
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 $\leq 1\text{m}$ to macro-tidal $\geq 8\text{m}$) 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 <i>et al.</i> (1992), Woodroffe and Mulrennan (1993),			
Qld	Beumer <i>et al.</i> (1996),	Beumer <i>et al.</i> (1996), Bryan (1982), Bunn <i>et al.</i> (1996), Hogan and Graham (1994), Hogan <i>et al.</i> (1995), Jackson (1996), Lupton <i>et al.</i> (1995), Russell (1987, 1988), Russell and Garrett (1985), Tait (1996)	Beumer <i>et al.</i> (1996), Jarvis and Colvin (1981), Morton (1989, 1992), Williamson <i>et al.</i> (1994),	Thom (1989), Walker <i>et al.</i> (1989a),	Russell and Hales (1994), Russell <i>et al.</i> (1996 a,b)	Beumer <i>et al.</i> (1996), Byron (1991), Chuk (1991), Garrett (1991), Ponded Pastures Steering Committee (1996),	Beumer <i>et al.</i> (1996), Beumer and Halliday (1994), Bucher and Saenger (1989), Butler (1996), Duke (1997), Hulsman <i>et al.</i> (1989), Hyland and Butler (1989), Quinn and Beumer (1983), Russell and Hales (1994), Russell <i>et al.</i> (1996 a,b)	Beumer <i>et al.</i> (1996), Brodie (1996), Goldsworthy (1994), Poiner and Peterken (1996), Shepherd <i>et al.</i> (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 <i>et al.</i> (1989, 1993, 1995 a,b), Lehane (1996), Lin <i>et al.</i> (1995), Lines-Kelly (1995a,b), Pearce (1990), Rodgers and Burke (1981), Sammut <i>et al.</i> (1993, in press), Virgona (1992), White <i>et al.</i> (1995, In Press)	Boon (1992), Bunn <i>et al.</i> (1996), Burchmore <i>et al.</i> (1993), Harris (1984), Mallen-Cooper (1993), Middleton <i>et al.</i> (1985), Pollard (1993a), Pollard and Hannan (1994), Shepherd (1992), Walker (1985), Walker <i>et al.</i> (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 <i>et al.</i> , (1985)	Collett <i>et al.</i> (1981), Larkum and West (1990), Shepherd <i>et al.</i> (1989), West (1983,1990a,b), West <i>et al.</i> , (1985)
Vic							Bucher and Saenger (1989,1991),	See Chapter 3; Edgar <i>et al.</i> (1993), Shepherd <i>et al.</i> (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 <i>et al.</i> (1989)
WA			Atkins (1989)	Neira and Potter (1992b),			Bucher and Saenger (1989),	See Chapter 3; Hastings <i>et al.</i> (in press), Shepherd <i>et al.</i> (1989), Walker <i>et al.</i> (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 Webbnnet (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 <i>et al.</i> (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 <i>et al.</i> (1996); FRI NSW see eg Mallen-Cooper <i>et al.</i> (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 <i>et al.</i> (1996a)	

R&D Gaps	Main Habitat	Main Fishery	Key Reference	Key Initiative Underway
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 ntnh NSW; emerging hazard in Qld	NSW estuarine and oysters; Qld estuarine	White <i>et al.</i> (in press), Pollard and Hannan (1994)	ASSMAC, Sugar Industry Infrastructure Package (Qld) Drainage schemes
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) Poned Pastures and their implications for fish nurseries	wetlands, saltmarsh, mangroves; NT, Gulf Country, Central Qld	Barramundi, Arid Catfish; other estuarine species		Poned 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 <i>et al.</i> (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 led 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 $\text{pH}=3$
- aluminium hydroxide floccs bind to clays and attach to skin and block gills at higher pH

- monomeric aluminium toxicity kills the fish at $\text{pH}=5$ [$\text{Al}(\text{OH})_2^{++}$]
- 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 acidified 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 $\text{pH}=2.5$, 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).

	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.

	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).

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 (see 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).

	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 (Battaglione 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 (<i>Arius graeffii</i>)	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 “entrepreneurial” 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 \leq 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 m²) and “rotenone” ichthyocide and larger fish were caught with multipanel gillnets (9 × 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 $\geq 2 \text{ ms}^{-1}$) 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 $\leq 1 \text{ ms}^{-1}$ 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 km² 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 km² 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 these 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 “Saltmarsh” (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 of 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 50cm²
- 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 NSWFRRI (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 m² 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 <i>Melaleucas</i> 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	<i>Zostera</i> , <i>Cymodocea</i>	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	<i>Avicennia marina</i>	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	<i>Halodule</i> , <i>Cymodocea</i>	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	<i>Avicennia</i> , <i>Rhizophora</i>	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	<i>Avicennia</i> , <i>Rhizophora</i>	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	<i>Avicennia</i>	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	<i>Aegiceras</i>		current	Jeff Borschmann, Greening Australia
Loder Ck, Southport		community concern over lack of mangroves	nil	plant nursery-reared seedlings and transplant naturally occurring seedlings	<i>Avicennia</i> , <i>Sporobolus</i> , <i>Casuarina</i>	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	<i>Avicennia</i>	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	<i>Avicennia</i>	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	<i>Avicennia</i> , <i>Aegiceras</i> , <i>Sporobolus</i>	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	<i>Avicennia</i>	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 due to channel diversion	stream bank re-profiled, "geotech" laid > HWS to promote terrestrial grasses	plant nursery-reared seedlings and natural regeneration of grasses	<i>Avicennia</i> , <i>Cynodon</i>	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	<i>Avicennia</i>	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	<i>Avicennia</i> , <i>Aegiceras</i>	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	<i>Melaleuca</i> forest, sedgelands, mangrove, saltmarsh, <i>Ruppia</i> , 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 mullet and black bream, reduction in carp habitat	research proposal	Brian Pierce, SARDI, Fisheries and Aquatic Sciences, West Beach, SA