, community structure, nursery role	Blaber et al. (1990a)
GoC	Gulf of Carpentaria	***	***	***	distribution, community structure	Blaber et al. (1994c)
GoC	Gulf of Carpentaria	nearshore	***	***	distribution, community structure, nursery role	Blaber et al. (1995b)
GoC	Gulf of Carpentaria	entire Gulf on 30nm grids in depths >17m	300 spp from 85 families	juv.-adult	distribution, community structure vs time of day, grid location and 11 abiotic factors. Six main site groupings ; 15 fish community groupings; relationship between fish dsn and depth, but not with other abiotic factors such as temp and %mud,sand,gravel	Blaber, Brewer and Harris (1994b)
GoC	Groote-Eylandt	tall, dense seagrass, short sparse seagrass, bare substrata	156 fish species	***	highest spp diversity in tall dense seagrass and least in bare sand. Immigration to forage over seagrass at night by piscivores is major cause of high abundance	Blaber, S. J. M., Brewer, D. T., Salini, J. P., Kerr, J. D., and Conacher, C. (1992b)
GoC	***	***	Caranx-bucculentus	juv.-adult	predation on prawns/food-selection/body-size/food-organisms/feeding-behaviour/prey-selection	Brewer, D. T., Blaber, S. J. M., and Salini, J. P. (1989)
GoC	Carpentaria-Gulf,-Albatross-Bay	nearshore bay	***	***	fish predation on prawns/trophodynamics/nearshore	Brewer, D. T., Blaber, S. J. M., and Salini, J. P. (1991)
GoC	Groote-Eylandt	tall, dense seagrass, short dense seagrass, bare substrata, mixed reef/seagrass	93 species	juv.-adult	feeding behaviour and stomach contents showed similar prey regardless of habitat, with important density-dependent predation on prawns	Brewer, D. T., Blaber, S. J. M., Salini, J. P., and Farmer, M. J. (1995)
GoC	Wellesley Islands	***	Penaeus esculentus, Metapenaeus endeavouri	juv.	nursery areas found in estuarine and sheltered areas by beam trawl	Coles, R. G. and Long, W. J. L. (1985)

Region	Location	habitat type	taxa	stage	type of study or results	reference
GoC	Embley-Estuary	estuary	21 species	sub.ad-adult	variety of ariid catfish, mullet species, barramundi and threadfin salmon had increasing CPUE with increasing turbidity. However, we believe this could equally well be explained by the hypothesis that gillnet efficiency increase with turbidity –	Cyrus, D. P. (1992)
GoC	Embley-Estuary	***	***	***	seasonal turbidity, temperature and salinity gradients and their effects on ecological-distribution	Cyrus, D. P. and Blaber, S. J. M. (1992)
GoC	Qld	***	Penaeus- merguiensis, Metapenaeus bennettae, P.esculentus, P.plebejus	***	osmoregulatory ability as a determinant of adults and juveniles habitat-selection	Dall, W. (1981a,b)
GoC	***	estuary	Penaeus merguiensis	juv.	overwintering	Dredge (1985)
GoC	Torres Strait	***	***	***	use of carbon-isotopes to propose basis of food-webs/energy-flow	Fry, B., Scanlan, R. S., and Parker, P. L. (1983)
GoC	Carpentaria-Gulf	***	Penaeus- merguiensis	new recruits, juv.	seasonal temperature and salinity-effects on recruitment, growth and mortality measured in the field	Haywood, M. D. E. and Staples, D. J. (1993)
GoC	Embley River estuary, and single season in Port Musgrave, Albatross Bay, Archer Bay estuaries	Enhalus, Halodule, Halophila, Caulerpa spp	Penaeus semisulcatus, P. esculentus	***	comparison of seagrass/algal beds as tiger prawn <10mm nurseries. Decreased salinity with wet season floods caused disappearance of upstream algae beds and the P. semisulcatus in them: seagrass biomass no change and 97% of P. esculentus in downstr beds	Haywood, M. D. E., Vance, D. J., and Loneragan, N. R. (1995)
GoC	lab experiment	seagrass vs bare sand	Lutjanus-russelli/Caranx-bucculentus	***	predation on Penaeus-esculentus is prevented largely shelter function	Laprise, R. and Blaber, S. J. M. (1992)
GoC	Embley River estuary	mangrove, seagrass, macroalgae	Penaeus esculentus, P. semisulcatus, P. merguiensis, Metapenaeus spp.	juv.-adults	Used isotopes of carbon, nitrogen and sulphur to compare contribution of seagrass and mangroves to food webs supporting juvenile prawns in estuary and also on offshore trawl grounds, and examined seasonality in primary food source utilisation	Loneragan, N. R., Bunn, S. E., and Kellaway, D. M. (In Press)
GoC	Groote Eylandt	several genera seagrass	Penaeus esculentus and P. semisulcatus	benthic post-larvae, new recruits, juv.	almost all postlarvae (90 %) were caught in intertidal and shallow subtidal seagrass on open coastline<=2.0 m deep. Highest catches in seagrass within 200 m of the high-water, and during pre-wet, wet season	Loneragan, N. R., Kenyon, R. A., Haywood, M. D. E., and Staples, D. J. (1994)
GoC	Embley River	/Rhizophora /Ceriops	Penaeus merguiensis	***	mapping of vegetation types by remote sensing to increase	Long, B., Vance, D., and

Region	Location	habitat type	taxa	stage	type of study or results	reference
	estuary	/Avicennia			knowledge of the critical components of mangrove ecosystems that support banana prawn production	Conacher, C. (1992)
GoC	Embley-Estuary	***	Lutjanus- russelli	juv.	rates of consumption of marine-crustaceans, and effects of temperature, with reference to predation on prawns	Smith, R. L., Salini, J. P., and Blaber, S. J. M. (1991)
GoC	***	***	Caranx bucculentus	***	rates of consumption of marine-crustaceans, and effects of temperature, with reference to predation on prawns	Smith, R. L., Salini, J. P., and Blaber, S. J. M. (1992)
GoC	Norman-Estuary	estuary, nearshore bay	Penaeus- merguiensis	juvs	juveniles /migrations /population-structure/growth	Staples, D. J (1980a)
GoC	Norman-Estuary	estuary	Penaeus-merguiensis	post-larvae, new recruits	/life-cycle/ecology /hydrology/recruitment	Staples, D. J. (1980b)
GoC	Groote Eylandt	Thalassia, Cymodocea, Syringodium, Halophila, Enhalus	Penaeus esculentus ++ others	juv.	Compared reef flat Thalassia beds, (ii) Shelving beach Cymodocea and Syringodium beds, (iii) River mouth Halophila beds and (iv) Sheltered embayments characterised by Enhalus. Prawn abundance increased with seagrass biomass	Staples, D. J. and Poiner, I. R. (1987)
GoC	Norman River estuary	mangrove creeks and channel	Penaeus merguiensis	***	Postlarvae migrated vertically in response to changes in tidal height, rising to near the surface just before low tide, and entered the estuary throughout the flood tide peaking maximum current, regardless of time of day or night. Deeper in wet season	Staples, D. J. and Vance, D. J. (1985)
GoC	Gulf of Carpentaria	***	Penaeus-merguiensis	sub-adults	emigration from nurseries is governed by rainfall	Staples, D. J. and Vance, D. J. (1986)
GoC	Carpentaria-Gulf	5 estuaries	Penaeus-merguiensis	***	regional comparisons of recruitment /population-dynamics/migration	Staples, D. J. and Vance, D. J. (1987)
GoC	experimental	experimental	Penaeus-merguiensis/Penaeus-esculentus/Metapenaeus-endeavouri	juv.	experimental-research on effects of diurnal-variations/tidal-cycles on behaviour /avoidance-reactions/activity-patterns of juveniles with reference to catchability/predation /habitat-selection	Vance, D. J. (1992)
GoC	Embley River estuary	mangrove creeks, mudflats	Penaeus merguiensis	postlarvae-juv.	settled on all habitat types in the estuary, but large catches were only taken on the mangrove-lined banks and dsn., except in the wet season, was not related to salinity. Upstream catches 5 times higher than those near the creek mouth	Vance, D. J., Haywood, M. D. E., and Staples, D. J. (1990)
GoC	Embley River estuary	Enhalus acoroides, Halodule uninervis, H. ovalis, also algae	Penaeus semisulcatus	post-larvae	6 yr study of environmental forcing in longitudinal estuarine comparison amongst habitats, times and size classes. Number of settlers determined n juvs, algal habitats lost	Vance, D. J., Haywood, M. D. E., Heales, D. S., and Staples, D. J. (1996b)

Region	Location	habitat type	taxa	stage	type of study or results	reference
		Caulerpa spp			*during wet. Consistent seasonal peaks and bimodal recruitment.*	
GoC	*Embley-Estuary*	***	*Penaeus-semisulcatus*	*juv.*	*variance in beam-trawl sampling induced by seasonal-variations/diurnal-variations/tidal-effects*	*Vance, D. J., Heales, D. S., and Loneragan, N. R. (1994)*
GoC	*Embley River estuary*	*Rhizophora, Ceriops fringe vs stand*	*Penaeus merguiensis and 55 fish species*	*juv*	*first study to quantify extent of movement of juveniles into forest margins. Found differences between "inland" and "fringe" sites. Prawns were indifferent, but fish were in greater numbers, size, biomass and diversity at fringe.*	*Vance, Dave J., Haywood, M. D. E., Heales, D. S., Kenyon, R. A., Loneragan, N. R., and Pendrey, R. C. (1996a)*
GoC	*Carpentaria-Gulf*	***	*Penaeus- merguiensis*	*juv.-adult*	*feeding-behaviour and diets related to body-size/tidal-effects*	*Wassenberg, T. J. and Hill, B. J. (1993)*
Indo-Pacific	*review*	***	***	***	*review of estuarine processes and communities in tropical oceans*	*Longhurst, A. R. and Pauly, D. (1987)*
Indo-Pacific	*Indo-Pacific*	*mangrove ecosystems*	*Penaeus merguiensis*	***	*Indo-pacific wide collecting indicated that the life-history was based on a common pattern of two cohorts per year. Differential survival resulted in one of the cohorts contributing more to the offshore fishery than the other. Rainfall controls emigration.*	*Staples, D. J. and Rothlisberg, P. C. (1990)*
NQ	***	*mangrove creeks, channel*	*Acanthopagrus berda, Ctenogobius criniger, Chelonodon patoca, Anodontostoma chacunda*	***	*feeding ecology, morphology and some notes on nursery function*	*Beumer, J. P. (1978)*
NQ	*Cairns-Bowen*	***	***	***	*inventory of seagrass beds and fish and prawn catches in them*	*Coles, R. G., Lee-Long, W. J., Helmke, S. A., Bennett, R. E., Miller, K. J., and Derbyshire, K. J. (1992)*
NQ	*Cairns Harbour*	*8 species of seagrass*	*134 fish , 20 prawn species*	*juv.*	*distribution of seagrasses and their population of juvenile prawns and fish*	*Coles, R. G., Lee-Long, W. J., Watson, R. A., and Derbyshire, K. J. (1993)*
NQ	*Cape York- Cairns*	*13 species of seagrass*	*6 Penaeid prawn species*	*juv.*	*seagrasses spatial-distribution/species-composition/life-cycle/habitat-preferences/population-levels. Enhalus and Thalassia were uncommon, perhaps stressed by turbidity*	*Coles, R. G., Long, W. J. L., Squire, B. A., Squire, L. C., and Bibby, J. M. (1987a)*
NQ	*Bowen-Water Park Point*	***	*penaeids*	*juv.*	*inventory of seagrass and nursery locations for penaeids in "one off" mapping exercise*	*Coles, R., Mellors, J., Bibby, J., and Squire, B. (1987)*

Region	*Location*	*habitat type*	*taxa*	*stage*	*type of study or results*	*reference*
NQ	*Halifax, Cleveland, Bowling Green Bays*	*nearshore bays*	*Scomberomorus spp.*	*larvae*	*feeding of larvae, especially on anchovy larvae*	*Jenkins, G. P., Milward, N. E., and Hartwick, R. F. (1984)*
NQ	*Halifax, Cleveland, Bowling Green Bays*	*cross-shelf transect*	*Scomberomorus spp.*	*larvae*	*separation of species along turbidity gradient*	*Jenkins, G. P., Milward, N. E., and Hartwick, R. F. (1985)*
NQ	*Water Park Point to Hervey Bay*	*seagrass*	***	*juv.*	*maps and inventory of sea-grass and nursery-grounds for - fish and prawns*	*Lee-Long, W. J., Coles, R. G., Miller, K. J., Vidler, K. P., and Derbyshire, K. J. (1992)*
NQ	*Cape York-Hervey Bay*	*14 spp seagrass*	***	***	*broad description of latitudinal and abiotic (depth, sediment, turbidity) patterns and newly found deepwater beds*	*Lee-Long, W. J., Mellors, J. E., and Coles, R. G. (1993)*
NQ	*Green Island*	*seagrass*	*carid, sergestid and penaeid prawns*	*juv.*	*Beam trawl, standing crop and "living index" of seagrass failed to correlate with penaeid abundance*	*Mellors, J. E. and Marsh, H. (1993)*
NQ	*Alligator Creek*	*Avicennia, Rhizophora, Ceriops drain-off creeks*	*Penaeus- merguiensis*	*post-larvae-juv.*	*prawns 1-21 mm carapace length entered the mangrove forest at high tide throughout the year. Diet of prawns varied with size and microhabitat. Barramundi 30-50 cm greatest predators with 22% of diet made up of prawns.*	*Robertson, A. I. (1988a)*
NQ	*Alligator Creek, and mangrove sampling in Escape, Lockhart, McIvor Rivers*	*Avicennia marina, Rhizophora stylosa, Ceriops tagal vs Halophila/Halodule*	*203 spp of fish, 47 spp of crustaceans*	*juv.-adult*	*comparison of community structure in seagrass vs Mangroves and inferences as to importance as nursery sites. comparisons were made amongst microhabitats, amongst regional river systems and amongst single species*	*Robertson, A. I. and Duke, N. C. (1987)*
NQ	*Alligator Creek*	*Avicennia marina, Rhizophora stylosa, Ceriops tagal*	*20 fish spp from 10 families selected*	*new recruits, juv.*	*recruitment for most spp in late dry to mid wet season. Study examined recruitment time, cohort growth, departure and "estuarine residency"*	*Robertson, A. I. and Duke, N. C. (1990a)*
NQ	*Alligator Creek*	*Avicennia marina, Rhizophora stylosa, Ceriops tagal*	*128 fish spp from 43 families*	*juv.- adult*	*a study of seasonal and tidal variation in microhabitat (forest, creek, accreting banks, channel) use by fish communities and estimates of density and biomass*	*Robertson, A. I. and Duke, N. C. (1990b)*
NQ	*Alligator Creek*	*Avicennia, Rhizophora, Ceriops channel vs seagrass, offshore*	*170 zooplankton taxa*	*larvae-adult*	*zooplankton community compared amongst mangrove creek, mainstream, adjacent seagrass flat and 10km offshore. Brachyuran eggs and zoeae important fish prey are an order of magnitude more abundant in summer in mangroves.*	*Robertson, A. I., Dixon, P., and Daniel, P. A. (1988)*
NQ	*Alligator Creek*	*Avicennia, Rhizophora, Ceriops creeks and channel snags*	*23 fish species from 15 families*	*juv.-adult*	*Baited fish trapping (Z traps) in deeper snags and channels caught 8 large taxa not vulnerable to usual netting techniques. Upstream decline in abundance and microhabitat differences were evident*	*Sheaves, M. J. (1992)*

Region	Location	habitat type	taxa	stage	type of study or results	reference
NQ	Alligator-Creek	***	Epinephelus coioides, E. malabaricus, Lutjanus- russelli, Acanthopagrus berda, A. australis, Arothron-manilensis	***	local movements, home ranges and lack of seasonal displacements	Sheaves, M. J. (1993)
NQ	6 sites in Bowling Green, Cleveland and Halifax Bays	mangrove creeks and channels	Epinephelus coioides, E. malabaricus, Lutjanus russelli, L. argentimaculatus	juv-sub-adult	Biological (size, age, reproduction) studies showed all these large, (up to 50cm) major taxa are reproductively immature in estuaries. Mark-recapture and tetracycline validation used with baited fish traps	Sheaves, M. J. (1995a)
NQ	6 sites in Bowling Green, Cleveland and Halifax Bays	mangrove creeks and channels	22 fish species, incl. Acanthopagrus berda, A. australis, Epinephelus spp, Lutjanus russelli	sub-adult-adult	Baited trap catches compared amongst tidal states, mesh sizes, entrance funnel designs, soak times, bait container designs and parts of one lunar cycle	Sheaves, M. J. (1995b)
NQ	3 sites in Bowling Green and Cleveland Bays	mangrove creeks and channel	Epinephelus coioides, E. malabaricus	juv.-sub-adult females	E. malabaricus shows better adaptation to cope with variable salinity, and is generally found further upstream and is more common in some estuaries than others.	Sheaves, M.J. (1996)
NQ	Cleveland-Bay	nearshore, bay	Carcharhinidae /Sphyrnidae	***	nursery-grounds/food-availability/seasonality	Simpfendorfer, C. A. and Milward, N. E. (1993)
NQ	Torres Strait	trawl ground		***	spatial-distribution/species-composition of prawns in relation to sediment type	Somers, I. F., Poiner, I. R., and Harris, A. N. (1987)
NQ	Torres Strait	seagrass species	Penaeid prawns	benthic post-larvae, juvs	spatial and temporal dynamics of prawn nursery role of seagrass, including extensive "reef top" seagrass beds	Turnbull, C. T. and Mellors, J. E. (1990)
NQ	Cairns Hbr	Zostera capricorni, Halodule pinifolia	Penaeus esculentus, P. semisulcatus, Metapenaeus endeavouri	***	potential total annual yield from Cairns Harbour seagrasses for the 3 maj. prawn species were 178 t (range 81-316 t) per yr with a landed value of $A1.2 million per yr range($0.6 million to $2.2 million per yr).	Watson, R. A., Coles, R. G., and Lee-Long, W. J. (1993)
NQ	Bowling Green Bay, Cleveland Bay	estuary, nearshore, bay trawl grounds	Amblygaster sirm, Herklotsichthys spp, Sardinella spp	***	ontogenetic shifts in nearshore resource use by baitfish species and autumn migration out into pelagic food chains topped by juvenile billfishes	Williams, D. McB. and Cappo, M. (1990)
NSW	Botany Bay	Zostera-capricorni/Posidonia-australis	6 invertebrate prey taxa	***	leaves were experimentally shortened and thinned an community structure was compared for 6 prey taxa and fish. Both had significant negative effects on communities	Bell, J. D. and Westoby, M. (1986a)
NSW	***	Zostera-	6 invertebrate prey	***	prey density found to be proportional to shoot density	Bell, J. D. and Westoby, M.

Region	Location	habitat type	taxa	stage	type of study or results	reference
		capricorni/Posidonia-australis	taxa		when experimentally thinned, with no influence of predation	(1986a)
NSW	Botany Bay	Zostera-capricorni/Posidonia-australis	fish and decapods	***	15 of 23 significant responses found in previous small-scale experiment did not appear when repeated at wider scale among beds. No other environmental correlates with the failure of the relationships were detected	Bell, J. D. and Westoby, M. (1986b,c)
NSW	Botany Bay	Zostera-capricorni	Gobiidae, Syngnathidae, Scorpaenidae, Ophichthidae	***	seagrass-fish-community was negatively affected by the abundance of Giffordia mitchellie - a macroalgal bloom of epiphytic-algae	Bell, J. D. and Westoby, M. (1987)
NSW	Port Hacking	Posidonia australis	Centropogon-australis	***	crustaceans comprised 90% of diet feeding-behaviour	Bell, J. D., Burchmore, J. J., and Pollard, D. A. (1978a)
NSW	Port Hacking	Posidonia australis	Monacanthus chinensis, Meuschenia freycineti, M. trachylepis	***	feeding-behaviour of Monacanthidae omnivorous on epiphytic algae and epifauna	Bell, J. D., Burchmore, J. J., and Pollard, D. A. (1978b)
NSW	Jervis Bay	Posidonia-australis	Stigmatopora-argus/Gymnapistes-marmoratus/Siphamia-cephalotes/Upeneichthys-porosus ++ others	***	consistent differences between the deep and shallow margins of seagrass in dominant-species/community-composition species-diversity	Bell, J. D., Ferrell, D. J., NcNeill, S. E., and Worthington, D. G. (1992)
NSW	Botany Bay	Avicennia marina	48 species of fish	juv.-ad.	Block-net. Exclusive use of this habitat by small juveniles of several species.14 species were economically important, making up 38% of individuals and 32% of biomass and were represented only by small juveniles.	Bell, J. D., Pollard, D. A., Burchmore, J. J., Pease, B. C., and Middleton, M. J. (1984)
NSW	***	Artif. seagrass vs Zostera capricorni	***	***	7 sq. m. artificial sea-grass deployed adjacent to Zostera capricorni. signif. less spp in ASUs , but same abundance, probably due to time needed to accumulate vagile macrofauna	Bell, J. D., Steffe, A. S., and Westoby, M. (1985)
NSW	***	Zostera capricorni	***	***	position of the bed within an estuary, not bed size, leaf density or height, and the abundance of competent larvae determined the consistent zonal patterns seen	Bell, J. D., Steffe, A. S., and Westoby, M. (1988)
NSW	Botany Bay	Artif. seagrass units	29 spp, including Achoerodus viridis	***	not specific selection for blade densities, or predation - rather availability of fish-larvae prepared to settle indiscriminately into any shelter	Bell, J. D., Westoby, M., and Steffe, A. S. (1987)

Region	Location	habitat type	taxa	stage	type of study or results	reference
NSW	Botany Bay	shallow (<4 m), deep (>4m), sandy vs muddy vs vegetated habitats (Zostera, Posidonia)	Sillago ciliata, S. maculata maculata, S. robusta, S. bassensis flindersi	juv.-ad.	habitat associations and feeding, reproduction ; also speculation on effects of dredging ;(1) S.ciliata and S. m. maculata ; shallow sandy beach <4 m and Zostera; (2) S. robusta, S. b. flindersi ;deep>4 m sandy sites. Ontogenetic. shifts in habitat use/diet	Burchmore et al. (1988)
NSW	Port- Hacking	Posidonia-australis	39 species	***	community-structure/trophic-relationships showed crustacean comprised 50% of community diets. 30% of fish were of economic importance	Burchmore, J. J., Pollard, D. A., and Bell, J. D. (1984)
NSW	5 estuaries and one ocean site comprising entire range of P.australis	Posidonia australis	323 invertebrate species	***	species-composition/community- structure/benthos. Polychaetes, molluscs, crustaceans dominated	Collett, L. C., Hutchings, P. A., Gibbs, P. J., and Collins, A. J. (1984)
NSW	Botany Bay	seagrass	Monacanthus chinensis	adults	6.5/biomass /plants /marine-ecology/feeding-behaviour/Invertebrate /production/ISW,-Australia,-Botany-Bay	Conacher, M. J., Lanzing, W. J. R., and Larkum, A. W. D. (1979)
NSW	East Coast	trawl grounds, shelf	Penaeus plebejus	***	identification of source of recruits for prawn fishery, and nursery habitats, using trace element analysis	Courtney, A. J., Die, D. J., and Holmes, M. J. (1994)
NSW	***	Zostera capricorni vs Bare sand	***	***	diversity and abundance of fish always greater in seagrass than over bare sand >100m away, but not always signif more abundant for bare sand <=10m away	Ferrell, D. J. and Bell, J. D. (1991)
NSW	GET	Posidonia-australis	***	***	beam trawl compared among-beds and among estuaries	Ferrell, D. J., McNeill, S. E., Worthington, D. G., and Bell, J. D. (1993)
NSW	Jervis Bay	bay	Pecten fumatus	juv.-ad.	distribution, growth, episodic recruitment variability	Fuentes (1994)
NSW	Hawkesbury-Nepean River	freshw. and estuary	***	***	nutrification/recruitment/estuaries/freshwater/changes-to-drainage	Gehrke, P. C. and Harris, J. H. (1996)
NSW	Clarence River	estuary	Metapenaeus macleayi	juv.-ad.	movement, growth	Glaister (1978b)
NSW	Clarence, Evans, Richmond Rivers	estuary vs oceanic catch	Metapenaeus macleayi	juv.-ad.	Consistent (among 3 river systems) influence of environmental-flows in Nov. river discharge on prawn distribution and production. Also suggest northward migration and inter-estuary exchange from sth to nth of adults. Lunar periodicity in downstr migration	Glaister, J. P. (1978a)
NSW	Sydney region 3	seagrass	Macrobrachium-	***	within/among estuary patterns attributed not to seagrass	Gray, C. A. (1991a)

Region	Location	habitat type	taxa	stage	type of study or results	reference
	estuaries		intermedium		bed type or size, rather the "aspect', water depth and their interactions with competent larvae	
NSW	Port-Hacking	Posidonia australis, Zostera capricorni	Macrobrachium-intermedium	***	No consistent temporal or spatial (between seagrass spp) variation in demography caught with beam trawl	Gray, C. A. (1991b)
NSW	8 north coast estuaries	Zostera capricorni	54 fish species (see Table 1.4.5.1)	***	seagrass vs bare-sand fish-community study. Abundances of spp varied as much between location as they did amongst estuaries. Economically important species were caught	Gray, C. A., McElligott, D. J., and Chick, R. C. (1996)
NSW	***	artificial pontoons	***	new recruits	fish recruitment to artificial-substrata was lower than seagrass 4 km away, ma y be due to position of pontoons in water-column and vertical-motion, as well as abundance of larvae	Hair, C. A. (1992)
NSW	Port-Hacking	artificial-seaweed	***	***	fish- larvae settling onto pontoons as a means of habitat-improvement	Hair, C. A. and Bell, J. D. (1992)
NSW	Botany Bay and 15 other sites	Zostera capricorni	Rhabdosargus-sarba/Girella-tricuspidata/Achoerodus viridis	new recruits, juv.	a "recruitment" sink was found where recruitment was up to 73 times higher for these taxa than elsewhere, although the pattern faded with ontogenetic dispersal away from beds	McNeill, S. E., Worthington, D. G., Ferrell, D. J., and Bell, J. D. (1992)
NSW	Botany Bay	Zostera capricorni, Posidonia australis	102 spp in 52 families ; including Girella, Acanthopagrus, Platycephalus, Sillago, mugilids	***	fish community comparative study. No signif. difference between 2 seagrasses w.r.t species richness or abundance, but Posidonia had overall higher biomass, perhaps due to structural complexity. Summer peak in all community measures, incl. juvenile recruit	Middleton, M. J., Bell, J. D., Burchmore, J. J., Pollard, D. A., and Pease, B. C. (1984)
NSW	Macquarie-L	coastal lagoon	106 taxa incl. Acanthopagrus australis, Rhabdosargus sarba, Pagrus auratus	larvae	3yr survey to determine spp comp., seasonal variation in abundance and size at entry of larvae into the estuary. tidal/diel dynamics of exit/entry of larval sparids into a coastal lagoon through a restricted entrance	Miskiewicz, A. G. (1986)
NSW	Clarence R.	estuarine/freshwater/drains	***	juv.-adult	comparison of floodgated vs ungated, and above/below gate comparisons of community composition and habitat quality	Pollard, D. (1993a)
NSW	***	coastal lagoons	comm. estuarine taxa	juv.-adult	comparison of community-composition/fisheries in permanently vs intermittently closed lagoons	Pollard, D. A. (1994a)
NSW	Hunter River	estuary	Metapenaeus macleayi	***	prawn production related to /rainfall/environmental-flows	Ruello, N. V. (1973)
NSW		***	***	***	orientation-behaviour of fish-larvae/geographical-	Steffe, A. S. and Westoby, M.

Region	Location	habitat type	taxa	stage	type of study or results	reference
					distribution predicted by mathematical-models/environmental-conditions/nearshore-dynamics	(1992)
NSW	***	Posidonia-australis/Zostera-capricorni	Stigmatopora, S. argus, S. nigra	adults	field expt to test effects of plant-morphology on fecundity /size-sex distribution	Steffe, A. S., Westoby, M., and Bell, J. D. (1989)
NSW	Clarence-R, -Richmond-R.	seagrass, brackish/fresh water submerged veg. , deep channels	see Table 1.4.5.1	new recruits, juv.-ad.	inventory of vegetated habitats/ longitudinal comparison of size and community composition of vegetated/unveg habitats and deep channels/stock-assessment/ community changes due to floodgates	West, R. J. (1993)
NSW	Clarence-R, -Richmond-R.	estuary	see Table 1.4.5.1	***	catch-sharing/landings/fisheries-production/commercial+sport-fishing	West, R. J. and Gordon, G. N. G. (1994)
NSW	16 estuaries	Zostera capricorni, Posidonia australis	Macrobrachium intermedium ++ other taxa	***	Variation in density of Z. capricorni shoots explained very little of the variation in abundance of animals. However, abundance the grass shrimp was more closely related to the density of shoots during non-recruitment seasons	Worthington, D. G., Ferrell, D. J., McNeill, S. E., and Bell, J. D. (1992a)
NSW	Botany Bay	Zostera-capricorni/Posidonia-australis/	Rhabdosargus sarba, Acanthopagrus australis, Achoerodus viridis, Girella tricuspidata	***	2-3 cohorts of all, except Girella, where up to 7 cohorts. Growth rates estimated	Worthington, D. G., Ferrell, D. J., McNeill, S. E., and Bell, J. D. (1992b)
NSW	Botany Bay	Artificial seagrass (ASUs) simulated isolated habitats 0, 25, 50, 100, 200, 400 leaves per sq. m.	21 species	***	newly-settled Achoerodus viridis increased greatly between 0 and 25 leaves per msq. At > 25 leaves per m sq A. viridis settled in approximately equal numbers. Epiphytic Giffordia increased structural complexity and confounded some treatments	Worthington, D. G., Westoby, M., and Bell, J. D. (1991)
NT	van Diemen Gulf	***	***	***	NT/3.5/4.5/barramundi-nurseries	Davis, T. L. O. (1985)
NT	Leanyer Swamp	mangrove swamp	38 spp from 24 families	new-recruits, juv.	season, the sequence of flood spring tides and the height of these tides determined the movement of the fish community. Abundance of some spp determined more by their breeding patterns/dispersal abilities of juveniles than by temp./salinity	Davis, T. L. O. (1988)
NT	Daly River	estuary	Lates calcarifer	juv.-ad.	distribution, migration, growth, seasonality	Griffin (1987b)
NT	Chambers Bay/Finke Bay	wetland, upper tidal , saltmarsh	Lates calcarifer	***	mapping of critical nursery habitat for barramundi, and vegetative correlates	Griffin, R. K. (In Press)

Region	Location	habitat type	taxa	stage	type of study or results	reference
nWA	Dampier	mangrove creeks	Caranx ignobilis, Carcharhinus limbatus, Scomberoides commersonianus and Scomberomorus semifasciatus ++ others	sub-ad.-adult	Large piscivores are unusually abundant in theses creeks. Feeding studies showed Atherinidae, Sillago spp. and Harengula (Herklotsichthys) the most preferred and Ambassis sp. the least preferred.	Blaber, S. J. M. (1986)
nWA	Dampier	mangroves and foreshores	165 spp	sub-ad-adult	Compared foreshore and creek communities. 54 spp common to both. Piscivores penetrated at high tide in clear creeks. Iliophagous spp abundant. Inshore region not a signif. nursery ground for offshore commercial spp and no overlap with fauna >20m	Blaber, S. J. M., Young, J. W., and Dunning, M. C. (1985)
nWA	Shark Bay	bay, shelf	Pagrus auratus	***	fine stock structure, within bay scale	Johnson et al. (1986)
SA	Barker Inlet	Zostera-muelleri	Stigmatopora-nigra/Sillaginodes-punctata/Rhombosolea-tapirina/Atherinosoma-microstoma	juv.	/community-composition/ compared amongst bare/seagrass. Juvenile whiting over seagrass, flounder over bare	Connolly, R. M. (1994a)
SA	Barker Inlet	Zostera-muelleri	Sillaginodes-punctata/Favonigobius-lateralis/	***	efficiency and catch-composition of seines and bouyant pop-net in sea-grass. Seines fast, but best for only presence/absence work.	Connolly, R. M. (1994b)
SA	Barker Inlet	Zostera-muelleri vs bare, cleared patches	Sillaginodes punctata ++ others	***	experimental clearance of seagrass to allow for comparisons amongst bare sand/ cleared patches/ untouched seagrass. Looked at response of epifauna and S.punctata	Connolly, R. M. (1994c)
SA	***	Zostera-muelleri	Sillaginodes-punctata	***	experimental set-up to examine vegetated vs bare habitat choice in day/night and satiated/hungry situations where food density could be manipulated	Connolly, R. M. (1994d)
SA	Coorong-Lagoon	***	***	***	effects of freshwater flows from river-discharge on/water-salinity/macrophytes /benthos and fish	Geddes, M. C. (1987)

Region	*Location*	*habitat type*	*taxa*	*stage*	*type of study or results*	*reference*
SA	*Coorong*	*estuary*	*Aldrichetta forsteri, Argyrosomus hololepidotus, Acanthopagrus butcheri, Rhombosolea tapirina, Arripis truttaceus*	*juv.-ad.*	*biology of maj. spp, environmental flows and catch rates; all mulloway >200mm; Effort and flounder and mulloway catch has declined markedly. recent increase in black bream. Biology and fisheries for major spp described.*	*Hall (1984)*
SA	*Port River Estuary-Barker Inlet*	*seagrass, mangrove, mudflats*	*41 spp of fish and elasmobranchs (see Table 1.4.5.1)*	*juv.-adults*	*Life-history patterns, direct effects of temp./salinity, and habitat differences amongst sites governed fish community distribution and this was influenced by warm effluent from the power station.*	*Jones, G.K., Baker,J.L., Edyvane, K. and Wright, G.J. (1996)*
SA	*West Coast Bays, Great Australian Bight*	*bays*	*Penaeus latisulcatus*	*post-larvae, juv.*	*Nett flood night tides correspond with spawning season. Nurseries in extensive littoral sandflats in lees or other shelter. Some bays had lethal extremes of salinity and temp. Preferred habitat is fine, bare sand in shallows*	*Wallner, B. (1985)*
SEQ	*Tin Can Bay*	*Zostera capricorni, Halophila before/after dieback*	*52 fish species from 34 families*	*benthic postlarval-juv.*	*Roller-beam trawl, ring-net. Loss of seagrass had no effect on numbers, may have affected overall species composition, but no effect on major 10 spp.*	*Beumer, J. and Halliday, I. (1994)*
SEQ	*Moreton-Bay*	*4 habitat types; mangrove fringe vs seagrass and sandy vs muddy substrata*	*25 teleosts from 12 families*	*new recruits - adults*	*spawning, recruitment, diet presented together with measurements of salinity, temp, turbidity, substrata. Juveniles of many spp are attracted to turbid shallows rather than estuaries per se. salinity and temp unimportant to most spp*	*Blaber, S. J. M. and Blaber, T. G. (1980)*
SEQ	***	*field and laboratory, mangrove/seagrass*	*Sillago analis*	*sub-ad.-adult*	*calculation of electivity indices prey-selection on siphon tips of Glauconome-virens/Annelida /Crustacea in field and lab. experiments*	*Brewer, D. T. and Warburton, K. (1992)*
SEQ	*Tin Can Bay*	*Zostera capricorni, Halophila*	*Penaeus plebejus, Metapenaeus bennettae, M. endeavouri, P.esculentus*	*benthic postlarvae and juv.*	*Beam Trawl. Comparison of catches at seagrass die-back site and sparse vs dense seagrass. P.plebejus dominated sparse and dense sites, and colonised dieback sites and such events may not be detrimental to all fisheries*	*Halliday, I. A. (1995)*
SEQ	*Tin Can Bay*	*Rhizophora stylosa fringe*	*42 spp of fish from 24 families*	*juv.-adults*	*Fence block-off method. Novel and effective means of assessing use of forest fringe. Lower abundances than other studies may be due to habitat complexity ; still important nursery for fisheries*	*Halliday, I. A. and Young, W. R. (1996)*

Region	Location	habitat type	taxa	stage	type of study or results	reference
SEQ	?	tidal mudflats	Scylla serrata	juv.-ad.	Distribution among microhabitats	Hill et al. (1982)
SEQ	experimental tanks	artificial seagrass vs bare sand	Penaeus-esculentus/Penaeus-semisulcatus	juv. and adult	ontogenetic differences in tank response and diel position and burying in response to seagrass	Hill, B. J. and Wassenberg, T. J. (1993)
SEQ	Sunshine Coast	bay, estuary	***	***	inventory of catches and habitats	Hyland (1993)
SEQ	Hervey Bay	bay, estuary	***	***	inventory of catches and habitats	Hyland (1993a)
SEQ	***	bay, estuary	Scylla serrata	juv.-ad.	distribution, movement	Hyland et al. (1984)
SEQ	Moreton Bay	Avicennia marina vs seagrass vs mudflats	53 fish species	juv.	Trap and seine nets to compare seagrass, mudflats and mangrove fringe habitats. Seagrass had distinct fauna not economically important; mudflats are transition zones between juv/adult habitats. Mangroves most important nursery for economically important species.	Laegdsgaard, P. and Johnson, C. R. (1995)
SEQ	***	***	***	***	studies of fish communities in canal estates /silting /stratification /species-diversity/hydrology /community-composition/dissolved-oxygen/sediments	Morton, R. M. (1989)
SEQ	Moreton Bay	Avicennia marina fringe and channel	***	***	Forty six percent of the species, 75% of the number of fishes and 94% of the biomass taken during the study (all methods combined) were of direct importance to regional fisheries.	Morton, R. M. (1990)
SEQ	Tallebudgera-Estuary/	***	***	***	study of hydrology /dissolved-oxygen/fishery-resources/community-composition in a canal estate	Morton, R. M. (1992)
SEQ	Fraser-I.	***	***	***	marine-fisheries/commercial+sport-fishing/stock-assessment	Morton, R. M. and Healy, T. (1992)
SEQ	Moreton-Bay	***	Pomatomus saltatrix	***	movement/nursery	Morton, R. M., Halliday, I., and Cameron, D. (1993)
SEQ	Toondah Hbr	Zostera capricorni	Penaeus esculentus	new recruits (benthic post-larvae), juv.	diets changed markedly with ontogeny of juveniles from diatoms to filamentous algae to sea-grass and Copepoda /Decapoda /Ostracoda /Gastropoda	O'-Brien, C. J. (1994a)
SEQ	Moreton-Bay	***	Penaeus-esculentus	juv.	population-dynamics/growth /mortality	O'-Brien, C. J. (1994b)
SEQ	Serpentine Creek	***	***	***	effects of sampling during different moon-phases, tidal direction and time of day	Quinn, N. J. and Kojis, B. L. (1981,1987)
SEQ	Moreton-Bay	***	***	***	fishery-resources/stock-assessment/	Quinn, R. H. (1992)
SEQ	Nerang River	river mouth vs 2km	Penaeus-plebejus	post-larval	PL's change from a diurnally-migrating to a tidally vertically	Rothlisberg, P. C., Church, J. A.,

Region	Location	habitat type	taxa	stage	type of study or results	reference
		offshore (20m) vs 12km offshore (50m)			migrating strategy once the pressure change at the bottom becomes a significant fraction of the total pressure. The importance of small localised near-shore spawning has been underestimated	and Fandry, C. B. (1995)
SEQ	Logan-Albert System, Moreton-Bay	***	Johnnies-vogleri/Polynemus-multiradiatus/Aseraggodes-macleayanus/Arius-graeffii	***	stomach-contents by age-composition and predation on Copepoda /Mysidacea/Acetes during and after freshwater flooding	Sumpton, W. and Greenwood, J. (1990)
SEQ	Moreton Bay	St Helen and Green Islands; 7 sites ; varying in seagrass and shell substrata	5spp in Apogon, Monacanthus, Paramonacanthus, Pelates, Leiognathus	new-recruits-adults	Diet and distribution study; juveniles of the 5 species recruited to the area, with all except L. moretoniensis being most abundant at the most vegetated site; evidence of ontogenetic migration into deeper water in all species	Warburton, K. and Blaber, S. J. M. (1992)
SEQ	Moreton-Bay	Zostera-capricorni	Penaeus-esculentus	juv.	seasonality of seagrass seed predation by prawns	Wassenberg, T. J. (1990)
SEQ	Moreton-Bay	estuary and bay shallows	Sillago-ciliata, S.analis, S.maculata	new recruits, 10-90mm long	Used QUINALDINE. Habitat preferences for sediment types and seasonal occurrence, with a guide to identification	Weng, H. T. (1983)
SEQ	Moreton-Bay	bay trawl grounds	***	***	catch-composition/commercial-species/ecological-zonation	Weng, H. T. (1988)
SEQ	Moreton-Bay	?	***	***	environmental correlates of fish community distribution and structure in shallow bay waters	Weng, H. T. (1990)
SEQ	Moreton-Bay	***	Penaeidae	***	nursery-role/ecological-distribution/environmental-factors/stock-assessment/	Young, P. C. (1978)
SEQ	Moreton Bay	***	Penaeus-plebejus/Penaeus-esculentus/Metapenaeus-bennettae	juv.	nursery habitats and seasonal-variations in recruitment to them	Young, P. C. and Carpenter, S. M (1977)
SEQ	Moreton Bay	***	Penaeidae	***	distribution of benthic megafauna	Young, P. C. and Wadley, V. A. (1979)
sWA	Swan River	estuary	Apogon ruppelli	juv.-ad.	age, growth, movement	Chrystal et al. (1985)
sWA	Swan River	estuary	Nematalosa vlaminghi	juv.-ad.	age, growth, distribution, reproduction	Chubb and Potter (1986)
sWA	Swan River	estuary	Mugil cephalus, Aldrichetta forsteri	juv.-ad.	age, growth, movement	Chubb et al. (1981)
sWA	Swan-Avon-Estuary	***	Nematalosa-vlaminghi	***	reproductive-cycle/oogenesis /movements within estuary around salinity changes	Chubb, C. F. and Potter, I. C. (1984)

Region	Location	habitat type	taxa	stage	type of study or results	reference
sWA	7 mile beach vs Dongara	Amphibolis antarctica, Halophila, Heterozostera	Panulirus cygnus	juv.	juveniles ate epifauna on Amphibolis at 30 mm carapace length, then shifted to herbivory of filamentous coralline algae except at Cliff head where they ate the trochid Cantharidus lepidus	Edgar, G. J. (1989)
sWA	Cliff Head vs 7 Mile	Amphibolis, Posidonia, Halophila, Heterozostera	macrofauna	***	species-diversity/community-composition/biomass /secondary-production and production of debris /particulate-organic-matter,	Edgar, G. J. (1990a)
sWA	Cliff Head vs 7 Mile	Amphibolis, Posidonia, Halophila, Heterozostera	***	***	used experimental microcosms to shade seagrass in various treatments then measured population-dynamics of vagile-species and production	Edgar, G. J. (1990b)
sWA	Cliff Head vs 7 Mile	Amphibolis, Posidonia, Halophila, Heterozostera	Panulirus-cygnus/	***	Feeding ecology and prey abundance. In the absence of gastropod abundance at 7 mile, the lobster juveniles ate filamentous coralline algae. They preyed heavily on trochid Cantharidus at Cliff Head. Intraspecifc competition is possible	Edgar, G. J. (1990c)
sWA	Cliff Head	Amphibolis, Posidonia, Halophila, Heterozostera	Portunus-pelagicus	***	Studies of food abundance and crab feeding showed ontogenetic difference and very fast growth. Seagrass herbivory and mostly slow-moving gastropods comprise diet.	Edgar, G. J. (1990d)
sWA	Cliff Head	Amphibolis, Posidonia, Halophila, Heterozostera	Panulirus-cygnus	***	predation and prey-selection by lobsters for trochid Cantharidus. Using caging experiments and estimation of consumption rates, lobsters known to graze down trochids and could compete intraspecifically	Edgar, G. J. (1990e)
sWA	Cliff Head	Amphibolis, Halophila	epifaunal invertebrates	***	daily turnover and colonisation of epifaunal invertebrates	Edgar, G. J. (1992)
sWA	***	Amphibolis antarctica, A. griffithsi	***	***	3 experimental leaf and epiphyte trimming treatments allowed inference that there were a) leaf-associated, b) epiphyte associated and c) taxa which need both	Edgar, G. J. and Robertson, A. I. (1992)
sWA	Rottnest Is., Cockburn Sound, Albany	Posidonia	48 fish species	***	compared fish and invertebrate production with sediments /particle-size/organic-matter/ in sea-grass and unvegetated sites. Production higher in sheltered vs exposed sites for unvegetated habitats	Edgar, G. J. and Shaw, C. (1993)
sWA	***	***	***	***	marine-environment/brackishwater-environment/fish-larvae/feeding- behaviour/prey-selection/comparative-studies	Gaughan, D. J. (1992)
sWA	***	***	***	***	longitudinal patterns of larval feeding in an estuary	Gaughan, D. J. and Potter, I. C. (Submitted)

Region	Location	habitat type	taxa	stage	type of study or results	reference
sWA	Swan River	lower estuary	32 families and 60 taxa; 29 identifiable to species	larvae	marine species collected just inside mouth were very similar in size to those collected a further 7.2 km upstream, indicating that they are transported rapidly through the lower estuary, presumably through tidal action; Clupeids predominant in samples	Gaughan, Neira , Beckley and Potter (1990)
sWA	Swan-Estuary	***	Gobiidae	***	ecological-distribution/salinity-tolerance//diets /spawning-grounds/dominant- species/feeding-behavior/population-density/temperature-effects/seasonal-variations/	Gill, H. S. and Potter, I. C. (1993)
sWA	Wilson Inlet	estuary; :"bare sand" vs Ruppia megacarpa	6 spp of atherinids and gobies	sub.ad-adults	effects of location, habitat and seasonal salinity and temperature changes on food-preferences; dominated by crustaceans and/or polychaetes; spp segregated over use of Ruppia habitat and diet	Humphries, P. and Potter, I. C. (1993)
sWA	Wilson Inlet	Ruppia-megacarpa vs bare sand	23 fish species of 16 families	juv.-adults	fish density and biomass signif positively correlated with Ruppia weight and leaf density	Humphries, P., Potter, I. C., and Loneragan, N. R. (1992)
sWA	Cockburn Sound	bay, shelf	Sillago robusta, S. bassensis	juv.-ad.	age, growth, reproduction	Hyndes and Potter (in press)
sWA	Swan River	estuary	Platycephalus speculator	juv.-ad.	early life, reproduction	Hyndes et al. (1992)
sWA	Warnbro Sound , Shoalwater Bay	Posidonia australis, P. sinuosa, vs Bare sand	Sillaginodes punctata, Sillago schomburgkii, S. bassensis, S. burrus, S. vittata, S. robusta	***	five of six whiting use shallow nearshore nursery habitats, but variable use of seagrass and variable ontogeny related to depth and exposure of habitat	Hyndes, G. A., Potter, I. C., and Lenanton, R. C. J. (1996)
sWA	Cockburn Sound	Posidonia australis and P. sinuosa	32 families	larvae	greater diversity and concentration in summer community-composition of larvae over degraded seagrasses - may be due to hydrodynamics?	Jonker, L. J. (1993)
sWA	Princess Royal Hbr, King George Sound	Posidonia and Amphibolis ++	epifauna and decapods	***	5.5/macrofauna/teleosts/sand crab/decapods/seagrass/gastropods/Western Australia/Australia/IWP	Kirkman, H., Humphries, P., and Manning, R. (1991a)
sWA	Blackwood river	estuary	***	***	inventory of habitats and resources	Lenanton, R. C. J. (1977)

Region	Location	habitat type	taxa	stage	type of study or results	reference
sWA	Busselton-Blackwood River mouth	estuary and 8 coastal sites, incl. Ruppia, Posidonia, Amphibolis, Heterozostera	62 teleosts, 3 elasmobranchs ; focus on 16 economically important species	juv.-adults	alternative non-estuarine habitats as nursery-grounds for 13 of 16 economically important fish spp. Rhabdosargus sarba and Mugil cephalus only 2 with estuarine-resident 0+, also Hyperlophus vittatus may be totally estuarine dependent	Lenanton, R. C. J. (1982)
sWA	Murchison River to Esperance	all marine and estuarine fisheries habitats	96 spp of finfish, 7 crustaceans, 12 molluscs	***	REVIEW; quantification of estuarine contribution to WA coastal fisheries production, and classification of fauna according to their life-histories and "dependence" on estuaries	Lenanton, R. C. J. and Potter, I. C. (1987)
sWA	Peel-Harvey-Estuary	***	***	***	effects of Macroalgal blooms on fishing-grounds/fisheries/	Lenanton, R. C. J., Loneragan, N. R., and Potter, I. C. (1985)
sWA	Swan-Estuary	10 sites from lower to middle to upper reaches	focus on 37 spp of 71 spp in 36 families	juv.-adult	longitudinal study of 1) salinity, temp., 3) distance from estuary mouth, site, season and year to test hypo. that marine stragglers more likely to be influenced by 1and 3 than estuarine residents	Loneragan, N. R. and Potter, I. C. (1990)
sWA	Swan-Estuary	***	***	***	longitudinal study/community-composition/seasonality /life-cycle/salinity-data/temperature-data/annual-variations/	Loneragan, N. R., Potter, I. C., and Lenanton, R. C. J. (1989)
sWA	Swan River	estuary	Amniataba-caudavittatus/Nematalosa-vlaminghi/Cnidoglanis-macrocephalus/Hyporhamphus-melanochir/Gerres-subfasciatus/Pomatomus-saltator	***	vertical and horizontal profiles and forcing by salinity/temp on composition of deeper water fish communities	Loneragan, N. R., Potter, I. C., Lenanton, R. C. J., and Caputi, N. (1987)
sWA	Peel-Harvey-Estuary	***	***	***	longitudinal study of salinity and temperature seasonality and its effect on the distribution of members of shallow-water fish communities	Loneragan, N. R., Potter, I. C., Lenanton, R. C. J., and Caputi, N. (1986)
sWA	Wilson-Inlet	estuary basin	17 families; 25 species	larvae	tidal forcing and opening regime and its effect on ichthyoplankton /fish-eggs/fish-larvae/species-diversity/community-composition; estuarine breeders dominated (99.9%); no change in "position" of community with opening – because of rarity of marine spp	Neira, F. J. and Potter, I. C. (1992a)
sWA	Wilson-Inlet	estuary channel	59 spp and 39 families; including	larvae	dynamics of movement of ichthyoplankton /dispersion through a tidal-inlet inferred from larval studies; larvae1)	Neira, F. J. and Potter, I. C. (1992b)

Region	Location	habitat type	taxa	stage	type of study or results	reference
			sparids, engraulids		leave and then return as post-flexion; 2) leave and do not return (Engraulis); 3) enter as postflexion (few-sparids)	
sWA	Nornalup-Walpole-Estuary	permanently open estuary	36 spp ; 23 families; mostly estuarine spawners	fish-larvae	community-composition in a permanently open estuary; larvae of 26 marine species were caught in the entrance but were either rare or absent in the basins; absence of larvae of most of the marine teleosts that are abundant in the basins	Neira, F. J. and Potter, I. C. (1994)
sWA	Swan estuary	lower, middle and upper regions 13 sites	37 families and 74 species	larvae	seasonal and longitudinal changes in fish-larval/abundance/distribution; each reached a maximum between mid-spring and early summer; Gobiidae comprised 88.2%; mean larval abundance far greater in lower than upper (14.7 vs 2.7); 59 spp were marine in lower	Neira, F. J., Potter, I. C., and Bradley, J. S. (1992c)
sWA	Swan-Estuary	permanently open estuary	Cnidoglanis-macrocephalus	***	age /growth /diets /sexual-maturity/sexual-reproduction	Nel, S. A., Potter, I. C., and Loneragan, N. R. (1985)
sWA	Review; comparing sWA with Southern Africa	estuaries; closed seasonally; permanently open	REVIEW	***	Clupeidae, Mugilidae, Atherinidae and Gobiidae were important families in both regions; teraponidae and Tetraodontidae, and the tropical families Apogonidae and Gerreidae, were abundant only in the estuaries of south-western Australia.	Potter, Beckley, Whitfield and Lenanton (1990)
sWA	Nornalup-Walpole	outer basin, inner basin, saline tributary	29 species in 21 families ; incl. rays and sharks	juv.-adult	effects of different opening regimes on fish community structure in permanently open and seasonally open estuaries; depth and salinity/entrance characteristics caused differences, but fauna remarkably similar to Wilson Inlet	Potter, I. C. and Hyndes, G. A. (1994)
sWA	***	***	Torquigener-pluerogramma	***	"blowies" have immensely variable recruitment, with a long estuarine phase. feeding, reproductive status and distribution are related to salinity gradients	Potter, I. C., Cheal, A. J., and Loneragan, N. R. (1988)
sWA	Peel-Harvey-Estuary	lower vs upper estuary	Portunus-pelagicus	juv.-adult	salinity-effects/spawning-seasons/sex-ratio/size-distribution//ecological-distribution;changes in distribution are apparently related to the marked seasonal variation in salinity which results from the very seasonal pattern of rainfall	Potter, I. C., Chrystal, P. J., and Loneragan, N. R. (1983c)
sWA	Wilson Inlet	seasonally landlocked estuary basin and river	38 species	juv.-adult	test 2 hypotheses; 1) closure will cause greater preponderance of "estuarine" spp, 2) lower estuarine fauna will comprise more “marine" spp following long opening period. Classification into 4 categories, incl.	Potter, I. C., Hyndes, G. A., and Baronie, F. M. (1993a)

Region	Location	habitat type	taxa	stage	type of study or results	reference
					estuarine-dependent, marine straggler	
sWA	Peel-Harvey-Estuary, Murray River	lower estuary, lagoon and inlet	29 families, 55 spp	juv.-adult	seasonality in community-composition/distribution/life-histories compared; 6 estuarine spp; 9 marine spp. General ontogenetic shift away from banks to deeper water; comparison with other WA estuaries, Cockburn Sound and Botany Bay faunas	Potter, I. C., Loneragan, N. R., Lenanton, R. C. J., Chrystal, P. J., and Grant, C. J. (1983a)
sWA	Peel-Harvey-Estuary	***	Penaeus-latisulcatus	juv.-sub-adult	movements, spatial-distribution, fishery-biology and departure; related to body-size/sexual- maturity/salinity-effects and distance from the mouth; they leave when change in freshwater discharge/salinity/temp were changing markedly;	Potter, I. C., Manning, R. J. G., and Loneragan, N. R. (1991)
sWA	Swan estuary	***	Metapenaeus-dalli	juv.-adults	influence of freshwater flows in life-cycle; completes life cycle within closed estuaries; ontogenetic movement to deeper water ; species not found >31 deg. South	Potter, I. C., Penn, J. W., and Brooker, K. S. (1986)
sWA	Peel-Harvey-Estuary	estuary vs Nodularia affected sites	55 spp in 29 families	juv.-adults	dense blooms of the blue- green alga Nodularia spumigena have affected fish and crab populations; fishermen have recorded greatly reduced catches; dead fish and crabs in fish kills	Potter, Loneragan, Lenanton and Chrystal (1983b)
sWA	Swan-Avon-Estuary	***	Atherinidae	***	life-cycle/longevity /growth /spawning	Prince, J. D. and Potter, I. C. (1983)
sWA	Swan-Avon-Estuary	***	Atherinidae	***	habitat-selection/niches /food-preferences/	Prince, J. D., Potter, I. C., Lenanton, R. C. J., and Loneragan, N. R. (1982)
sWA	7 mile beach	Halophila ovalis, Heterozostera tasmanica	Panulirus argus	juv.	sea grass infauna consist mainly of fast growing spp with several generations per year, but biomass is insufficient support observed lobster densities. Lobsters may be food limited and have important effect on infaunal communities	Rainer, S. F. (1989)
sWA	7 mile beach	seagrass	***	***	Together with Nebalia , small crustaceans with high P:B ratios may have a significant role in secondary production in the seagrass beds. 3 fish predators were found	Rainer, S. F. and Unsworth, P. (1991)
sWA	7 mile beach	seagrass	Panulirus cygnus	food of juv.	Study of growth, recruitment, reproduction, production of bivalve. Production by Solemya sufficient to supply up to 22% of the food requirements for greater than or equal to 2-yr- old juveniles of P. cygnus .	Rainer, S. F. and Wadley, V. A. (1991)
sWA	Geographe Bay	Posidonia spp	19 fish species	***	sampled using small beam trawl in seagrass are dominated	Scott, J. K. (1981b)

Region	Location	habitat type	taxa	stage	type of study or results	reference
					by the odacid Neoodax radiatus and Eighteen other species. Stomach contents analysed	
sWA	Cockburn Sound	Posidonia, bare sand	69 species of fish and invertebrates	***	unpubl. thesis. comparing a 40m and a 25m seine to sample nearshore fish community in seagrass and bare sand. Sign diff amongst bare-veg. habitats. More sp and wider size range in 40m seine	vanderKlift, M. (1994)
sWA	Owen Anchorage (Cockburn Sound)	mosaic of bare sand, patchy seagrass of 5 genera	***	***	a review using 2 techniques to assess the ecological significance of seagrass to assess the short-, medium- and long-term effects of shell-sand dredging	Walker, D. I., Kinhill Engineers Pty Ltd, Museum of Western Australia, Annandale, D., and Lavery, P. (Unpublished)
sWA	Swan-Estuary	***	Amniataba-caudavittata	***	growth /local-movements/diets /age-composition	Wise, B. S., Potter, I. C., and Wallace, J. H. (1994)
Tas	SE Tasmania	estuaries, bays	***	***	school and gummy sharks/nursery role and feeding/ seasonal inshore/offshore movements for overwintering	Anon. (1993c)
Tas	SE Tasmania	seagrass	Nesogobius sp., Gymnapistes marmoratus, Neoodax balteatus, Acanthaluteres spilomelanurus	adults	diet, feeding chronologies, gastric evacuation rates and daily ration showed differences in hernibovry and zooplankton, macro-invertebrate contribution	Robertson, C. H. and White, R. W. G. (1986)
Tas	west coast Tasmania	shelf	Macruronus novaezelandiae	larvae	several lines of evidence that suggest that the food chain supporting the larvae of the region's dominant midwater predator is not based on phytoplankton but rather on microbial decomposition of seagrass detritus outwelled by storms	Thresher, R. E., Nichols, P. O., Gunn, J. S., Bruce, B. D., and Furlani, D. M. (1992)
Tas	d'-Entrecasteaux-Channel	bay dredge grounds	Pecten- fumatus/ Chlamys-asperrimus/ Equichlamys-bifrons	***	scallop-fisheries/stock-assessment	Zacharin, W., Green, R., and Waterworth, C. (1990)
tropics	Gulf of Carpentaria, Torres Strait, Moreton Bay	bay and offshore trawl grounds	Penaeus-esculentus, P. semisulcatus	juv.-adult	2 spp eat similar taxa of benthic fauna. Quantitative differences in diet suggest they are selective. Strong regional differences In diet were probably due to differences in the availability of prey	Wassenberg, T. J. and Hill, B. J. (1987b)
Vic	Port-Phillip-Bay	***	Pecten-alba	new recruits	spat collection as indicator of recruitment /stock-assessment	Coleman, N. (1989)

Region	Location	habitat type	taxa	stage	type of study or results	reference
Vic	*Western Port*	*mainly Heterozostera and Zostera muelleri and bare sand*	*75 fish species*	*****	*nearshore/seagrass vs unvegetated sediment vs channel-. Seagrass supported over twice the fish production as unveg. , but did not provide a significantly more important nursery habitat for economically important species.*	*Edgar, G. J. and Shaw, C. (1995b)*
Vic	*Western Port*	*seagrass vs bare substrata*	*macro-invertebrates*	*****	*Diversity/epifaunal production greater in vegetated intertidal cf bare. Secondary infaunal production correlated with amt of organic material in sediment and declines over long-term occur with seagrass loss and decline in production of seagrass detritus*	*Edgar, G. J., Shaw, C., Watson, G. F., and Hammond, L. S. (1994)*
Vic	*Port-Phillip-Bay*	*****	*Pseudorhiza-haeckeli/Cyanea-capillata*	*****	*examination of jellyfish predator-prey-interactions with fish-eggs//fish-larvae/*	*Fancett, M. S. and Jenkins, G. P. (1988)*
Vic	*Victoria*	*bays, shelf*	*Pagrus auratus*	*juv.-ad.*	*regional growth variation*	*Francis and Winstanley (1989)*
Vic	*Port Phillip Bay*	*bay*	*****	*****	*community changes over 2 decades*	*Hobday et al. (1996)*
Vic	*Western Port*	*bay*	*Arripis truttaceus*	*juv.*	*diet*	*Hoedt and Dimmlich (1994)*
Vic	*Port Phillip Bay*	*bay*	*****	*larvae*	*distribution, community structure, seasonality*	*Jenkins (1986)*
Vic	*****	*****	*Rhombosolea tapirina, ++*	*larvae*	*diet, prey selection, predatory impact*	*Jenkins (1987)*
Vic	*****	*****	*Sillaginodes-punctata*	*larvae, new recruits*	*recruitment "hotspots" and temporal-variations in settlement/wind- driven-circulation/hydrodynamics*	*Jenkins, G. P. and Black, K. P. (1994)*
Vic	*Swan-Bay*	*****	*Sillaginodes-punctata*	*larvae, new recruits*	*back-calculations of timing of larval-settlement and larval history from daily rings on otoliths*	*Jenkins, G. P. and May, H. M. A. (1994)*
Vic	*Western Port*	*Heterozostera*	*Monacanthidae /Aldrichetta-forsteri/Sillaginodes-punctata*	*****	*parallel declines in seagrass dieback/loss and commercial fisheries not as clear as first apparent, and variable depending on life-history*	*Jenkins, G. P., Edgar, G. J., May, H. M. A., and Shaw, C. (1993d)*
Vic	*Swan Bay, Corner Inlet*	*Zostera muelleri, Heterozostera tasmanica*	*Sillaginodes punctata + other spp*	*new recruits, juv.*	*species richness, abundance and biomass compared between bare substrata and 2 spp of seagrass, King George Whiting associated with unvegetated patches in Swan Bay, but this is a special case*	*Jenkins, G. P., May, H. A., Wheatley, M. J., and Holloway, M. G. (1997)*
Vic	*Swan- Bay*	*****	*Rhombosolea tapirina*	*****	*larval feeding histories based on back-calculations from otolith daily increments*	*Jenkins, G. P., Shaw, M., and Stewart, B. D. (1993a)*
Vic	*Swan Bay, Western*	*Heterozostera*	*67 spp*	*new recruits,*	*compared seagrass with unvegetated substrata to infer*	*Jenkins, G. P., Watson, G. F.,*

Region	Location	habitat type	taxa	stage	type of study or results	reference
	Port, Corner Inlet	tasmanica		juv.	seagrass dieback effects on fish production	and Hammond, L. S. (1993b,c)
Vic	Port Phillip Bay	Heterozostera	Sillaginodes punctata	***	recruitment inversely related to distance from bay mouth, but then redistribution of juveniles. No correlation with seagrass biomass overall. Correlations between recruitment and feeding success	Jenkins, G. P., Wheatley, M. J., and Poore, A. G. B. (In Press)
Vic	Corner Inlet	Heterozostera tasmanica	Hyporhamphus-melanochir	sub-adult-adult	garfish ate seagrass during the day and then ate nocturnally-emergent crustaceans at night	Klumpp, D. W. and Nichols, P. D. (1983a)
Vic	Corner Inlet	Posidonia-australis	Leviprora laevigata	sub-adult-adult	juveniles ate fish and squid, while adults ate Nectocarcinus-integrifons/	Klumpp, D. W. and Nichols, P. D. (1983b)
Vic	Corner Inlet	Posidonia-australis	Nectocarcinus-integrifons	***	this rock crab eats and assimilates seagrass fronds	Klumpp, D. W. and Nichols, P. D. (1983c)
Vic	Gippsland Lakes	estuarine	Acanthopagrus butcheri	***	survival recruitment of black bream in the events of poor water-quality/algal-blooms	Longmore, A. R., Norman, L., and Strong, J. (1990)
Vic	Western Port, Gippsland Lakes	Heterozostera tasmanica, H. muelleri, Caulerpa, Zostera, Ruppia, Lepilaena	Sillaginodes punctata, Monacanthidae, Haletta semifasciata, Acanthopagrus butcheri, Girella tricuspidata	adult fishery	sea grass loss and recovery and parallels in commercial fishery decline and return are discussed in light of recruitment processes	MacDonald, C. M. (1992)
Vic	Swan-Bay	seagrass sediments	Rhombosolea-tapirina	larvae	back-calculations of timing of larval-settlement and larval history from daily rings on otoliths	May, H. M. A. and Jenkins, G. P. (1992)
Vic	Corner-Inlet	Heterozostera tasmanica, Posidonia australis	***	***	biochemical-composition of lipids as chemical markers of these seagrasses for use in food-chain and other studies	Nichols, P. D., Klumpp, D. W., and Johns, R. B. (1982)
Vic	Corner-Inlet	Heterozostera tasmanica, Posidonia australis	Hyporhamphus-melanochir, Leviprora laevigata	adults	use of isotopes of carbon-13 to delimit the seagrass role in food-chains/carbon-cycle/	Nichols, P. D., Klumpp, D. W., and Johns, R. B. (1985)
Vic	Port-Phillip-Bay	bay, all subtidal habitats, Sabella beds	20 most important trophic links in ;sharks, rays, demersal and pelagic fish	juv.-adults	PPBES, definitive description of fish-food webs; Sand Flathead dominant predator; Pebble Crab Philyra very important prey in deeps; introduced-pests Pyromaia and Corbula are important trophic links in deeps; prey consumption lowest in areas invaded by Sabella	Officer, R. A. and Parry, G. D. (1996)
Vic	Port-Phillip-Bay	7,12,17 and 22m depth trawl stations	35 taxa for diets; sharks, rays, demersal	juv.-adults	PPBES, ; spatial, interannual, seasonal differences in fish communities; fish diets; Neoodax balteatus has increased	Parry, G. D., Hobday, D. K., Currie, D. R., Officer, R. A., and

Region	Location	habitat type	taxa	stage	type of study or results	reference
			and pelagic fish		due to Sabella; seasonal and depth related migrations; 4 groupings based on depth/sediment/benthos type; no fish eat Sabella	Gason, A. S. (1995)
Vic	Western Port	Heterozostera tasmanica, Zostera muelleri	Sillaginodes punctata	juv.	initial diet is harpacticoid copepods and amphipods, whereas Callianassa is major prey for older fish	Robertson, A.I. (1977)
Vic	Western Port	Heterozostera tasmanica, Zostera muelleri vs Bare Mud	Torquigener, Aldrichetta, Gymnapistes, Rhombosolea, Atherinosoma, Clinus, Arenigobius, Sillaginodes punctata, Atopomycterus, Favonigobius	sub-ad.-adult	Trophic interactions. Macrobenthos the major energy source for fish (88% of total food) with crustacea, followed by polychaetes. Seagrass had twice the total secondary production as bare mud, but ratio of consumption to production much greater over mud	Robertson, A.I. (1984)

Appendix 5: Summary of results of fisheries-habitat studies on rocky coasts and reefs, by region, location, habitat type, fisheries taxa, life-history stage and source.

*NQ= North Qld, SEQ = South East Qld, sWA = South-western WA, nWA = northern WA, *** = not identified*

Region	Location	habitat type	taxa	stage	type of study or results	reference
NQ	Townsville	Sargassum	epifauna	***	epifaunal abundance greatest during July-Sept. and showed a negative correlation with Sargassum biomass but a positive correlation with levels of epiphytes. Artificial macroalgae and fish exclusion cages used to test habitat complexity vs predation hypos	Martin-Smith, K. M. (1993)
NSW	NSW	"urchin barrens" and other abalone habitat	Haliotis rubra / Centrostephanus rodgersii	juv.-adult	urchins have a negative impact on abalone, but abalone settle in greatest number on crustose coralline algae in "urchin barrens". A suite of manipulative experiments to outline mechanisms of interaction - toward establishing urchin fishery to enhance abalone	Andrew, N. L. (1993a unpubl. Research proposal)
NSW	Cape banks, Botany Bay	Ecklonia radiata	Odax cyanomelas	adult	Seasonal herbivory (severing primary meristem) in discrete patches each year was followed by recruitment ; generating single age-class of plants. May be due to change in aggregation of fish due to spawning.	Andrew, N. L. and Jones, G. P. (1990)
NSW	Sydney, Jervis Bay, Mowarry Pt, Green Cape, Disaster Bay	"Fringe" habitat	Haliotis rubra, Centrostephanus rodgersii	***	urchins and abalone are segregated at the nearest-neighbour scale, and were negatively associated at 20% of sites within 10 sq m transects. Hypotheses regarding the maintenance of these patterns are discussed.	Andrew, N. L. and Underwood, A. J. (1992)
NSW	Avoca-Wollongong	rocky reefs	Cheilodactylus fuscus	sub-ad.-adult	Feeding study. Benthic-feeder ; polychaetes, brachyurans, amphipods, gastropods, bivalves with seasonal variability	Bell, J. D. (1979)
NSW	Sydney region	rocky reefs	Girella-elevata	new recruits-adults	Algae comprised the principal food, making up 77% of the diet in adults, 74% in juveniles and 40% in small juveniles. Small juveniles ate mainly crustaceans (36%) and there were ontogenetic shifts in feeding morphology, gut length and diet	Bell, J. D., Burchmore, J. J., and Pollard, D. A. (1980)
NSW	NZ vs NSW	rocky reef	Odax pullus, O. acroptilus, Aplodactylus arctidens, Girella-tricuspidata	sub-ad.-adult	O. pullus eats fucoid and laminarian algae and evidence of selection of reproductive structures of fucoid algae. O. acroptilus eats small benthic invertebrates. other 2 facultative herbivores with diets dominated by understorey and epiphytic red algae	Choat, J. H. and Clements, K. D. (1992)

Region	Location	habitat type	taxa	stage	type of study or results	reference
NSW	Sydney	rocky reefs	Parma microlepis, Achoerodus viridis	sub-adults, adults	Use of ICP-MS trace element analysis to compare constituents at early life vs later life portions of otoliths, with reference to mapping sources of population replenishment through ontogenetic habitat change	Dove, S. G., Gillanders, B. M., and Kingsford, M. J. (1996)
NSW	Botany Bay	"urchin barrens" and Ecklonia radiata habitat	Atypichthys strigatus	juv.-adult	experimental disturbance of substratum showed more response in barrens. Fish also followed disturbance by other larger spp and exhibited "cleaning" behaviour	Glasby, T. M. and Kingsford, M. J. (1994)
NSW	Botany-Bay	artificial habitats	***	new recruits	Experimental shade/depth/exposure/ ; abundance of several spp varied significantly with at least one of these factors - habitat may be provided for a greater number of species if artificial structures are installed under a wide range of conditions.	Hair, C. A., Bell, J. D., and Kingsford, M. J. (1994)
NSW	Cape banks, Botany Bay	"urchin barrens", Ecklonia	Parma, Hypoplectrodes, Parupuneus, + tropical "vagrants" (Abudefduf, Pomacentrus, Thalassoma, Halichoeres, Stethojulis, Acanthurus)	new recruits-adults	diversity indices should be used with caution to indicate status. "Buffering" mechanisms include larval dispersal, high "inertia" in relative abundance and population structures of long-lived spp, and broad ecological requirements of many spp	Holbrook, S. J., Kingsford, M. J., Schmitt, R. J., and Stephens, J. S. Jr (1994)
NSW	Jervis Bay	<1 m rocky reef	26 species from 17 families	new recruits-juv.	recruits of economically important species were negligible in number : some Arripis trutta, Cheilodactylus fuscus, Achoerodus viridis	Jenkins, G. P., Watson, G. F., Hammond, L. S., Black, K. P., Wheatley, M. J., and Shaw, C. (1996)
NSW	Jervis Bay	2-7m kelp forest (Ecklonia)	27 species from 29 families	juv.-adult	older juveniles and adults of commercial spp were observed (eg. sparid, girellids), but previous studies would suggest these initially recruit to estuarine seagrass and bare habitats then move	Jenkins, G. P., Watson, G. F., Hammond, L. S., Black, K. P., Wheatley, M. J., and Shaw, C. (1996)
NSW	***	Ecklonia radiata	understorey algae, invertebrates, infauna	***	Fish exclusion experiments ;effects on understorey species in a sublittoral Ecklonia radiata kelp assemblage. Significant caging artefacts acted on certain species early in the experiments and on most species after 8 wk.	Kennelly, S. J. (1991)

Region	Location	habitat type	taxa	stage	type of study or results	reference
NSW	Kempsey - Merimbula	sandstone cliffs and fringing rocky reef	37 species of fish, 11 molluscs, 2 echinoderms, 3 decapods, 1 ascidian	juv.-adult	multi-factorial sampling designs identified the times and scales of human gathering and fishing along 1000 km of coast. Girellids, sparids and tailor were major. components of fish catch, but ascidians, crabs and molluscs were collected for bait.	Kingsford, M. J., Underwood, A. J., and Kennelly, S. J. (1991a)
NSW	Seal Rocks	tidepool	***	juv.	repeated defaunation annually ; fish assemblage was of moderate diversity, dominated by juveniles of subtidal species; variation in component species over the long-term collections, but composition remained relatively constant	Lardner, R., Ivantsoff, W., and Crowley, L. E. L. M. (1993)
NSW	***	rocky reefs	***	***	Improving multispecies rocky reef fish censuses by counting different groups of species using different procedures.	Lincoln Smith, M. P. (1989)
NSW	Port Stephens to Eden	rocky nearshore reef	Cheilodactylus fuscus, Crinodus lophodon, Girella tricuspidata, G. elevata and 26 others	sub-ad.-adult	speared catch was not representative of rocky reef fish assemblage, but focuses on "reef-dependents". Little overlap with other users except for G. elevata	Lincoln Smith, M. P., Bell, J. D., Pollard, D. A., and Russell, B. C. (1989)
NSW	1) amongst reefs 29 km apart. 2) 3 levels: regions (100-200 km) locations (5-12 km) and reefs (1-3 km).	rocky reefs <12 m	Scorpaenidae ,Dinolestidae ,Mullidae ,Pempherididae ,Scorpididae ,Pomacentridae ,Cirrhitidae	recently settled juvs	differences in abundance among reefs for many species, but these were masked by great variability in abundance within reefs; among or within reefs, rather than among locations and regions.	Lincoln-Smith, M. P., Bell, J. D., and Hair, C. A. (1991)
NSW	Jervis Bay	breakwaters vs natural rocky reefs		recruits-adults	breakwaters often had higher species richness and abundances of fish than the natural reefs. Recruitment in spring-summer; greatest on sthn side of bay ; suggests breakwaters on the Nthn side not have comparable assemblages	Lincoln-Smith, M. P., Hair, C. A., and Bell, J. D. (1994)
NSW	Port Hacking, Sydney Hbr	***	Cheilodactylus fuscus	sub-ad. - adult	development of technique for underwater visual appraisal of sex, based on orbit-tubercle, to improve home-range and bio-accumulation studies	Schroeder, A., Lowry, M., and Suthers, I. (1994)
NSW	south coast of NSW	***	Haliotis rubra	juv.-adult	growth variation amongst sites within 20km was almost s great as for within entire range. Harvesting by width limit may free slow growers from food limitation	Worthington, D. G. and Andrew, N. L. (submitted)

Region	Location	habitat type	taxa	stage	type of study or results	reference
NSW	Broughton Island, Sydney, Merry's Beach, Eden	***	Haliotis rubra	juv.-adult	Tagging :growth curves and rates differed amongst sites within 1-20km. There was also sign. variation in growth of individuals within sites and this variation differed amongst sites. Faster growers were morphologically distinct. Width limits are discussed	Worthington, D. G., Andrew, N. L., and Hamer, G. (1995)
NZ	Leigh Marine Reserve	Shallow Broken Rock Habitat	Jasus-edwardsii, Evechinus chloroticus	sub-adult-adult	field surveys of abundance and laboratory manipulations of prey shelter and size showed that differing micro-habitat requirements of the 2 spp acts to dislocate any relationship between the abundance of the 2 spp	Andrew, N. L. and MacDiarmid, A. B. (1991)
NZ	North Island	***	Jasus edwardsii	***	pueruli on collectors greatest in depth <= 12m, although some settlement down to 50 m	Booth, J. D. (1989)
NZ	15 locations at northern and southern ends of North Island	kelp forests and echinoid dominated reefs	22 species in 11 families	post-settlement	2 types of reef 1) coralline reef flats dominated by echinoids; supported different fish fauna with large benthic-feeders, 2) algal reefs with high-density laminarian/fucoid algae; large Nos of small spp, mainly labrids, with a few large benthic-feeders	Choat, J. H. and Ayling, A. M. (1987)
NZ	Goat Island Bay	coralline algal flats	Upeneichthys-porosus/Chrysophrys-auratus	***	Experimental fish exclusion. Juvenile C. auratus and U.porosus achieved their highest densities over coralline turf areas and fed on the associated invertebrates. Gammarid amphipods constituted the main food items of each species.	Choat, J. H. and Kingett, P. D. (1982)
NZ	***	rocky reef	Forsterygion varium	new-recruits-adults	relative importance of recruitment and post-recruitment processes in determining these patterns was evaluated by monitoring the abundance, survival, growth and movement of two separate cohorts of juveniles in habitats of different complexity	Connell, S. D. and Jones, G. P. (1991)
NZ	Leigh	urchin-barrens, Ecklonia, Carpophyllum, Sargassum, Corallina	Pseudolabrus celidotus	adults	complex home-range and territorial behaviour by Terminal-phase males and females classified as "resource defence polygyny". Preference for deep, bare-rock areas with extensive shelter as spawning sites	Jones, G. P. (1981)
NZ	***	6 habitat types within site	Pseudolabrus-celidotus	new-recruits	Shallow broken rock (SBR) habitats dominated by macrophytic brown algae consistently had highest recruitment. Adult removal experiment showed recruitment was independent of adult numbers. Macroalgae affected recruitment in algal removal/addition experimental	Jones, G. P. (1984a)

Region	Location	habitat type	taxa	stage	type of study or results	reference
NZ		6 habitat types within site	Pseudolabrus-celidotus	***	Number of juveniles reaching maturity limited adult densities; limited by 1)Density-dependent mortality. Proportion of juveniles surviving first year was inversely correlated with initial densities, 2) Density-dept maturation - Juvenile. growth inversely correlated with dens	Jones, G. P. (1984b)
NZ	north-eastern NZ	rocky reefs	fish	all post-settlement	review article, addressing all spatial scales from small-large. Maj. biological features of the habitat (eg. urchins, macroalgae) affect fish populations at all scales, but habitat has a far greater impact on fish communities than vice versa	Jones, G. P. (1988b)
NZ	Leigh	urchin-barrens, Ecklonia, Carpophyllum, Corallina	Pseudolabrus celidotus, Tripterygion varium	adults	female aggression by larger female P. celidotus inhibited maturation of smaller females	Jones, G. P. and Thompson, S. M. (1980)
NZ	coastal waters	pelagic habitats	includes major reef spp	pre-settlement	Review. The importance of physical and biological processes influencing the distribution and survival of ichthyoplankton will vary among categories (eg. pelagic and reef fish) and taxonomic groups within. Vertical and horizontal patterns are described	Kingsford, M. J. (1988)
NZ	coastal waters, NE NZ	pelagic habitats, including 0-2m deep above reef	includes some major temperate reef families	pre-settlement	distribution of pre-settlement sparids, mullids (pelagic eggs), and blenniids and monacanthids (demersal eggs) was not determined in a predictable way by the proximity of reefs. Sparid patches 1-2km across moved quickly through	Kingsford, M. J. and Choat, J. H. (1989)
NZ	Poor-Knights-I.	water column above rocky reef	Chromis dispilus, Caprodon longimanus, Scorpis violaceous, Decapterus koheru	***	hypothesis that fish have a localised effect on zooplankton was investigated in detail within a small reef area. Lowest zooplankton densities were usually found in the archway where planktivorous fish were abundant.	Kingsford, M. J. and MacDiarmid, A. B. (1988)
NZ	Auckland Islands	sub-antarctic rocky reefs	8 spp	***	diversity and abundance of species of large reef fish was low; a total of eight species; mostly benthic carnivores; spp composition varied among locations; Bovichthys, Latridopsis, Latris, and Pseudolabrus were in deep water on reefs	Kingsford, M. J., Schiel, D. R., and Battershill, C. N. (1989)

Region	Location	habitat type	taxa	stage	type of study or results	reference
NZ	Leigh	9 "areas" in 7 rocky reef habitats based on topography, flora, echinoids, depth	Cheilodactylus spectabilis	juv.-adult	Home-ranges and spatial patterns mapped and diet and behaviour studied. Topographic complexity has positive effect on density ; size increases with depth ; only small individuals were territorial. Larger fish moved through overlapping home ranges.	Leum, L. L. and Choat, J. H. (1980)
NZ	NE NZ	down-slope gradient amongst rocky reef habitats	Cheilodactylus- spectabilis	***	on a within-day basis ripe females visited large males on the reef edge, peaking in density at dusk. These males were highly territorial towards similar sized conspecifics, with particular sites being defended by the same fish each year	McCormick, M. I. (1989a)
NZ	Okarakiri Marine Reserve	10 rocky reef habitats based on topography, flora, depth	Cheilodactylus spectabilis	juv.-adult	density, size, sex distribution mapped down depth gradient over 12mo. Females and juveniles inhabited shallows, males in deeper. Habitat choice evident. Spatial patterns consistent over decadal, between-month, between-day, within-day scale over range of depths	McCormick, M. I. (1989b)
NZ	NE NZ	10 habitat types within rocky reefs	Cheilodactylus- spectabilis	***	size and sex distribution over a 10 yr period for a range of reef habitats, and density and size trends are examined. "Storage effects" mask underlying instability in age composition	McCormick, M. I. and Choat, J. H. (1987)
NZ	Goat Island	rocky reef	50 fish species	***	Most rocky reef fishes ate amphipods, crabs, fishes, gastropods, copepods, errant polychaetes, hermit crabs, and small bivalves; foods taken mainly reflect those organisms of suitable size that are abundant and accessible	Russell, B. C. (1983)
SA	Pt Lincoln-Franklin Hbr	granite-gneiss	Haliotis- roei	adult	Survey. Found in shallow water (0-2 m) in places of moderate to strong water movement. Length frequency distribution negatively skewed as is expected for an unfished stock. common algae and principal larger grazing animals are given for each site.	Branden, K. L. and Shepherd, S. A. (1982a)
SA	Thorny Passage	rocky reef	Haliotis- roei	adult	Survey. Catch rates above 65 mm in length ranged from 1-21 kg (live weight) per diver hour at 16 sites. Habitat notes of the substrata, the common algae and principal larger grazing animals for each site are added in the Appendix.	Branden, K. L. and Shepherd, S. A. (1982b)

Region	Location	habitat type	taxa	stage	type of study or results	reference
SA	Great Australian Bight	aeolianite wave-cut platforms	Haliotis- roei, H. cyclobates	sub-adult-adult	Survey. Found in shallow water (0-4 m deep) in places of moderate water movement. H. cyclobates occurs in sheltered bays epizoic on the razor fish Pinna bicolor. Common algae and principal larger grazing animals are given for each site.	Branden, K. L. and Shepherd, S. A. (1984)
SA	Investigator-Group	***	? fish species	***	distribution/abundance survey by 1) visual census along belt transect lines - consistent and repeatable, but does not sample whole community, and 2) by recording the log abundances observed for a fixed time period in a variety of habitats - more species	Branden, K. L., Edgar, G. J., and Shepherd, S. A. (1986)
SA	Yorke Peninsula	artificial, pier habitat	Cheilodactylus nigripes	juv.-adults	small-scale mapping of home range, temporal change; distribution positively correlated with topographical complexity for shelter and feeding. Benthic-feeder on gammarids, polychaetes, ostracods, bivalves and other infauna.	Cappo, M. (1995)
SA	Yorke Peninsula	<1 m Hormosira	15 species from 10 families including Sillaginodes punctata, Aldrichetta forsteri, Haletta semifasciata	new recruits-juv.	ontogenetic shift in juvenile habitat is probably occurring for S. punctata which utilised shallow reef/algal habitat	Jenkins, G. P., Watson, G. F., Hammond, L. S., Black, K. P., Wheatley, M. J., and Shaw, C. (1996)
SA	5 islands in Investigator Group	<=30 m	90 species in 43 families	***	Fish inventory. Brief notes on habitat and abundance are given for each spp .	Kuiter, R. H. (1983)
SA	South-East, Kangaroo Island and West Coast	bryozoal limestone overlain by calcarenite vs granitic rocks	Jasus novaehollandiae	all post-settlement	review of biology and movement shows variation at a range of spatial scale in life-history parameters and abundance, with indications of density-dependence -- but no tests yet of this hypothesis	Lewis, R. K. (1986)
SA	West Island	boulder slope at Abalone Cove	16 crab species	***	Four of the species are mainly herbivorous but eat small amounts of animal matter and one species is omnivorous. Four of the species also ate small abalone in cage experiments and represent potential agents of abalone mortality.	Mower, A. G. J. and Shepherd, S. A. (1988)
SA	West Island	granite boulder slope	Haliotis laevigata	2+ juveniles	18 yrs of monitoring densities showed 2 oscillations due to strong recruitment and density-dependent mortality through predation, mainly by stingrays, octopus and crabs	Shepherd, S. A. (1990)

Region	Location	habitat type	taxa	stage	type of study or results	reference
SA	West Island	rocky reef	Haliotis rubra, H. laevigata	***	stocks are composed of local populations linked by larval dispersal into metapopulations ; an explanation is given of the role of refugia in enhancing egg production, conserving genetic diversity, providing for scientific study	Shepherd, S. A. and Brown, L. D. (1993)
SA	Fleurieu and Yorke Peninsulas	inshore rocky reefs	Pseudolabrus-tetricus	juv.-adult	age at length estimated from scale-reading up to a longevity of 8+	Shepherd, S. A. and Hobbs, L. J. (1985)
SA	Waterloo Bay, West Coast	travertinised limestone	Haliotis laevigata	2+ juveniles	spatial distribution of recruitment correlated during each year with gradient of water movement, habitat complexity, predator density, depth. Recruitment during 6 yrs of closure = 2.7 times that of preceding 7 yrs of fishing	Shepherd, S. A. and Partington, D. (1995)
SA	West Island	"experimental" boulders	Haliotis laevigata, H. scalaris	***	association of juvenile abalone with crustose coralline algae appears to be important for food and as a refuge from predators. Wrasses are important predators of juveniles but do not take individuals <5 mm long.	Shepherd, S. A. and Turner, J. A. (1985)
SA	Taylor and Owen Islands, Thorny Passage	granite, Ecklonia, Cystophora, Seirococcus, Scaberia, Sargassum	Haliotis laevigata	3 month old recruits	Adult densities were manipulated in the field. Deduced that larvae are transported near-bottom for 100s of m and are concentrated in lee eddy and stagnation zones caused by bottom/shore topography. Recruitment highest here and independent of adult density	Shepherd, S. A., Lowe, D., and Partington, D. (1992)
sWA	Shark Bay, Abrolhos, Dongara, Jurien, Lancelin, Alkimos, Fremantle	limestone reef	Panulirus cygnus	puerulus recruitment, egg production	(as above) and ; Spawning stocks from the coastal regions must provide an important contribution to Abrolhos, because Abrolhos egg production unchanged over 20yrs, but coastal egg production has declined due to 1-2yrs fishing before maturity	Caputi, N., Chubb, C. F, and Brown, R. S. (1995b)
sWA	Abrolhos	limestone reef	Panulirus cygnus	puerulus recruitment	The Leeuwin Current and spring westerly winds cannot explain a 50% decrease over 1970's - 1991 in settlement at the Abrolhos Islands on the edge of the shelf 60 km offshore. Fishing-down of spawning stock in the region is the major cause of decline	Caputi, N., Chubb, C. F., and Brown, R. S. (1995a)
sWA	Alkimos, Dongara	limestone reef	Panulirus cygnus	puerulus recruitment	puerulus settlement is positively correlated with strong Leeuwin Current in La Nina years. The correlation peaks in April and mechanisms are discussed and proposed to explain why. The spawning stock-recruitment relationship is not significant here	Caputi, N., Fletcher, W. J., Pearce, A., and Chubb, C. F. (1996)

Region	Location	habitat type	taxa	stage	type of study or results	reference
sWA	as above	limestone reef	Panulirus cygnus	puerulus recruitment, egg production	description of long-term, fisheries-independent data collection on 1) recruitment - monthly; of puerulus on artificial seaweed collectors, 2) spawning indices and egg production	Chubb, C. F., Caputi, N., and Brown, R. S. (1995)
sWA	***	Sargassum-patens	Halichoeres tenuispinis	***	Field exclusion experiments support the hypothesis that the secondary production of epifaunal communities on macrophytes is constrained by quantifiable food resource ceilings. Fish did not alter macrofaunal production, but removed most larger animals	Edgar, G. J. and Aoki, M. (1993)
sWA	7 mile beach, Cliff Head	limestone reef , seagrass, macroalgae (Scytothalia, Ecklonia)	Panulirus cygnus	post-puerulus <= 25 mm CL	pp prefer shelters covered by seagrass/algae of a size positively related to their CL until 16-20mm when they leave for reef dens. Found also to 30m deep. "Collectors" are good indicators of settlement. Artificial. habitats may prove useful, but not pp transfer	Fitzpatrick, J., Jernakoff, P., and Phillips, B. F. (1989)
sWA	7 mile beach	limestone reef	Panulirus-cygnus	puerulus and juv.	Psammoperca waigiensis was the most consistent predator followed by Pelates humeralis. The predation is concentrated on newly settled lobsters possibly accounting for a large proportion of the juvenile mortality.	Howard, R. K. (1987)
sWA	7 mile beach	limestone reef	Panulirus-cygnus	puerulus and juv.	Six spp of fish predators were found. Conservatively, annual removal by fish of thousands of lobsters per hectare is likely, suggesting that predation is a major factor in juvenile mortality. Explains cryptic behaviour of newly-settled stage	Howard, R. K. (1988)
sWA	7 mile beach	limestone reefs	Panulirus cygnus	new-recruits	Six fish predators (Psammoperca, Pelates, Pseudolabrus, Plectorhynchus). Vulnerability strongly related to size and cryptic behaviour.. Predation may critically affect mortality on nursery reefs	Howard, R. K. (1989a)
sWA	Dongara	limestone reef and surrounding seagrass	***	juv.-adults	diel gillnetting and (2) quantitative rotenone sampling of enclosed areas of substratum. Long-term and day-to-day variability was low. High catches at reef-edge sites suggest that the majority of fishes forage on or near limestone patch reefs	Howard, R. K. (1989b)
sWA	Rottnest-I.	rocky reef	***	new recruits-juv.-adults	arrival of tropical larvae in March and April coincides with the strengthening of the Leeuwin Current, a southward flow of warm tropical water, at that time.	Hutchins, J. B. and Pearce, A. F. (1994)
sWA	7 mile beach	limestone reef	Panulirus cygnus	post-puerulus	Surveys. Habitat preference tests using artificial habitats and	Jernakoff, P. (1990)

Region	Location	habitat type	taxa	stage	type of study or results	reference
					the response of the post-pueruli to transferral between shelters. Very cryptic; shelter in small holes on the reef face, in ledges, caves ; especially with vegetated cover ; move daily and gregarious	
sWA	7 mile beach, Cliff Head	limestone reef	Panulirus cygnus	juv.	Densities at least three times greater at 7 Mile Beach than at Cliff Head. However, juveniles grew faster at Cliff Head than at Seven Mile Beach. Density in ledges was twice that in caves; density in caves was 10 times that on reef face.	Jernakoff, P., Fitzpatrick, J., Phillips, B. F., and De-Boer, E. (1994)
sWA	7 mile beach	limestone reef	Panulirus cygnus	post-pueruli	foraged in seagrass and macroalgae on limestone reefs, and animals on settlement collectors foraged only on the collectors. The major diets were coralline algae, molluscs and crustaceans. The ratios of these in foreguts depended on moult stage	Jernakoff, P., Phillips, B. F., and Fitzpatrick, J. J. (1993)
sWA	7 mile beach	limestone reef	Panulirus cygnus	juv.	Diet. Molluscs (high growth site) vs foliose coralline algae (low growth site) ; broad diet and high densities suggest a significant role of grazing and predation by this species in structuring habitat.	Joll, L. M. and Phillips, B. F. (1984)
sWA	***	review life-history w.r.t oceanic processes	Panulirus cygnus	puerulus	correlation of annual mean sea levels along the west Australian continental shelf with annual levels of recruitment to the lobster fishery suggest role of ENSO events	Pearce, A. F. and Phillips, B. F. (1988)
sWA	***	review life-history w.r.t oceanic processes	Panulirus cygnus	puerulus	Offshore larval transport affected by wind-driven circulation; return by the deeper oceanic circulation; level of puerulus settlement shows close correlation between adjacent sites but Sthn sites receive lower levels than farther north	Phillips, B. F. and Pearce, A. F. (1992)
sWA	Waterman ++ other sites	coastal reef platforms	Haliotis-roei	juv.-adult	short period of intense spawning in July and August, followed by low levels of spawning until December ; herbivorous, feeding on a variety of macroalgae present in the drift. Algae consumed varied seasonally and between platforms	Wells, F. E. and Keesing, J. K. (1989)
Tas	D'Entrecasteaux Channel	Durvillea, Lessonia, Macrocystis, Ecklonia, Sargassum, red algae	Notolabrus tetricus, N. fucicola, Pictilabrus laticlavius, Pseudolabrus psittaculus, Penicipelta vittiger, Meuschenia australis	sub-ad.-adult	Tag-recapture and u/w observation showed that all spp were permanent reef residents (all except M. australis in <=100x25m), but sex changing wrasses site-attached and territorial males. Other wrasses not territorial. Open sand a natural boundary for MPAs	Barrett, N. S. (1995)
Tas	Maria Island,	marine reserves vs	Notolabrus,	***	densities of Jasus, urchins and the means size of wrasse,	Edgar, G.J. and Barrett N.S. (In

Region	Location	habitat type	taxa	stage	type of study or results	reference
	Tinderbox, Ninepin Pt, Governor Island	reference reef sites	Penicipelta, Jasus, Heliocidaris, Haliotis (71 fish, 24 echinoderm, 17 mollusc, 92 plant species)		leatherjackets, abalone and Jasus, all increased within the reserves relative to outside, over the first year, however, a doubling in population numbers or >=10% increase in size needed for significance	Press)
Tas		crustose coralline algae	Haliotis ruber	new recruits	In lightly grazed areas, the animals ingested a layer 1-2 mu m thick, consisting of the algal cuticle and the bacterial biota (mostly Moraxella) indigenous on it. In heavily grazed areas, the cytoplasmic contents of the epithallium also ingested	Garland, C. D., Cooke, S. L., Grant, J. F., and McMeekin, T. A. (1985)
Tas	***	rocky reef	Meuschenia-australis, M. freycineti, Acanthaluteres-spilomelanurus/Penicipelta- vittiger	***	Diet. A.spilomelanurus and P. vittiger ate large amounts of algae, amphipods, bivalves and hydrozoans. Both Meuschenia ate macro- invertebrates such as sponges, echinoderms and larger molluscs.	Last, P. R. (1983)
Tas	Kent and Hogan groups in northern Bass Strait	rocky reef	Haliotis rubra, H. laevigata	adult	The blacklip stock was "stunted" by with < 16% of the biomass of the abalone vulnerable being above the current legal size ; greenlip stocks are less abundant but are not "stunted".	Prince, J., Sellers, T., Ford, W., and Talbot, S. (1987)
Tas	Storm Bay ++ other east coast sites	tidepool and subtidal rocky reef	Heteroclinus perspicillatus, Heteroclinus sp.	all post-settlement	little or no consistency of temporal patterns within or among years, but at all scales spatially concordant settlement. Various environmental correlates outlined inc. wind, chlorophyll	Thresher, R. E. (1992)
Tas	Storm Bay ++ other east coast sites	tidepool and subtidal rocky reef	Heteroclinus perspicillatus, Heteroclinus sp.	all post-settlement	pulses of settlement of a species of temperate reef fish were invariably preceded by brief, irregularly occurring peaks of phytoplankton production. The lag time was consistent with a "critical period" hypothesis	Thresher, R. E., Harris, G. P., Gunn, J. S., and Clementson, L. A. (1989b)
temp	temperate Australasia	rocky reef/algal	review, herbivorous fish and urchins	***	fish and sea urchins exhibit distinct patterns of distribution among depth strata. Within depth strata, all herbivores are restricted to (sea urchins), or forage preferentially in (fish), particular habitat patches, causing a mosaic of different feeding activity	Jones, G. P. and Andrew, N. L. (1990)
Vic	Port Phillip Bay	sandstone ledge reefs and basalt boulders	Coscinasterias calamaria	adults	abalone are not often eaten unless mussel stocks are depleted and starfish are at high densities. This is most likely on offshore reefs where mussel recruitment is usually	Day, R., Dowell, A., Sant, G., Klemke, J., and Shaw, C. (1995)

Region	Location	habitat type	taxa	stage	type of study or results	reference
					high (but can fail)	
Vic	Port Phillip Bay	2-7 m basalt or ironstone ; Ecklonia, Caulerpa, Laurencia, Sargassum, Cystophora, Ulva	71 species, 36 families including Notolabrus, Neoodax, Acanthaluteres	new-recruits-adults	increased spp richness and abundances on reefs cf adjacent unvegetated. habitat. Wide variation amongst locations in community structure, may be related to macroalgal cover and topography. No recruitment of commercial spp observed, and minimal other recruitment	Jenkins, G. P., Watson, G. F., Hammond, L. S., Black, K. P., Wheatley, M. J., and Shaw, C. (1996)
Vic	Port Phillip Bay	<1 m basalt or ironstone ; Ulva, Cladophora, Caulerpa, Codium, ; Cystophora, Caulocystis, Sargassum, Ecklonia; Heterosiphonia, Laurencia etc	>=34 species from >=8 families including Sillaginodes punctata, Aldrichetta forsteri, Neoodax, Haletta, Meuschenia, Acanthaluteres	new-recruits-adults	when reef-algal and seagrass habitats both occur in shallow, high recruitment areas, the reef-algal habitat may be at least as important. Ontogenetic shifts from seagrass to reef/algal to bare sand for Sillaginodes punctata.	Jenkins, G. P., Watson, G. F., Hammond, L. S., Black, K. P., Wheatley, M. J., and Shaw, C. (1996)
Vic		Ecklonia-radiata	Parma-victoriae, Monacanthids, Odax cyanomelas	***	Experimental kelp clearances in shallow water; major increase in the feeding by leatherjackets and damselfish (established territories on cleared patches); large brown macro-algae affect distribution of herbivorous fish at a number of spatial scales.	Jones, G. P. (1992)
Vic	Port Phillip Bay -	"closed" area vs "open" to harvesting	effects of shoreline harvesting on molluscs	***	3 of the 4 collected species, Cellana, Austrocochlea, and Nerita, were significantly larger at the protected sites, and Nerita was markedly less abundant at heavily visited sites. Possible that Turbo populations are replenished from deeper water.	Keough, M. J., Quinn, G. P., and King, A. (1993)
Vic	laboratory analysis of food value	macroalgae Gigartina radula, Plocamium mertensii, Ecklonia radiata, Phyllospora comosa, Jenerettia lobata, Ulva lactuca, Macrocystis augustofolia	Haliotis-rubra	adult	Toughness accounted for much of the variation (60%) in the feeding rate on the macroalgal diets; little evidence for chemical deterrence of herbivory for H. rubra, but suggest that food toughness is a primary factor in the feeding preferences of abalone	McShane, P. E., Gorfine, H. K., and Knuckey, I. A. (1994)
Vic	***	macroalgal reef	Parma-victoriae	adult	No correlation between territory size and abundance of algal food, body size, age or time spent on defence ; little variation in territory size over time, despite seasonal changes in food algae; inversely correlated with local	Norman, M. D. and Jones, G. P. (1984)

Region	Location	habitat type	taxa	stage	type of study or results	reference
					densities of conspecifics	
WA	Abrolhos Islands	sub-tropical	Choerodon rubescens	adult	sex change from female to male at 8-9+ yrs and longevity 13+. Eats mainly molluscs (especially whelks) and echinoderms (especially. urchins). Comprised 47% of trapcatch ahead of Pagrus auratus (11.7%) and Bodianus (?) (7.6%)	Walker, M. H. (1983)

Appendix 6: Summary of results of fisheries-habitat studies on continental shelves, by region, location, habitat type, fisheries taxa, life-history stage and source.

*Ant = Antarctic Territories GoC = Gulf of Carpentaria, NQ= North Qld, SEQ = South East Qld, sWA = South-western WA, nWA = northern WA *** = not identified*

Region	Location	habitat type	taxa	stage	type of study or results	reference
Ant	Antarctic-Ocean	review of 15 yrs demersal trawling by Russians	***	***	Species comp, distribution of bio-resources, bio-productivity and food chains have been found to be closely connected to the latitudinal vertical and circum-Antarctic patterns of the water structure to the south of the Antarctic convergence	Lubimova, T. (1985a)
Ant	Antarctic-Ocean	review of Russian trawl data	squids	***	Grouped as tropico-subtropical, notal and Antarctic. In view of the absence of beaks in sediments, 2 hypotheses are suggested: all squids migrate to the Antarctic in the summer or the abundance of the true meso- and bathypelagic squids is very low.	Lubimova, T. G. (1985b)
Ant.	South-Georgia	Antarctic shelf to 500m	Champsocephalus gunnari	juv.	juvenile icefish collected 82-146 mm. Catches highest in the west, south and south-east shelf areas and the greatest abundance was found in shallow waters of 100-200 m depth. A typical pattern of diurnal vertical migration of fish was observed	Boronin, V. A., Zakharov, G. P., and Shopov, V. P. (1987)
Ant.	Antarctic	pelagic	krill	***	the designation of regions and sub-regions based on the distribution of populations of Antarctic marine living resources. In order to select meaningful boundaries for such areas, first priority given to surface circulation of southern waters and krill	Chittleborough, R. G. (1988)
Ant.	Weddell Sea	demersal 99-1243m	Trematomus, Dolloidraco, Prionodraco, Chionodraco	juv.-adult	using u/w photographs of substratum and fish, and trawl data, was able to identify various relationships with sediment type, topographic complexity and epibenthic macrofauna and filter feeders	Gutt, J., and Ekau, W. (1996)
Ant.	Prydz Bay	Antarctic shelf	Euphausia superba	sub-adult	Maximum aggregation density was estimated to be 1530 g/m; total biomass 57,000 tonnes wet weight; mainly of very large sexually immature males,	Higginbottom, I. R. and Hosie, G. W. (1989)
Ant.	South-Georgia	pelagic, Antarctic shelf	Champsocephalus-gunnari	larvae	Distribution of fish larvae at South Georgia: Horizontal, vertical, and temporal distribution and early life-history relevant to monitoring year-class strength and recruitment	North, A. W. (1988)

Region	Location	habitat type	taxa	stage	type of study or results	reference
Ant.	Scotia-Sea	Antarctic shelf, pelagic	Martialia hyadesi	***	likely that exploitation of the sub-Antarctic ommastrephid species will be attempted in the future. This spp is an important component of the diet of several species of albatross and the southern elephant seal and probably other vertebrates	Rodhouse, P. G. (1991)
Ant.	South Georgia shelf	Antarctic demersal	Champsocephalus-gunnari, Notothenia, Euphausia-superba	***	concentrations for Champsocephalus gunnari, Notothenia squamifrons , and (to some extent) N. rossii off Kerguelen are determined. The distribution of about 60 species on the South Georgia shelf and the Scotia area is investigated.	Slosarczyk, W., Witek, Z., and Kalinowski, J. (1985)
Ant.	Antarctic and sub-Antarctic waters	review	***	***	The history, situation and prospects of fisheries; essentially 2 forms of living resource: fish species; and the Antarctic krill. Large invertebrates such as lobsters and shellfish do not occur in the area.	Williams, R. and Nicol, S. (1991)
east coast	Cape Grenville (>12S) to Vic/NSW border (>36S)	inshore bays and shelf, pelagic	21 families of teleost used as baitfish	***	Inventory of bait species, bait grounds and baitfish biology along most of the East coast. Emphasis on maps, local knowledge gleaned from multiple port meetings.	Glaister, J.P. and Diplock, J.H. (1993)
east coast	a warm-core eddy, the EAC, the Coral Sea and the Tasman Sea.	pelagic	***	***	Mesopelagic fishes and crustaceans inside a newly formed, warm-core eddy off eastern Australia were similar in composition and abundance of species to those from the more northerly Coral Sea and East Australian Current (EAC) source waters of the eddy	Griffiths, F. B. and Wadley, V. A. (1986)
GoC	south-eastern Gulf	demersal prawn trawl	demersal fish and cephalopods	***	Temporal changes in community composition resulted in large changes between different seasons in the structure of site groups derived by classification; temporal effects within seasons were also found.	Rainer, S. F. (1984)
GoC	grid pattern through entire Gulf of Carpentaria	various sediment types	79 spp of fish and sharks	juv.-adult	Diets of entire community; 23 of 40 most abundant predators were major piscivores ; ate mainly Pleuronectiformes, Leiognathidae, Anguilliformes.14 of the 17 minor piscivores ate mainly Brachyura, Penaeidae, Stomatopoda and other Crustacea). Seasonality.	Salini, J. P., Blaber, S. J. M., and Brewer, D. T. (1994)

Region	Location	habitat type	taxa	stage	type of study or results	reference
GoC	entire Gulf down to about 40m isobath	demersal prawn trawl grounds	9 spp of Penaeus, Metapenaeus in 4 commercial groups	adult	spatial dsn related to depth/and or sediment type. P.merguiensis<20m, no sediment. pref ; P. esculentus, M.endeavouri<35m, sand, muddy-sand ; P. semisulcatus>35m, mud, sandy-mud; M.ensis 35-45m, more than 60% mud. Also distinct regional patterns of abundance	Somers, I.F. (1994)
Indian ocean	Indian ocean	pelagic	Thunnus maccoyii, T. alalunga, Katsuwonus pelamis	larvae	Thunnus maccoyii and T. alalunga larvae moved into the surface layers during the day. Katsuwonus pelamis , however, moved into deeper water during the day. All species of tuna were more evenly dispersed in the mixed layer at night.	Davis, T. L. O., Jenkins, G. P., and Young, J. W. (1990a)
Indian ocean	Indian ocean	pelagic	Thunnus maccoyii, T. alalunga, Katsuwonus pelamis	larvae	index of patchiness was consistently high for all tuna species, ranging from 3.0 to 5.2 for T. maccoyii . There was no change in the index when tow distance was doubled to 1200 m, which suggests that the dominant patch size was somewhat larger than previously thought	Davis, T. L. O., Jenkins, G. P., and Young, J. W. (1990b)
NQ	Townsville	cross-shelf macrobenthic fauna	***	***	zoning of the epifaunal assemblages across the shelf. A diverse epifaunal component had survived cyclone damage to the time of sampling, although heavy siltation was apparent across the shelf with particular marked effects in the shallower stations	Birtles, A. (1986)
NQ	NW Coral Sea	pelagic	Thunnus obesus, T. alalunga	sub-ad.-adults	significance and dynamics of the 26 degree isotherm at 50m depth, whale sharks and bathymetry to surface handline fishery	Hasada, Koichi (1988)
NQ	Halifax, Cleveland, Bowling Green Bays	shallow (<40m) soft-bottom, pelagic	Scomberomorus semifasciatus, S.queenslandicus, S. commerson	larvae	S.semifasciatus feed almost exclusively on larval fish, and S.queenslandicus and S.commerson feed almost exclusively on larval fish and larvaceans. S.queenslandicus exhibit ontogenetic change; larvaceans decreasing; larval fish increasing in diet	Jenkins, G. P., Milward, N. E., and Hartwick, R. F. (1984)
NQ	Halifax, Cleveland, Bowling Green Bays	shallow (<40m) soft-bottom, pelagic	Scomberomorus semifasciatus, S.queenslandicus, S. commerson	larvae	S.semifasciatus restricted to coastal bays and the inner margin of the lagoon. S.queenslandicus in the coastal bays but extended over the lagoonal region as well. S. commerson occurred only in the lagoon. Related to spawning sites, longshore currents	Jenkins, G. P., Milward, N. E., and Hartwick, R. F. (1985)

Region	Location	habitat type	taxa	stage	type of study or results	reference
NQ	Lizard Island	pelagic ; GBR Lagoon; neuston, 0-6m, 6-13m, 13-20m	50 taxa in 24 families	larvae	Vertical dsn highly structured in day ; nearly unstructured at night; most taxa highest concentrations deep in day; day/night changes in pattern apparently were due to randomization or spread, rather than active migration	Leis, J. M. (1991b)
NQ	Lizard Island, Coral Sea	pelagic	Chanos chanos	larvae	concentration, abundance and size-frequency data deduced that spawning was in the Coral Sea or outer edge of shelf, apparently after adult spawning migration of >=50 km. Larvae moved inshore to at least midshelf, by use of currents and swimming	Leis, J. M. and Reader, S. E. (1991)
NQ	Great-Barrier-Reef	ribbon reefs	Istiophoridae	Preflexion larvae	spawning or hatching of blue/black marlin/sailfish eggs was concentrated in the area within 0.25 nautical mile seaward of the reef crest. Preflexion larvae of blue marlin and sailfish were essentially confined to the upper 6 m of the water column	Leis, J. M., Goldman, B., and Ueyanagi, S. (1987)
NQ	Coral Sea	tuna aggregation area	Thunnus-albacares, Thunnus-obesus	sub-ad.-adult	The yellowfin and the bigeye taken from the tuna aggregations fed almost exclusively on a single species of deepwater lanternfish (Diaphus sp.), not sampled in catches from the other 2 areas.	McPherson, G. R. (1991)
NQ	Great Barrier Reef Lagoon	pelagic <40m	38 families of fish ; and lologinid squids	late-stage larvae, juvs	Size-frequencies indicated that the light traps sampled late-stage larvae and pelagic juveniles exclusively; Coefficients of variation among replicate traps were taxon-specific, ranging from 0.9 (for clupeids) to 0.2-0.1 (for pomacentrids).	Thorrold, S. R. (1992)
NQ	GBR Lagoon ; cross-shelf off Townsville	8-40m pelagic	Scomberomorus semifasciatus, S. commerson/queenslandicus, Cybiosarda-elegans, Euthynnus-affinis, Thunnus sp, Rastrelliger sp	large post-larvae and small juvs	Innovative technique to catch previously unseen life-stages. A patch of Scomberomorus, Thunnus coherent over >= 1 km. All scombrids relatively abundant at station 16-24 km from the coast; corresponded to position of a coastal boundary layer in the area.	Thorrold, S. R. (1993)
NQ	Townsville cross-shelf transect	GBR Lagoon and inter-reef,	***	***	composition affected more by location of sample sites than by time. Ordination differentiated "nearshore", "midshelf" and "inter-reef" groups "wet" and "dry" season groupings; "wet" with higher abundances of several "nearshore" spp. No effect of reef proximity	Watson, R. A., Dredge, M. L. C., and Mayer, D. G. (1990)
NQ	Townsville cross-shelf transect	mid-shelf reef to outer shelf	zooplankton, ichthyoplankton	***	distribution of total dry weight of zooplankton, copepod numbers and ichthyoplankton across the outer continental	Williams, D. McB., Dixon, P., and English, S. (1988)

Region	Location	habitat type	taxa	stage	type of study or results	reference
					shelf in the central Great Barrier Reef was examined.	
NSW	Sydney-Port Stephens	demersal trawl	Helicolenus papillosis; Squalus megalops; Squatina australis; Rexea solandri	***	assess the quantity of fish on the deepwater trawling grounds off the Sydney-Port Stephens area,	Anon. (1977)
NSW	Tasman-Sea	warm core eddy ; midwater to 500m	88% of 26 taxa were in family Myctophidae	***	night structure within eddy distinct from surrounding water masses; most distributions correlated with thermal structure; eddy spp (n = 5), outside eddy/cold-water spp (n = 5), warm-water spp (n = 1), cold-water spp (n = 8) and widespread spp (n = 7)	Brandt, S. B. (1981)
NSW	Sydney	Artif FADS vs controls	***	larvae-pre-settlement	great numbers that were present in low abundance in open water included pelagic, reef and estuarine-associated fish as follows: juvenile carangids, sphyraenids, mullids, mugilids and larval ambassids, sillaginids, sparids and gerreids.	Druce, B. E. and Kingsford, M. J. (1995)
NSW	off Sydney	(20 to 30 m) over the 30, 70 and 100m isobaths across each transect;	***	larvae	Horizontal trends in the distributions of the abundant taxa were evident in the inshore-offshore direction, but not longshore ; Gobiidae, Labridae, Sillaginidae, Sparidae, Ambassidae, Clupeidae and Clinidae/Tripterygiidae were most abundant inshore	Gray, C. A. (1993)
NSW	North Head, Bondi and Potter Point	sewage plume, plume front, adjacent clear, shelf water	49 families, including sparids, sciaenids, sillaginids, girellids, mugilids, carangids	pre- and post-flexion larvae	sewage plumes form a turbid, 1-5 m deep lens of lowered salinity overlying clear, shelf waters. Many fish were concentrated in plume fronts and advection or active attraction influences dsn of fish at scales <1km. ; may prolong exposure to pollutants	Gray, C. A. (1996)
NSW	Long Reef, Port Hacking	30m vs 60m vs 100m	75 demersal trawl species	juv.-adult	assemblages at 30 and 60 m were most similar to each other ; they consistently differed from those at 100 m depth ; may reflect a change in the demersal ichthyofauna from nearshore to offshore assemblage. Longshore diffs due to substrata?	Gray, C. A. and Otway, N. M. (1994)
NSW	3 cliff-face sewage outfalls, 3 control sites ; between Long Reef-Marley	25-30m pelagic, net tows at surface and 20m	127 taxa	larvae	plumes vs control correlations were swamped by the spatial heterogeneity in dsn and relative. abundance of larvae. Striking vertical differences and amongst autumn, spring and summer periods. These diffs consistent amongst plume/control. Least catches in December	Gray, C. A., Otway, N. M., Laurenson, F. A., Miskiewicz, A. G., and Pethebridge, R. L. (1992)
NSW	Botany Bay	pelagic (dynamic estuarine plumes	zooplankton, 29 families of reef,	larvae	Major differences (some conservative) found over 400-800m of water encompassing plume, front, ocean. Sillaginids, gobiids,	Kingsford, M. J. and Suthers, I. M. (1994)

Region	Location	habitat type	taxa	stage	type of study or results	reference
		intruding 11km out across shelf)	pelagic, estuarine and benthic fishes		gerreids, sparids most abundant in plumes. Fronts may act to retain, or plumes act as cues to larvae of estuarine spp.	
NSW	Sydney, Long Reef-Port Hacking	soft-bottom, 60m	49 fish species	sub-ad.-adult	Trawl survey and dietary study to assess changes in trophic groups in BACI design around sewage outfalls. At least 5 hypotheses can be proposed to explain rise in 1 trophic group (crust., fish, echinoderms., polychaetes) of mainly triglids, urolophids	Otway, N. M., Sullings, D. J., and Lenehan, N. W. (1995b)
NSW	entire coast	inland, estuarine, coastal, demersal, pelagic	teleosts, elasmobranchs, molluscs, crustaceans	juv.-adult	Compilation, collation, review and synthesis of all reported production data in the period 1940-1992 and discussion of trends	Pease, B. C. and Grinberg, A. (1995)
NSW	entire coast	***	all fisheries	***	Fisheries effort and production figures for 1991/92	Pease, B. C. and Scribner, E. A. (1994)
NSW	Botany Bay	pelagic (dynamic estuarine plumes intruding 11km out across shelf)	Blenniidae, Kyphosidae, Monodactylidae, Pomacentridae, Gerreidae, Mugilidae, Mullidae, Sparidae	larvae	nutritional significance of larval feeding in estuarine plume fronts is often taxon specific and responded variably to 1) estuarine plume vs 2) front vs 3) shelf water. Used GFI and prey id. ; mugilids and kyphosid feeding selectivity for harpacticoids	Rissik, D. and Suthers, I.M. (In Press)
NSW	SE Fishery	demersal trawl, shelf	Rexea-solandri	***	very fecund; possible that strong recruitment may result from relatively small spawning biomass, given suitable environmental conditions. However such conditions would need to be sustained over a period of years to bring about any substantial recovery	Rowling, K. R. (1992)
NSW	Tasman Sea	pelagic	Rexea solandri	pre-recruits	No consistent relationship between ENSO and gemfish recruitment, but 2 peaks in the early 1970's and 1980's match peak periods in the number of days of strong zonal west winds. Mechanism unknown and may be no cause-effect at all. Winds have 11yr cycle.	Thresher, R. E. (1994a)
NT	NT tiger prawn grounds	trawl grounds	Scylla-serrata	adults	migrating adults caught l0 - 60 m depth (mean 28.5 m), 3 to 95 km offshore (mean 17.9 km). Mostly (87 %) in Oct-Nov; migration allows dispersal of megalopa stage to recruit to habitats distant from those of the parents	Hill, B. J. (1994)
NT	Timor-Arafura seas, Gulf of Carpentaria	<20m - >200m	364 species from 104 families	juv.-adult	Cross-shelf, regional scale demersal and pelagic fish trawling inventory with biological synopses provide a baseline dataset in CSIRONET on relative abundance and size by depth and region. A variety of ecosystem level questions are proposed	Okera, W. and Gunn, J. S. (1986)

Region	Location	habitat type	taxa	stage	type of study or results	reference
NT	Joseph Bonaparte Gulf 128E - western Gulf of Carpentaria 138E	20-50m on prawn trawl grounds	73 families of fish, 11 families of elasmobranchs, 4 fam. of crustaceans, 6 fam.of molluscs	juv.-adult	218 taxa in 73 families of fish dominated by-catch (75-92 % weight of bycatch); 2612 t of sharks and rays ; crustaceans excluding commercial prawns (1060 t); molluscs (1166 t); echinoderms (660 t); other invertebrates (483 t); reptiles (144 t)	Pender, P. J., Willing, R. S. and Ramm, D. C.(1993b)
NT	Joseph Bonaparte Gulf 128E - western Gulf of Carpentaria 138E	18-76m on prawn trawl grounds	selected 115 taxa of teleost	juv.-adult	Large-scale patterns of abundance of fish bycatch in prawn trawls; distinct 1) western and 2) eastern groups separated at 132E, and shallow (<30m) and deep (>30m) groups within these. Other conclusions from previous studies dependent on scale of sampling	Ramm, D. C., Pender, P. J., Willing, R. S., and Buckworth, R. C. (1990)
NT	114-142 deg longtd ; North West Shelf to Cp York	mixed seabed type, 50-90m,	24 commercial catch categories, >= 69 spp of fish, squid and cuttlefish	juv.-adult	Desktop assessment of size and extent of groundfish resources in the Nthn sector of AFZ using observer and logbook data from foreign trawlers. Lethrinidae, Lutjanidae, Nemipteridae, Centrolophidae (Psenopsis only), Synodontidae, Trichiuridae predominated	Ramm, D.C. (1994)
NT	Arafura, Timor Seas, Gulf of Carpentaria	shelf pelagic, neritic	17 spp from Triakidae, Hemigaleidae and Carcharhinidae	***	distribution, size composition, sex ratio, reproductive biology and diet. 3 groups based on reproduction. Notably small demersal spp reproduced continuously through year; Diets were omnivorous to highly selective. Fish was an important component in all but 1spp	Stevens, J. D. and McLoughlin, K. J. (1991)
nWA	North West Slope	***	Caridae	***	Recent research (Rainer 1992) suggests that the diets of some North West Slope (NWS) prawns, which are trawled by demersal gear, indicate that prawns not only migrate into midwater at night, but also feed there.	Rainer, S. (1994)
nWA	NW Slope	315-485 m	carids and penaeids	***	penaeids Aristeus virilis, Haliporoides sibogae and Plesiopenaeus edwardsianus ate benthic/demersal prey; penaeid Aristaeomorpha foliacea and the carid Heterocarpus sibogae ate both midwater and demersal animals; H. woodmasoni ate mainly midwater animals.	Rainer, S. F. (1992)
nWA	North West Shelf and NT	demersal trawl	***	***	Tropical demersal fisheries have 3 pronounced attributes which lead to difficulty in their biological management; (1) a large number of species are exploited, (2) there are biological interactions between species and (3) fishing mortality is unequal	Sainsbury, K. J. (1982)
nWA	North West Shelf	demersal trawl	Lethrinidae, Nemipteridae,	***	continental shelf of north-western Australia has been exploited since 1959. The history of exploitation is	Sainsbury, K. J. (1987)

Region	Location	habitat type	taxa	stage	type of study or results	reference
			Lutjanidae, Synodontidae, Serranidae		*summarised, and concurrent changes in fish community are inferred from data collected during research surveys.*	
nWA	*North West Shelf*	*40m and 80m, epibenthic*	*357 taxa of epibenthic crustaceans, including 308 decapods*	***	*highly diverse fauna of epibenthic decapod crustaceans; only 35% of the most common spp differed in abundance between depths. The abundances of 30% of these common spp related to particle size of sediment or to the biomass of macrofauna.*	*Ward, T. J. and Rainer, S. F. (1988)*
nWA	*eastern Indian Ocean*	*pelagic*	*Thunnus-maccoyii, T.alalunga, Katsuwonus-pelamis*	***	*Copepod nauplii, calanoids, cyclopoids and cladocerans main prey of SBT/yellowfin. Skipjack ate appendicularians, fish larvae. Indexes of feeding success of SBT positively correlated with prey biomass suggests food was limited*	*Young, J. W. and Davis, T. L. O. (1990)*
nWA	*North West Shelf*	*cross-shelf transect, stepped oblique tows down to 100m*	*104 taxa*	*fish larvae*	*Distributional patterns. pooled larvae least at shelf break; denser towards both shore and ocean; other patterns due to sampling gear, depth of sampling site and time of year of sampling.*	*Young, P. C., Leis, J. M., and Hausfeld, H. F. (1986)*
NZ	***	*Surface drift algae Carpophyllum, Sargassum*	***	*pre-post-flexion and pre-settlement fish*	*some Monacanthidae, Arripidae, Emmelichthyidae, Syngnathidae, Clinidae, Tripterygiidae more abundant around drift algae than in open water Although some fish associated with algae were preflexion forms, most were postflexion or juvenile forms*	*Kingsford, M. J. (1992a)*
NZ	*north-eastern coast*	*neuston*	***	*neustonic larvae*	*tripterygiids (Forsterygion spp.), an engraulid (Engraulis australis) and a clupeoid (Sardinops neopilchardus) accounted for 80% of the total catch. Most neustonic larvae caught at stations 3.2 or 6.0 km offshore*	*Tricklebank, K. A., Jacoby, C. A., and Montgomery, J. C. (1992)*
review	*review*	*estuarine, shelf, deep sea*	*review of life-history implications with examples*	***	*The lack of sufficient basic knowledge of the biology of most species, especially in the tropics and deep sea; decline of support for basic research are an important constraint to the development of reliable models of divisions between habitats*	*Blaber, S. J. M. (1991)*
review	*world-wide dsn of species*	*pelagic*	*Thunnus-maccoyi*	*all*	*classification; early life-history; trophic relationships; aging and growth of juveniles and adults; maturation and spawning; stock structure, distribution and migration; natural mortality; the southern bluefin tuna fisheries;*	*Caton, A. (1991)*
review	*review*	*pelagic drifting structures and*	*73 families of fish*	*preflexion to juvs*	*importance of biotic structures of a wide size range (eg. , marine snow, jellyfish, drift algae) and interactions between*	*Kingsford, M. J. (1993)*

Region	Location	habitat type	taxa	stage	type of study or results	reference
		oceanographic features			biotic and abiotic (oceanographic features) structures in the pelagic environment are discussed.	
review	review	convergence zones, internal waves, Langmuir circulations, fronts	***	eggs, larvae and pre-settlement stages	a surprising number of oceanographic processes manifest themselves as lines at the ocean surface; aggregation, retention, onshore and offshore movement, concentration of food, interactions with other plankters. Slicks and research utility are described	Kingsford, M.J. (1990)
review	Antarctic- Ocean	***	***	***	19 species have been recorded in FAO statistics, most species belonging into the sub-Channichthyidae ("Icefish"). A short description of the life cycle of 18 of these species is given. population dynamics and stock assessment, are summarised	Kock, K.-H., Duhamel, G., and Hureau, J.-C. (1985)
review	review	pelagic	fish	larvae	Future research should aim to 1) collect larval feeding data on more species and 2) examine further the relationship between feeding ecology, recruitment success and seasonal and interannual variations in plankton production.	Young, J. W. (1992)
SA	Great Aust Bight	pelagic, shelf	Thunnus maccoyii	juv.	Innovation in use of GIS, acoustics, archival tags, aerial surveys, LIDAR to assess juvenile abundance and recruitment	Anon. (1995l)
SA	lower Spencer Gulf	frontal zone	42 taxa including Sillaginodes punctata, Sillago schomburgkii, S. bassensis, a sparid and a hemirhamphid	larvae	pronounced discontinuity in larval distribution is apparent across the frontal zone of Spencer Gulf, consistent with a reduction in gulf-shelf exchange. Both larval diversity and concentration peak within the frontal zone. no productivity measures	Bruce, B. D. and Short, D. A. (1992)
SA	Great Australian Bight	demersal	Nelusetta ayraudi	juv.-adult	Review of fisheries biology. eggs spawned during late Apr appeared the following Dec as 7mth old 96.5mm juveniles in bays - then emigrated offshore in autumn.	Grove-Jones, R. P. and Burnell, A. F. (1991)
SA	Great Aust. Bight, 2 Gulfs - Kangaroo Island	Lower Gulfs and Shelf pelagic	Sardinops neopilchardus	eggs, larvae, GSI	pilchards most common <= 100m. GSI (Mar-Apr), larval abundance (Mar-May) and egg abundance all indicate spawning in Feb-May with peak in Apr-May and at eastern head of GAB. Daily-Egg-Production-Method should be aimed there first	Hoedt, F. and Jones, G. K. (In Press)
SA	Great Aust. Bight, 2 Gulfs - Kangaroo Island	Pelagic,	Sardinops neopilchardus	eggs and schools	A suite of upwelling cells identified and related to dsn of eggs and acoustic records of pilchard schools. Pilchards may have been attracted to feed/spawn in these areas, and intra-annual shifts in spawning caused by intrusion of cooler	Hoedt, F. E., Jones, G. K., Jackson, G., and Dimmlich, W. F. (In Press)

Region	Location	habitat type	taxa	stage	type of study or results	reference
					water over shelf	
SA	South East region	deepwater canyons, demersal, 200-800m	Hyperoglyphe antarctica (++ 14 other taxa)	sub-ad.-adult	Survey. April highest CPUE occurred in 400-700m and coincided with spawning and upwelling of nutrients from deeper waters. Ate mostly pelagic tunicates Pyrosoma	Jones, G. K. (1985)
SA	Great-Australian-Bight	demersal trawl		***	assess the distribution of commercial and potentially commercial fish species across the GAB slope and to determine the extent of trawlable ground on the slope. Additional objectives were to investigate the biology of the major commercial species	Newton, G. and Klaer, N. (1991)
SA	Great Australian Bight; Cp Pasley 123E- Kangaroo Island 137E	pelagic 40-300m	Scomber australasicus, Trachurus declivis, Sardinops neopilchardus,	sub-ad.-adults	Cross-shelf and longshore pelagic trawling and studies of diet, dsn by depth and age of major pelagic planktivores. Euphausids, mysids, copepods major prey	Stevens, J. D., Hausfeld, H. F., and Davenport, S. R. (1984)
sWA	off Albany	Leeuwin Current	Sardinops-sagax-neopilchardus	eggs	variation in the location of the different pilchard stages consistent with eastwards transport rate of 0.5 to 1.0 knots. vs December, when the Leeuwin Current weak no evidence of unidirectional transport	Fletcher, W. J., Tregonning, R. J., and Sant, G. J. (1994)
sWA	31.58S-32.28S; lower west Coast	shelf (5-15m)	Sillago burrus, S. vittata	juv.-ad.	age, growth, reproduction; both spp use shallows <=1.5 m as nursery but S.burrus leaves at 60mm by 3mo old and S. vittata leaves after a year and 90mm long	Hyndes, Potter and Hesp(in press)
Tas	***	pelagic midwater and surface drift objects	Hyperoglyphe antarctica	juv.	Centrolophids (trevalla, warehous) complex life-histories; undergo dramatic shape changes during their growth – juveniles are generally paler, have a more evenly rounded forehead and a relatively smaller eye ; appears to move to deeper water after >= 460 mm LCF	Baelde, P. and Last, P. (1993)
Tas	shelf off eastern Tasmania	upper continental slope (420 to 550 m)	15 spp including Brama, Lepidopus, Macruronus, Genypterus	sub-ad.-adults	four trophic categories: pelagic piscivores, epibenthic piscivores, epibenthic invertebrate feeders; benthopelagic omnivores. Pelagic piscivores eat myctophid Lampanyctodes; their diet is narrow, with large overlap between spp	Blaber, S. J. M. and Bulman, C. M. (1987)
Tas	Sub-tropical convergence	pelagic	review	***	Tas. lies on the STC and surrounding waters therefore very sensitive to interannual changes in the position of the STC. plankton biomass, the timing of the spring bloom, the structure of the food chain, and the recruitment of commercial fisheries correlated	Harris, G. P. (1987)
Tas	eastern coastal shelf	nr Sub-tropical	***	***	(1945-85) observations at Maria Island showed strong	Harris, G. P., Davies, P.,

Region	Location	habitat type	taxa	stage	type of study or results	reference
		Convergence			interannual variability in SST; spring bloom often extended by as much as three months in some years. links between climate and the fisheries.	Nunez, M., and Meyers, G. (1988)
Tas	eastern coastal shelf	Sub-Antarctic water, Sub-Tropical convergence, EAC	Trachurus declivis	adult	High ZWW stress causes advection of colder, nutrient-rich SAW up the eastern side of Tas. and reduces water column stability; result is periodic overturn of the water column and increased new production. Spring blooms tend to be later but stronger	Harris, G. P., Griffiths, F. B., and Clementson, L. A. (1992)
Tas	Storm Bay	2.5deg C rise in water temp due to influence of EAC	***	***	Pulses of algal growth in Storm Bay (measured as chlorophyll) followed peaks in the 40 day wind oscillation and resulted from the resuspension of nutrients regenerated by decomposition in bottom waters	Harris, G. P., Griffiths, F. B., Clementson, L. A., Lyne, V., and van-der- Doe, H. (1991)
Tas	St Helens - Eaglehawk Neck	pelagic; cross-shelf	Trachurus declivis	eggs, larvae, adults	impact of oceanographic variability on spawning adults and early life-history stages; considering which factors may have influenced interannual variability in egg and larval abundance.	Jordan, A. J. (1992)
Tas	St Helens - Eaglehawk Neck	pelagic; cross-shelf, 0-50m, 70-100m, 150m	Trachurus declivis	eggs, larvae	spawns on entire east coast shelf break in summer. La Nina did not affect location or timing of spawning, but may have advected eggs inshore (via EAC), and caused reduced egg production later by lean adults. No evidence of inshore movement for recruitment	Jordan, A., Pullen, G., Marshall, J., and Williams, H. (1995)
Tas	Maatsuyker ridge	seamounts	***	***	recent major seabed mapping project off Tasmania, combined with the discovery of 4 new fish species in the deepwater coral habitat	Koslow, A. and Exon, N. (1995)
Tas	GAB-SE Aust	mid-slope (800-1200 m) demersal	37 families and 111 species	***	biogeographic patterns, consistent with oceanic circulation at intermediate depths is evidence against the recent hypothesis that deepwater fish communities cannot be defined over broad areas and are only random assemblages. Offshore/downslope energy inputs?	Koslow, J. A., Bulman, C. M., and Lyle, J. M. (1994)
Tas	SE Fishery	pelagic, longline grounds	Bramidae	***	A guide to the identification of 8 species of pomfrets that are likely to form the basis of a fledgling fishery off southern Australia	Last, P. and Baron, M. (1994)
Tas	east of Maria-I	surface to the bottom (500 m); demersal and pelagic	54 families; 115 spp ; Myctophidae, Squalidae, Sternoptychidae contributed 25%	juv.-adult	Benthic biomass was relatively low and stable, but derived from many species. Pelagic biomass was high, fluctuated widely and was composed of a few species. Biomass was highest in summer	May, J. L. and Blaber, S. J. M. (1989)

Region	Location	habitat type	taxa	stage	type of study or results	reference
Tas	west coast	***	Macruronus-novaezelandiae	larvae	differed consistently in mean size and age between sites; consistent with the hypothesis that larvae are being passively advected by longshore currents from a spawning area on the west coast to habitats along the southeastern and eastern coasts.	Thresher, R. E., Bruce, B. D., Furlani, D. M., and Gunn, J. S. (1989a)
Tas	eastern Tasmanian shelf	pelagic longlining grounds	Thunnus-maccoyii	sub-ad.-adult	1) need to determine which of 4 hypotheses explain recent influx of young fish (3-4yr) 2) better understanding of SBT relationship with oceanographic features and events should lead to greater fishing efficiencies	Young, J. and Lyne, V. (1993)
Tas	eastern Tasmania	continental slope waters	Maurolicus muelleri, Lampanyctodes hectoris and Diaphus danae	***	M. muelleri,L. hectoris, D. danae ate euphausiids and secondarily on copepods, although larger D. danae fed on other lanternfish. synchronisation of size structure of predator populations and feeding intensity, with seasonal variations in prey	Young, J. W. and Blaber, S. J. M. (1986)
Tas	Maria Island	pelagic	Nyctiphanes australis, Trachurus declivis	juv-adult	Survey of krill abundance, jack mackerel stomach contents and hydrology ; absence of krill in 1989 and subsequent failure of the jack mackerel fishery in that year ; influx of subtropical Nthn waters low in nutrients onto the shelf in La Nina event	Young, J. W., Jordan, A. R., Bobbi, C., Johannes, R. E., Haskard, K., and Pullen, G. (1993)
Tas	148-152E; East Aust Current vs Sub-tropical Convergence vs Sub-Antarctic water mass	surface-400m, pelagic	107 taxa from 43 families of midwater fish	post-larvae-adults	The STC is not an area of increased micronekton abundance; does not contain a distinct community during autumn/winter. EAC community. was sign. diff from that of SAW, but not from STC. Thin EAC layer <200m can be distinguished from SAW. Depth important	Young, J. W., Lamb, T. D., and Bradford, R. W. (1996)
temp	Great Australian Bight - Tasman Sea	pelagic	Jasus edwardsii	phyllosoma	Research proposal. Emphasises fishery managed as 7 functionally independent. units, yet obvious regional differences in egg production and oceanographic forcing. Proposal to synthesise existing data and hindcast ocean climate to define testable questions, gaps	Bruce, B., Griffin, D., Young, J., and Kennedy, R. B. (1995b unpubl. Research proposal)
temp	Victoria, Tasmania	three areas of the upper continental slope (420-550 m)	Macruronus-novaezelandiae	sub-ad.-adults	diel vertical migrations similar to those of its prey to within 50 m of the surface at night – almost entirely of mesopelagic fauna. The major prey are myctophid fish Lampanyctodes hectoris , other fishes, natant decapods, euphausiids and squid.	Bulman, C. M. and Blaber, S. J. M. (1986)
temp	Victoria, Tasmania		Hoplostethus-	juv.-adult	Juvs. fed on bentho- and meso-pelagic crustaceans, while	Bulman, C. M. and Koslow, J.

Region	Location	habitat type	taxa	stage	type of study or results	reference
			atlanticus		*mature fish consumed predominantly. fish and squid; diet changed significantly with depth, geographical area, and year. Metabolism and body comp. is similar to that of active, migratory mesopelagic fishes*	*A. (1992)*
temp	*Great Aust. Bight*	*demersal trawl >400m*	***	***	*exploratory trawl*	*Colgan, K., Grieve, C., and Newton, G. (1994)*
temp	*entire Aust range of pilchard*	*pelagic*	*Sardinops neopilchardus*	***	*genetic criteria were used to identify 4 contiguous, quasi-independent pilchard sub-populations. Complex patterns of segregation are evident and homing to different spawning areas cannot be discounted on existing evidence*	*Dixon, P. I., Worland, L. J., and Chan, B. H. Y. (undated) FRDC#89/25*
temp	*review*	*mid-slope community.*	*Hoplostethus atlanticus, Oreosomatidae*	***	*By trophic modelling, shown that sedimentation from the surface would provide very little of the energetic requirements of this community.; likely that there is a significant lateral flux of energy into the mid-slope community.*	*Koslow, J. A. (1994)*
temp	*review of information*	*mid-slope*	*Hoplostethus atlanticus*	***	*distributed over the mid-continental slope waters of southern Australia, the Tasman Rise and Cascade Plateau. Size compositions tend to be bimodal with a major mode of fish measuring about 40 cm (caudal fork length) and a minor mode between about 21-29*	*Lyle, J. M., Evans, K. R., and Wilson, M. A. (1989)*
temp	*South-Eastern Aust.*	*surface waters, shelf*	*Nototodarus-gouldi*	***	*biology of Gould's squid off south-eastern Australia*	*O'-Sullivan, D. (1980)*
temp	*Southeast (NSW, Vic, Tas)*	*demersal trawl*	*Nemadactylus macropterus, Platycephalus richardsoni, Centroberyx affinis, Sillago bassensis*	*sub-ad-adult*	*(SET) is the largest established demersal fishery in Australia. More than 80 species have been recorded from it, but 9 contributed about 80% by weight ; major inshore species are jackass morwong, tiger flathead, redfish and school whiting.*	*Smith, D. (1991)*
temp	*South East shelf*	*SE Trawl*	*80 species with 19 comprising 92% of catch*	***	*Need (a) basic biology, biomass and distribution of major species at least; (b) assessments of sustainable yields; (c) catch, effort, and target-bycatch ratios. Progress on these is reviewed*	*Tilzey, R. D. J. and Klaer, N. L. (1991)*
temp	*South East shelf*	*SE Trawl*	*Neoplatycephalus-richardsoni, Sillago-bassensis flindersi, Nemadactylus-macropterus, Rexea-*	***	*A review is presented of the distributions of the major commercial fish species involved in the Australian South East trawl fishery; catch/effort was used as an indication of comparative abundance.*	*Tilzey, R. D. J., Zann-Schuster, M., Klaer, N. L., and Williams, M. J. (1990)*

Region	*Location*	*habitat type*	*taxa*	*stage*	*type of study or results*	*reference*
			solandri, Centroberyx-affinis, Macruronus-novaezelandiae, Hoplostethus-atlanticus			
Vic	*Victoria*	*demersal and pelagic*	*52 fish spp*	***	*Arrow squid most widely consumed, being found in the diets of eight species and over the whole geographical range; Cephalopods (octopus very imp.), gastropods and bivalves were found in the diets of 21, 6, 5 spp respectively*	*Coleman, N. (1984)*
Vic	*Bass Strait and Western Port nr Phillip Island*	*inshore bay and shelf to 10km offshore*	*Engraulis australis, Sardinops neopilchardus*	*eggs, larvae*	*Survey of spatial and temporal dsn and abundance. Anchovy eggs and spawning adults varied greatly between years (adults shift) and both spp had considerable spatial variability in Bass Strait. Bay entrance especially important spawning ground*	*Hoedt, F. E. and Dimmlich, W. F. (1995)*
Vic	*eastern Bass Strait*	*SE demersal trawl*	*Sillago bassensis, Platycephalus richardsoni, Nemadactylus macropterus*	***	*maximum sustainable yields are presented for school whiting (Sillago bassensis), tiger flathead (Platycephalus richardsoni) and jackass morwong (Nemadactylus macropterus). Only the tiger flathead is found to be at any risk of over-exploitation*	*Wankowski, J. W. J. (1987)*
Vic	*eastern Bass Strait*	*SE demersal trawl*	*37 taxa*	***	*Of the 37 species, 20 had high potential catch rates; of the 20, there were no substantial commercial landings. Seasonal variation in biomass and standing stock was large, both within the area as a whole and between depth zones.*	*Wankowski, J. W. J. and Moulton, P. L. (1986)*
WA	*entire austral range of species*	*pelagic*	*Sardinops neopilchardus*	*adults*	*review of knowledge on history of exploitation and fisheries biology until 1990*	*Fletcher, W. J. (1991)*
WA	*Great Australian Bight*	*30-240m*	*Nelusetta ayraudi*	*juv.-adult*	*Juveniles 6-10cm found in midwater school in 74m. Fish size increased with depth. Diet; fish, salps, gastropods, crustaceans, algae.*	*Lindholm, R. (1984)*

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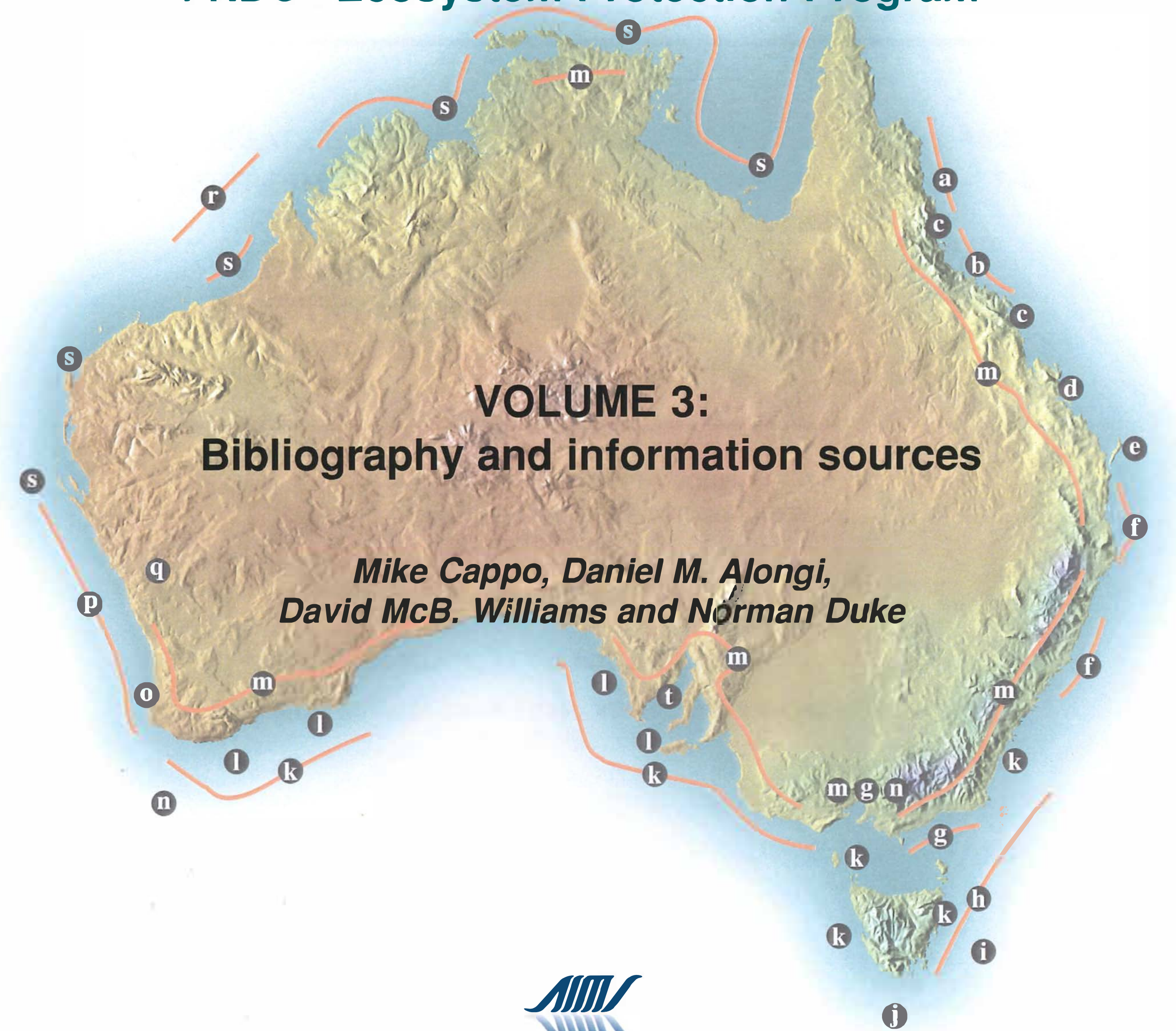

VOLUME 3:
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Other Sources of Information

Appendix 7. List of Researchers and Managers Cited as Personal Communications (in interviews, workshops or from seminars) , by Organisation, Subjects Covered and "Pro-cite" keywords

AUSTRALIAN CONSERVATION FOUNDATION (1)
320, Caswell, Tricia
NAT/conservation/policy/multidisciplinary-science

AUSTRALIAN FISHERIES MANAGEMENT AUTHORITY (AFMA) (3)
760, Phillips, Bruce // Rayns, Nick, and McGuire, Katrina
NAT/AFMA/trawl/effects-of-fishing/recruitment-variability

770, Huber, Dorothea
NAT/bycatch/pelagic-fish/billfish-tuna

780, Chapman, Lindsay
NAT/tuna/pelagic-fish/bycatch/nutrification/seafloor-souring

AUSTRALIAN MUSEUM (1)
890, Leis, Jeff
NSW/larvae/bioregionalisation/larval-behaviour/sandy-beach

AUSTRALIAN NATURE CONSERVATION AGENCY (ANCA) (1)
880, Coyne, Peter and Pretty, Sharon
NAT/ANCA/IMCRA/bioregionalisation

AUSTRALIAN SEAFOD INDUSTRY COUNCIL (2)
370, Leadbitter, Duncan
NSW/restoration/changes-to-drainage/property-rights

600, Leadbitter, Duncan
NSW/estuaries/research-issues

BUREAU OF RESOURCE SCIENCES, DEPT OF PRIMARY INDUSTRIES AND ENERGY (7)
680, Hamdorf, Ian
NAT/FEHC/contaminants

690, Kerr, Steve

NAT/ballast-water/introduced-pests

700, Rawlin, Grant
NAT/disease/introduced-pests

710, Caton, Albert
NAT/whiting/bioregionalisation

720, Staples, Derek
NAT/effects-of-fishing/monitoring

730, Stewart, Phil
NAT/atlas-of-fisheries-resources/finforms

740, Williams, Geoff
NAT/effects-of-fishing/FRDC Cronulla Workshop

CHARLES STURT UNIVERSITY (1)
350, Robertson, Alistar
NAT/estuaries/policy/research-issues/overviews/multidisciplinary-science

COOPERATIVE RESEARCH CENTRE FOR ECOLOGICALLY SUSTAINABLE DEVELOPMENT OF THE GREAT BARRIER REEF, TOWNSVILLE (CRC REEF) (Conference)
Done, Terry
NQ/coral-reef/Sargassum/nutrification

110, Robertson, John
NQ/GIS/coral-reef/effects-of-fishing

110, Bode, Lance
NQ/modelling/larval-transport

1650, Mapstone, Bruce
NQ/effects-of-fishing/coral-reefs

CSIRO AND MELBOURNE WATER, COORDINATORS, PORT PHILLIP BAY ENVIRONMENTAL STUDY (Conference)
(1)
990, Port Phillip Bay Environmental Study, Public Seminars
VIC/nutrification/denitrification/PPBES/contaminants/pollution/sedimentary-processes

CSIRO CENTRE FOR ENVIRONMENTAL MECHANICS, CANBERRA (5)
360, White, Ian
NSW/ASS/fish-kills/changes-to-drainage

820, Webster, Ian
NSW/sediments/nutrification/denitrification

830, Ford, Phil
NSW/bioirrigation/denitrification

840, White, Ian
NSW/ASS/restoration/EUS

850, Tan, Yunhu
NSW/bacteria/ASS/catalytic-factors

CSIRO DIVISION OF FISHERIES, CLEVELAND LABORATORIES (9)
110, Poiner, Ian (Seminar)
NQ/effects-of-fishing/trawling/bycatch/coral-reef

240, Poiner, Ian
NQ/MACS

250, Pitcher, Roland
NQ/effects-of-fishing/shelf-sediments/benthos/bycatch/habitat-mapping

260, Long, Brian
NQ/habitat-mapping/GIS

270, Die, David
NQ/prawn-nurseries/GoC/recruitment

280, Blaber, Steve and Brewer, Dave
NQ/estuarine-dependence/bycatch/effects-of-fishing

290, Loneragan, Neil
NQ/Peel-Harvey/prawn-nurseries/eutrophication/estuaries/mangroves/seagrass/isotopic-ratios

300, Vance, Dave and Haywood, Mick
NQ/predation/prawn-nurseries

310, Kenyon, Rob
NQ/seagrass/prawn-nurseries/restoration

CSIRO DIVISION OF FISHERIES, HOBART LABORATORIES (10)
1100, Last, Peter
TAS/bioregionalisation

1110, Thresher, Ron
TAS/introduced-pests/recruitment-variability/biomarkers/zonal-westerlies

1120, Stevens, John
TAS/shark-nursery/seagrass/temperate

1170, Parslow, John
TAS/modelling/innovation/monitoring/technologies/trophodynamics/shelf-processes

1180, Bruce, Barry
TAS/larval-biology/life-history/shelf

1190, Sainsbury, Keith
WA/effects-of-fishing/NW-shelf

1200, Koslow, Tony
TAS/trophodynamics/shelf/sea-condition-hindcasting/SE-trawl-habitat/effects-of-fishing/seamounts

1220, Abbott, Denis
TAS/NAT/literature-searches/ASFA-database

1230, Davis, Tim
TAS/NQ/barramundi-nursery/tuna-spawning

1290, Lyne, Vince
TAS/modelling/trophodynamics/bioregionalisation/innovation/habitat-mapping

CSIRO DIVISION OF FISHERIES, MARMION LABORATORIES (5)
1450, Kendrick, Gary
WA/seagrass/macroalgae/temperate-reef

1460, van der Klift, Matt
WA/seagrass/fish-communities/WA/bare-sand/nurseries

1470, Kirkman, Hugh
WA/seagrass/subtidal-habitats/habitat-mapping/temperate-reef/seagrass-dieback/seagrass-recovery/bioturbation

1480, Nielsen, John and Jernakoff, Peter
WA/grazing/epifauna/temperate-seagrasses

1490, Jacoby, Charles
WA/mesocosms/Jervis-Bay/sandy-beach

CSIRO DIVISION OF OCEANOGRAPHY, HOBART LABORATORIES (7)
1130, Nichols, Peter
TAS/biomarkers/biomonitoring

1140, Craig, Peter
TAS/oceanography/overviews/larval-transport

1150, Volkman, John and Butler, Ed

TAS/contaminants/algal-blooms/ICM/surface-microlayer

1160, Walker, Stephen
TAS/modelling/introduced-pests/PPBES/larval-transport

1210, Griffin, David
TAS/rock-lobster/oceanographic-data-needs

1240, Cresswell, George
TAS/oceanography/current-patterns/upwelling/El-Nino

1250, Hunter, John
TAS/modelling/nutrification/flushing-regimes

CSIRO DIVISION OF WILDLIFE ECOLOGY, CANBERRA (1)
340, Cork, Steven
(Seminar)
NAT/policy/resource-use/decision-support

DEPT OF BOTANY, THE UNIVERSITY OF ADELAIDE (1)
1620, Westphalen, Grant
SA/sand-dredging/seafloor-souring/redox-potential/epifauna/infauna/SA

DEPT OF ENVIRONMENT SPORT AND TERRITORIES, COASTS AND MARINE BRANCH, ENVIRONMENTAL STRATEGIES DIRECTORATE (2)
860, Ilett, Anne
NAT/CTC/IMCRA

870, Rose, Louise
NAT/monitoring/OR2000

DEPT OF ENVIRONMENT SPORT AND TERRITORIES, DIRECTOR, STATE OF ENVIRONMENT REPORTING UNIT (1)
790, Haines, Alan
NAT/SOER/monitoring

DEPT OF ENVIRONMENT SPORT AND TERRITORIES, ENVIRONMENTAL RESOURCES INFORMATION NETWORK (ERIN), MARINE AND COASTS (2)
670, Blake, Steve
NAT/GIS/NATMIS/bioregionalisation

800, Crossley, Dave
NAT/NATMIS

DEPT OF ZOOLOGY, THE UNIVERSITY OF ADELAIDE (1)
1610, Butler, Alan

SA/temperate-reefs/metapopulations/monitoring/introduced-pests/sand-dredging/seafloor-souring

EDITH COWAN UNIVERSITY, WESTERN AUSTRALIA (1)
1350, Lavery, Paul
WA/WA-estuaries/nutrification/seagrass-dieback/Cockburn-Sound/macroalgae/algal-blooms/biomonitoring/estuary-closures/fisheries-links

ENSIGHT, SYDNEY WATER (1)
560, Miskiewicz, Tony
NSW/nutrification/larval-supply/sewage-plumes

ENVIRONMENTAL OFFICER, QCFO, BRISBANE (1)
230, Doohan, Mark
SEQ/changes-to-drainage/ponded-pastures/mangroves/biovalue

ENVIRONMENTAL PROTECTION AGENCY, WA (1)
1400, Simpson, Chris
WA/WA-priorities/regional-issues/nutrification/TBT/introduced-pests/biomonitoring/biocides/seagrass-loss/research-needs

ERIN, CSIRO, AGSO, DEST, ANCA (etc) (1)
1660, Commonwealth Trust Consortium Bio-physical regionalisation Workshop
NAT/bioregionalisation/oceanography/upwelling/zootones/ecotones/physical-surrogates/natural-dynamics/climate-change/biomonitors/CAMRIS/NATMIS/forcing-functions/barriers/sediments

FISHCARE, DEPT OF PRIMARY INDUSTRIES AND ENERGY (1)
810, Johnson, Grant and Waterman, Annette
NAT/FISHCARE

GREAT BARRIER REEF MARINE PARK AUTHORITY, GBRMPA (Seminars) (2)
110, Oliver, Jamie
NQ/monitoring

110, Brodie, John
NQ/nutrification/coral-reef/sedimentation/outfalls/sewage-plumes/ICM/biocides

GRIFFITH UNIVERSITY, QUEENSLAND (1)
900, Connolly, Rod
SA/SEQ/whiting/seagrass/nurseries

INTECOL CHAIR, LOUISIANA STATE UNIVERSITY (1)
330, Turner, Eugene
NAT/restoration

KINHILL, Western Australia (1)
1390, Morrison, Peter and Hillman, Karen
WA/seagrass/seagrass-dieback/sand-shell-dredging/Cockburn Sound/nutrification/restoration/fish-surveys/patch-dynamics

KOORAGANG WETLAND REHABILItATION PROJECT, DEPT OF BIOLOGICAL SCIENCES, UNIVERSITY OF NEWCASTLE (1)
380, Streever, Bill
NSW/restoration

LAND AND WATER RESOURCES RESEARCH AND DEVELOPMENT CORPORATION (1)
750, Schofield, Nick
Land and Water Resources Research and Development Corporation
NAT/LWRRDC/NRHP/research-programs

MARINE AND FRESHWATER RESOURCES INSTITUTE, VICTORIA (11)
980, Parry, Greg
VIC/Sabella/nearshore-fish-community/trophodynamics/effects-of-fishing

1000, Smith, Dave
VIC/overviews/monitoring/larvae

1010, Hickman, Neil
VIC/pollution/researchers/VFRI

1020, Arnott, Graham
VIC/shellfish-toxins/algal-blooms/monitoring

1030, Gunthorpe, Leeann
VIC/contaminants/surface-microlayer/larvae/abnormalities/pollution

1040, Brown, Lauren
VIC/shark-nursery/nurseries/feeding

1050, Longmore, Andy
VIC/monitoring/water-quality/sediments

1060, McDonald, Murray
VIC/catch-history/seagrass-decline/embayment

1080, Gorfine, Harry
VIC/abalone/research-issues/bioregionalisation

1090, Winstanley, Ross
VIC/snapper-life-history/introduced-pests

1680, Jenkins, Greg

VIC/whiting/nurseries/seagrass-dieback/Sabella/feeding/linkages/larval-transport/meiofaunal-/production/temperate-reef/macroalgae/recruitment/bare-sand/recruitment-hotspots/snapper

MURDOCH UNIVERSITY, WA (1)
660, McComb, Arthur
WA/seagrass/WA-research-overview

NORTHERN TERRITORY DEPT OF PRIMARY INDUSTRIES AND FISHERIES, DARWIN (NTDPIF) (4)
10, Field, Dave
NT/water-quality/pollution/mosquito-control

20, Ramm, Dave
NT/effects-of-fishing/trawling/bycatch/benthos

30, Knuckey, Ian
NT/mud crabs/abalone

1670, Griffin, Roland
NT/barramundi/nurseries/estuaries/wetlands/ponded-pastures/saline-intrusion/floodplains/aquatic-weeds/changes-to-drainage/EUS/fishways/barriers/restoration/recruitment-variation/mosquito-control/biomarkers

NSW DEPT OF FISHERIES, PYRMONT (1)
1330, Smith, Adam and Pollard, Dave
NSW/MEPAs/NSW/shark-bycatch

NSW FISHERIES RESEARCH INSTITUTE, CRONULLA (13)
430, Williams, Rob
NSW/restoration/review/changes-to-drainage/barriers/mangroves/ICM

450, Otway, Nick
NSW/restoration/nutrification/monitoring

460, Gray, Charles
NSW/recruitment/estuaries/plumes/larvae

470, Ferrell, Doug
NSW/snapper-life-history/nurseries/nearshore-fish-community/recruitment

480, Steffe, Aldo
NSW/larvae/recruitment/hydrodynamics/estuaries

490, Reid, Dennis
NSW/freshwater/CPUE/monitoring

500, Gordon, Geoff
NSW/monitoring/modelling

510, Ortiz, Ernesto
NSW/OR2000/GIS/bioregionalisation

520, Pease, Bruce
NSW/CPUE/estuarine-fisheries/monitoring

530, Andrew, Neil
NSW/temperate-reefs/urchin-barrens/abalone/bycatch

540, West, Ron
NSW/estuaries/fisheries-links/restoration/inventory/monitoring

550, Harris, John
NSW/freshwater/fishways/changes-to-drainage

1340, Gibbs, Philip
NSW/restoration/monitoring/sampling-gear

NSW TECHNICAL COMMITTEE, ASSMAC MEETING (1)
120, White, Ian and Williams, John
NSW/ASS/restoration

QDEH, INGHAM REGIONAL OFFICE, AT TULLY-BOWEN ZAC RESEARCH DAY, TOWNSVILLE (1)
1640, Hicks, John
NQ/overviews/policy

QLD DEPT OF PRIMARY INDUSTRIES, LAND USE AND FISHERIES, OONOONBA VETERINARY LABORATORIES, TOWNSVILLE (1)
100, Creighton, Col // Malcolm, Hamish, and Draheim, Zoe
NQ/overviews/estuaries/changes-to-drainage/restoration/sedimentation/ICM

QLD DEPT PRIMARY INDUSTRIES, LAND USE AND FISHERIES, NORTHERN FISHERIES CENTRE, CAIRNS (NFC) (8)
40, Coles, Rob // Lee Long, Warren, and McKenzie, Len
NQ/seagrass/changes-to-drainage/mosquito-control/regional-planning/restoration/nurseries

50, Clarke, Anne
NQ/permit approvals/marine plant legislation

60, Derbyshire, Kurt

NQ/GIS/planning/ICM/land-use

70, Russell, John
NQ/ASS/ICM/restocking/barramundi-nursery/wetlands/mangroves

80, Gribble, Neil
NQ/Effects-of-fishing/prawn-nurseries/food-chains/bycatch

90, Garrett, Rod //McPherson, Geoff, and Bibby, Jeff
NQ/estuaries/nearshore-fish-community/finfish/nurseries/gillnet-fishery

110, Coles, Rob
NQ/seagrass/algae/tropical

110, McKenzie, Len
NQ/seagrass/algae/tropical

QLD DEPT PRIMARY INDUSTRIES, LAND USE AND FISHERIES, SOUTHERN FISHERIES CENTRE, DECEPTION BAY (SFC) (10)
130, Quinn, Ross
SEQ/Sillago/sand-dredging/mangroves/fish-communities/restoration

140, Courtney, Tony
SEQ/prawn-nurseries/bycatch/prawn-nurseries

150, Danaher, Karen
SEQ/GIS/habitat-mapping

160, Butcher, Adam
SEQ/Sillago/nurseries/red-spot-trawl whiting

170, Wager, Rob
SEQ/riparian-zone/freshwater-threats/restocking

210, Dunning, Malcolm
SEQ/GIS/CHRIS/mangroves/estuaries/fish-communities

220, Halliday, Ian
SEQ/mangroves/fish-nursery/fish-feeding/ontogeny

400, Beumer, John
SEQ/estuaries/mangroves/restoration/policy/SEQ/review

410, Zeller, Brad
SEQ/restoration/SEQ

420, Quinn, Ross

SEQ/restoration/SEQ

QLD DEPTOF PRIMARY INDUSTRIES, AGRICULTURAL BIOTECHNOLOGY CENTRE (1)
1320, Lewis, Richard
NQ/ciguatera/biotoxins

QLD FISHERIES MANAGEMENT AUTHORITY, NORTH QLD FISH STOCKING SEMINAR (1)
1310, Cadwallader, Phil // Hogan, Alf //Hamlyn, Alex //Tait, Jim // Jackson, Peter // Keenan, Clive // Russell, John // Palmer, Paul, and Rimmer, Mike
NQ/restocking/inbreeding-depression/stock-enhancement/fishways/culverts/changes-to-drainage/habitat-/modification/translocation/interbasin-water-transfer/introduced-pests

SARDI, AQUATIC SCIENCES AND AQUACULTURE CENTRE, WEST BEACH (10)
1500, Johnson, John
SA/nutrification/seagrass/biomonitoring/issues-overview/artificial-reefs

1510, Pierce, Bryan
SA/Coorong/restoration/environmental-flows/estuaries/tidal-access/changes-to-drainage/barriers/salinity/black-bream/mulloway/nurseries

1520, Fowler, Tony
SA/whiting/life-history/nurseries/seagrass/recruitment/larval-transport/natural-dynamics

1530, Seddon, Stephanie
SA/seagrass/seagrass-dieback/recovery/lost-production/CPUE/short-term-effects

1540, Shepherd, Scoresby
SA/abalone/urchin-barrens/natural-dynamics/effects-of-fishing/climate-change/disease/temperate-reefs/species-interactions/seagrass

1550, Kangas, Mervi
SA/prawn-nurseries/sandy-beach/nutrification/effects-of-fishing/pollution/TEDs/larval-transport/hydrodynamic-modelling/sampling-gear

1560, Jones, Keith
SA/seagrass/seagrass-dieback/nutrification/Barker-Inlet/nurseries/recruitment-indices/macroalgae/SA/baitfish/natural-dynamics

1570, Hoedt, Frank
SA/anchovies/pelagic-fish/pilchards/baitfish/fisheries-oceanography/natural-dynamics/upwelling

1580, McGlennon, Dave
SA/snapper-life-history/spawning-aggregations/recruitment-pulses/natural-dynamics/artificial-reefs/SA/migration

1590, Baker, Janine
SA/MEPAs/harvest-refugia/bioregionalisation/habitat-mapping/thermal-effluent

SCHOOL OF BIOLOGY AND ENVIRONMENTAL SCIENCE, MURDOCH UNIVERSITY (3)
1420, Hyndes, Glenn
WA/Sillago/WA/nurseries/seagrass/bare-sand/estuaries/restoration/Dawesville-Channel/Cockburn-Sound

1430, Potter, Ian
WA/estuaries/WA

1440, Paling, Eric
WA/seagrass-restoration/transplants/Cockburn-Sound/sand-shell-dredging/nutrification/patch-dynamics

SOUTH AUSTRALIAN DEPT OF ENVIRONMENT AND NATURAL RESOURCES, OFFICE OF THE ENVIRONMENT PROTECTION AUTHORITY (1)
1600, Kirkegaard, Ian // Bellette, Kathryn, and Cugley, John
SA/restoration/habitat-issues/SA/agricultural-chemicals/contaminants/stormwater/seagrass-dieback/multi-function-oxidases/biomonitoring/wetlands/estuaries-wetland-scrubbers

SOUTHERN CROSS UNIVERSITY, CENTRE FOR COASTAL MANAGEMENT, LISMORE (3)
180, Saenger, Peter
NSW/restoration/northern-rivers/mangroves/ICM

190, Zann, Leon
NAT/SOMER/northern-rivers/threats/overviews/COTS

200, Digby, Mike
NSW/GIS/ASS/changes-to-drainage

SYDNEY UNIVERSITY, Biological Sciences (2)
620, Kingsford, Mike
NSW/temperate-reef/plumes/bioregionalisation

630, Dorfmann, Erik
NSW/sea-birds/diets

SYDNEY UNIVERSITY, DEPT OF BOTANY (1)
610, Ritchie, Ray and Larkum, Tony
NSW/seagrass-production/nutrification/algal-blooms/seagrass-/seagrass-dieback

TASMANIAN DEPT OF PRIMARY INDUSTRIES AND FISHERIES, TAROONA LABORATORIES (3)
1260, Edgar, Graham
TAS/introduced-pests/climate-change/urchin-barrens/temperate-reef/bioregionalisation/effects-of-fishing

1270, Crawford, Christine
TAS/mariculture/seafloor-souring/algal-blooms/monitoring

1280, Jordan, Alan // Mills, Dave, and Moverley, John
TAS/habitat-mapping/seagrass-loss/seagrass/nurseries/temperate/seafloor-souring/nearshore-fish-community/multi-gear-sampling

UNIVERSITY OF MELBOURNE, DEPT OF ZOOLOGY (5)
930, Day, Rob
VIC/abalone/growth-variability/modelling

940, Watson, Graeme
VIC/seagrass/nurseries/embayments/zooplankton

950, Shaw, Craig
VIC/sandy-beach/surf-zone/nearshore-fish-community/temperate/nurseries

960, Holloway, Mike
VIC/introduced-pests/Sabella/recruitment

970, Keough, Mick
VIC/monitoring/temperate-reef/intertidal-harvesting/introduced-pests

UNIVERSITY OF QUEENSLAND, DEPT OF BOTANY (1)
650, Dennison, Bill and his research group
SEQ/biomonitoring/monitoring/seagrass/nutrification

UNIVERSITY OF QUEENSLAND, DEPT OF ZOOLOGY (2)
910, Johnson, Craig // Ault, Tim, and Laegdsgaard, Pia
SEQ/mangroves/nurseries/sub-tropical/trophodynamics/coral-reef

920, Greenwood, Jack // Tibbetts, Ian, and postgrad. students
SEQ/sub-tropical/mangroves/nearshore-fish-community/canal-estates/fish-/communities

UNIVERSITY OF TASMANIA, DEPT OF BOTANY (1)
1300, Hallegraeff, Gustav
TAS/algal-blooms/nutrification/toxins

UNIVERSITY OF WESTERN AUSTRALIA, CENTRE FOR WATER RESEARCH (1)
1380, Hamilton, David
WA/modelling/estuaries/WA/nutrification/algal-blooms/macroalgae/ICM/salinity/groundwater

UNIVERSITY OF NEW SOUTH WALES (3)
570, Dixon, Pat
NSW/bioregionalisation/thermal-effluent/restocking

580, Suthers, Iain
NSW/plumes/fronts/larval-supply/estuaries

590, King, Robert
UNSW, Botany
NSW/seagrass/NSW

VICTORIAN DEPT OF CONSERVATION AND NATURAL RESOURCES (2)
390, Hull, Grant
VIC/estuaries

1070, Garnham, John
VIC/monitoring/pollution/polluters-pay/environmental-priorities

WESTERN AUSTRALIAN MARINE REASEARCH LABORATORIES (3)
1360, Lenanton, Rod
WA/freshwater-diversion/changes-to-drainage/estuaries/WA/nutrification/Dawesville-channel/sandbars/salinity/black-bream/effects-of-fishing/drift-macrophytes/seagrass/nurseries/algal-blooms

1370, Caputi, Nick
WA/rock-lobster/WA/recruitment/Leeuwin-Current/environmental-variability/range-effects

1410, Ayvazian, Suzie
WA/fishing-litter/effects-of-fishing/baitfish-removal/WA/temperate-reef/nurseries

WBM OCEANICS (1)
640, Morton, Rick
SEQ/restoration/canal-estates

WORKSHOP - COASTAL RESOURCE INVENTORIES AND MAPPING, QUEENSLAND DEPT OF ENVIRONMENT AND HERITAGE (1)
1630, Blackman, Gavin // Johnson, Andrew // Gilbert, Trevor // Losee, Scott// Blake, Steve // Draheim, Zoe, and Storrie, Jamie
NQ/GIS/coastal-resource-atlas/oilspill/NATMIS/decision-support/ICM/CHRIS