ISSUE 5:
Introduced and Translocated Pests and Diseases

5.1 Overview and FRDC role

5.1.1 The issues

The invasion of the Asian clam *Potamocorbula amurensis* in San Francisco Bay, the zebra mussel *Dreissena polymorpha* in the Laurentian Great Lakes and the comb jelly *Mnemiopsis leidyi* in the Black Sea are dramatic overseas examples of the catastrophic impact of ship-vectored introductions of marine pests. Fisheries and mariculture have collapsed in some instances and there seems little hope of eradication in some locations.

Introduced pests and diseases may pose the most important long-term threat to coastal ecosystems, and to the harvest industries located there. This is because they differ from all the other issues and impacts discussed in this review in three main ways:

- the other human impacts are more or less localised and can generally be rehabilitated by removal of the source of a stressor, but pests and diseases spread widely to the limits of their physiological tolerances - often a very wide geographic range
- prospects for complete eradication appear to very poor, although R&D has been insufficient to explore all possibilities
- the ecological roles and impacts of invading species can only be partially predicted from knowledge of their biology and ecology in donor regions.

A large number and wide variety of plants, animals and pathogens have been introduced into, or translocated amongst, Australian aquatic environments. Best-recognised are the spread of weeds and fishes in freshwaters, but of more immediate concern for the FRDC - in view of the relatively high value of coastal mariculture and fisheries - are the recently recognised ship-vectored introductions to temperate bays. These include toxic dinoflagellates (*Gymnodinium* and *Alexandrium* spp), Japanese kelp (*Undaria pinnatifolia*), Northern Pacific seastar (*Asterias amurensis*) and Mediterranean fanworms (*Sabella spallanzani*).

The European shore crab (*Carcinus maenas*) has a much lower profile in the popular media, perhaps because of the length of time it has been here (since the late 1800s) and its inconspicuous nature, yet some authorities (see Thresher 1997) suggest that this species could very well be Australia's most environmentally-destructive introduced marine pest. This exemplifies both the lack of knowledge of relative impacts and the control by the media of the discussion on risks, hazards and control opportunities. Ship-vectored introductions of ballast water or hull-fouling organisms are also present in the tropics, but have less of a media profile, and there will no doubt be further discoveries as port surveys progress in Australia.

Recurrent, toxic and nuisance algal blooms, and the potential for introduction of water-borne pathogens, have resulted in a public health hazard and millions of dollars in lost revenue for shellfish mariculture. Biotoxins causing paralytic shellfish poisoning (PSP), and to a much rarer extent amnesic shellfish poisoning (ASP) and diarrhetic shellfish poisoning (DSP), have been reported in Tasmania and Victoria when cultured shellfish are exposed to recurrent dinoflagellate blooms. Closures and loss of revenue have occurred at these times, and fish kills have resulted during the "red tides" in the Port River estuary of South Australia.

At the time of writing further algal and dinoflagellate blooms have occurred in Coffin Bay and Boston Bay near mariculture enterprises, but the general lack of knowledge of phytoplankton dynamics in Australia makes it difficult to distinguish natural and artificial "triggers". The poorly-known taxonomy of some dinoflagellates has also hampered separation of native and introduced taxa.

The human health risks associated with blooms and pathogens (see Chapter 3) produces a "halo effect" (p.c. #1300 G. Hallegraeff) that can depress all seafood sales. Disease in mariculture is a constant threat and a recent review concluded that the pathogens *Aeromonas salmonicida* (which causes furunculosis), infectious pancreatic necrosis virus (which causes infectious pancreatic necrosis), *Myxosoma cerebralius* (which causes whirling disease) *and Renibacterium salmonarum* (which causes bacterial kidney disease) are the greatest threat to Australia. The salmonids, prawns and oysters that comprise the majority of estuarine mariculture industry are the fisheries that would be most affected by such introductions.

A review of Australia's "disease preparedness" by Crane and Rawlin (1997) for the FRDC (FRDC#95/087) showed that

- most of the States and Territories are now addressing legislative deficiencies
- there is a severe lack of resources at the levels of both policy development and operations in relation to aquatic animal health.

Diseases and other pathogens may "cross over" into wild stocks and habitats. The most likely cause of the massive mortalities of pilchards in 1995 was from a novel Herpesvirus to which the Australian pilchard population was naive and whose origin was, therefore, most likely to be exotic (see Fletcher *et al.* 1997). Our informants mentioned the possibility of an introduction of the *Rhabdovirus* that has caused "right-eye" and "red spot" disease in barramundi and other NT fish since 1986. There is also an opinion that the *Aphanomyces* fungus associated with epizootic ulcerative syndrome (EUS) was introduced with aquarium fish before the 1970's (see section 2.2.1).

The Northern Pacific seastar has consumed cultured oysters and mussels and poses a threat to Tasmanian mariculture. The European shore crab is a voracious predator that poses a similar threat, particularly in its recent invasion of Tasmania, and there is concern that rack and line shellfish culture will be hampered by overgrowth with Japanese kelp and fanworms.

The Northern Pacific seastar and Japanese kelp have visibly altered the structure of soft-bottom and temperate reef habitats in some localised areas. Nearby are some of Australia's most valuable shellfisheries for abalone and rock lobster. These reefs lie in southern "nests of endemicity", and the starfish has been implicated in the decline of the spotted handfish - possibly the first extinction of a marine fish species (p.c.#1180 B.Bruce).

The fanworm competes for phytoplankton food with Port Phillip Bay scallops and other bivalves, is not eaten by fish - because of its very high vanadium content -- and locally modifies water circulation, and possibly benthic denitrification processes and seagrass beds. It is known to use dead rhizomes from *Posidonia* dieback as a holdfast. Changes to the Port Phillip Bay habitat by fanworms have included depression of food consumption by fish in fanworm beds and enhancement of populations of the little rock whiting *Neoodax balteatus*.

In the Swan River the Asian mussel *Musculista senhousii* may displace *Halophila* seagrass, as overseas studies show that this mussel overgrows, out-competes and may displace seagrasses. The toxic alga *Caulerpa scapelliformes* may have a similar effect in Botany Bay. There has been spectacular overgrowth of *Posidonia* seagrasses in the Mediterranean by a hybrid of *Caulerpa taxifolia* and there is still a risk that this popular aquarium plant will be introduced to Australia.

The effects of other introduced marine taxa may be less visible, but no less profound- Officer and Parry (1996) found that the bivalve *Corbula gibba* and the crab *Pyromaia tuberculata* are now included in the 20 most important linkages in the Port Phillip Bay food web. This may have encouraged an expansion of the spiky globefish population in the Bay.

The New Zealand screwshell (*Maoriculpus rosaceous*) is now considered to dominate the shellfish biomass on parts of the Australian shelf, and has been implicated in declines of native shellfish, but studies and evidence are lacking. Food webs and sediment type may have been altered by the sheer abundance of this species.

Some of the marine pests are characterised now by relatively restricted ranges but have the potential, under known temperature and salinity tolerances, to invade vast areas of southern Australia. Others, such as the fanworm and European shore crab are widespread. There is obviously a clear need to reduce the risks of translocation of these pests amongst ports, particularly by the fishing industry. The New Zealand screwshell is present from the Great Australian Bight to southern Queensland.

The challenge for the FRDC is to invest in ways of identifying and managing the threats posed by these pests to mariculture and fisheries, in the context of broader endeavours by the Australian Ballast Water Management Advisory Committee (ABWMAC) and Centre for Research on Introduced Marine Pests (CRIMP). These other initiatives have focussed first on risk assessment and reduction of introductions and broad scale monitoring of invasions. Indeed, protocols must also be developed by the FRDC's stakeholders to help:

- prevent their own industries introducing and spreading diseases and pests
- following best practises and developing secure procedures in translocating species across faunal provinces for aquaculture and preventing their escape

- following genetic best practises in translocating native freshwater fishes amongst drainages
- preventing and containing diseases arising in mariculture.

There is also an existing or potential role for the fishing industry in reducing the abundance of some introduced and translocated pests, such as European carp (*Cyprinus carpio*), by harvesting and expanding markets. However, once an industry becomes reliant on pest stocks there is the risk that deliberate spread will occur and that there will be resistance to its eradication or depletion.

There is clear evidence that invasions by pests and diseases in freshwater are facilitated by habitat disturbance, but similar evidence is lacking for marine waters. The potential synergies between the issues of pest invasions and changes to drainage and habitat modification, nutrient and contaminant inputs, and possibly effects of harvesting and mariculture, should be considered by the FRDC in assessing the priorities for the "Ecosystem Protection Program".

In summing up the Australian Society for Fish Biology (ASFB) Workshop on effects of introduced and translocated fishes in Australia, Courtenay (1990) identified that:

- there is a paucity of information on interactions between non-native and native fishes and their food webs and habitats
- there were often earlier or simultaneous alterations to habitats or other anthropogenic disturbances that may have facilitated the establishment of alien species
- introductions and translocations are primary or secondary forces in declines or other perturbations to native fish populations, in synergy with other disturbances
- molecular genetics shows that there are measurable differences between populations within species and translocations can alter the natural course of evolution, through hybridisation
- habitat modifications such as impoundments often result in demand for introductions of species that can tolerate these modifications
- Australia's impoverished and depauperate inland fish fauna makes it particularly vulnerable to aquarium fish introductions
- allowing for any non-native aquatic species into a nation under legislation is, in effect, approving its possibility of becoming a part of the biota of that nation.

Our interviews indicated that these freshwater aspects have much relevance to the recent invasions of marine pests. For example, tannin loads in the Derwent River are suppressing dinoflagellate blooms through light attenuation, and periodic freshwater flushing gives tolerant natives a competitive "edge" over introduced species - yet proposed damming of such rivers will probably release the marine pests from such natural control mechanisms and allow further establishment.

Prospects for complete eradication of pests seem to be low but the research base has been inadequate. Similarly the lack of evidence of the impacts of many pests has been due to a lack of study of Australian aquatic ecosystems, particularly before and after pests become established. This weakness in the evidence, not the impacts, should not discourage investment in R&D - research into the biology, ecology and spread of the pests is the major route by which techniques for managing and minimising the risks and hazards can be developed.

The freshwater research has identified the need for *integrated* control and management methods based on knowledge of "weak" points in the invader's life-history. Narrow attempts at control, such as poisoning, may produce "weed by weed" replacements of invaders, but holistic manipulations of water regime, stocked predators and riparian vegetation may enhance native predators at the same time as reducing invaders. Weed and insect invasions are sometimes met by "fast-tracking" of approvals of new herbicides and pesticides, with unknown implications for receiving waters.

Yet not all introductions are perceived as bad - in a fisheries context they can be classified according to their "desirability" in this review as:
desirable

- economically important and popular sportfish and mariculture species (eg. salmonids such as trout and Atlantic salmon)
- intentional introductions that have become locally important to mariculture or fishing, and are benign (eg. Pacific oysters in SA)
- intentional or unintentional translocations of native, freshwater, sportfish species outside of normal habitats or genetic ranges (eg. golden perch, silver perch, barramundi strains, murray cod, redclaw, marron).

undesirable

- ship-vectored introductions or species introduced unintentionally in the live-fish trade that have potential to dramatically alter ecosystem function and production from

fisheries and mariculture (eg. cyst-forming dinoflagellates such as *Gymnodinium catenatum*, Northern Pacific Seastar, Japanese kelp, fanworms, *Corbula*, *Maoriculpus*)
- pasture grasses that are economically valuable to graziers but are serious weed pests when spread to aquatic systems (eg. para grass, *Hymenachne*)
- intentional introductions by the aquarium fish industry that can profoundly alter wetland processes (aquatic weeds eg *Salvinia, Eichornia, Pistia*) or have become established with unknown effects (eg. weather loach, tilapia, *Oreochromis*, poeciliids)
- introductions of woody weeds that profoundly alter riparian or floodplain structure and presumably function (eg. willows, *Mimosa pigra*, rubber vine, blackberries)
- intentional introductions that were perceived to have some economic benefit (eg. European carp, goldfish, redfin perch, tench, mosquito-fish)
- escaped, feral populations from mariculture (eg. Pacific oysters in northern Tasmania, Victoria and NSW).

In this chapter we briefly summarise the “undesirable” marine and freshwater pests that threaten fisheries production and fisheries habitats, with recommendations for FRDC investment in Table 5.1.2 and a summary of the literature in Table 5.1.1.

The few early reviews of the subject (eg. Lehane *et al.* 1996, SOER 1996) highlight the following gaps in knowledge:
- poor taxonomy and lack of baseline data of endemic and introduced biota
- lack of knowledge of range and rate of spread of invaders
- lack of knowledge of effects on fisheries and mariculture
- poor development of management options for existing pests
- “weak” monitoring and testing protocols for disease introduction
- a need to start exclusion of pests at the overseas source ports where ballasting occurs.

Artificial spawning, rearing and stocking techniques have been refined in the last decade for major sportfish such as golden perch, Australian bass and barramundi. These advances and a rapid growth in impoundment sportfisheries have resulted in an increasing demand for restocking that has spread recently into “open” estuarine systems. Research on the stocking of open systems has expanded to include whiting (*Sillago* sp), dusky flathead (*Platycephalus fuscus*), mangrove jacks (*Lutjanus argentimaculatus*), grunter (*Pomadasys kakaan*) and mulloway (*Argyrosomus hololepidotus*).

Whilst there are certainly R&D opportunities to enhance impoundment fisheries there is a consensus of concern for the possibility of “genetic pollution” if best-practice is not developed and applied to stocking of open systems. The same concerns also apply to escape of large numbers of barramundi and other native species from aquaculture facilities during floods and other mishaps.

5.1.2 The literature

For the FRDC to gain the full knowledge of the threat of introduced pests and diseases it would be necessary to conduct a review of the growing body of international literature on overseas pests and diseases (see Carlton and Geller 1993 for general review). However, our brief was to examine only Australian information and literature in Table 5.1.1 has been selected from the (sparse) results of our searches in this area, on the basis of its relevance to fisheries and mariculture harvests and habitats. It broadly reflects the way that research has fallen out into risk assessment and surveys to grapple with the scope of the threats, with lower initial emphasis on identifying and managing the impacts of the marine pests existing here now. The freshwater research is thin - but more evenly spread across sub-issues.

This may be because of the relatively recent focus of attention on the coastal issues. Our literature searches found very few Australian studies of the effects of the main marine pests on ecosystems and harvests - especially compared to the issues outlined in other chapters. However, since the searches were completed there have been eleven technical reports from the Centre for Research on Introduced Marine Pests.

The literature in this area is sparse and new, including a handbook (Furlani 1996) and bibliography of introduced marine species (Furlani 1997) and a variety of studies pitched at different levels in the survey and sampling (eg. Hayes 1997), biology and dispersal (eg. Rainer 1995), impact and control areas of R&D opportunity. Comprehensive reviews of biology, demography and potential for control and eradication exist only for the European shore crab (see Thresher 1997). There have been studies of the early life-history critical for dispersal of the Northern Pacific seastar (eg. Bruce *et al.* 1995a) and some studies of control options for carp (eg. Grewe 1996).

Freshwater R&D on pests is moving toward “tweaking the system” through provision of environmental flows and restoration of riparian vegetation in integrated programs to reduce pests. A fishery for European carp and stocking of barramundi to eat tilapia are regional parts of this integrated approach that have benefits for the fishing industry.

University-based research is focussing on understanding the environmental processes producing monospecific algal blooms and on the survey methods for, and life-histories of, some pests at specific locations (eg. fanworm studies in WA, SA and Port Phillip Bay). Results and reviews are consequently not yet available. Research progress and overviews of priorities for R&D on Ballast Water Imports were summarised in Manning *et al.* (in press), Herfort and Kerr (in press), and Kerr (in press) supplied during a visit to Bureau of Resource Sciences in 1995, but we have not been able to update the sources of these references.

The value of studying natural dynamics, trophodynamics and life-histories at large scales and long terms - in contrast to single-species stock assessments - has been realised in studies of Port Phillip Bay food webs and fish communities (eg. Officer and Parry 1996, Hobday *et al.* 1996). A major spin-off has been the ability to detect effects of introduced fanworms, bivalves and crabs and thereby derive testable hypotheses for future experiments.

Definitive reviews of the biology, threats, control measures and R&D needs for weeds and other pests in freshwaters have been prepared by Finlayson *et al.* (1996) in the Scoping Review for the LWRRDC “Wetlands R&D Program”. Despite the importance to fisheries of coastal tropical wetlands we found a surprising lack of research on the environmental effects of aquatic weeds and pasture grasses. In a review of the topic Lukacs and Pearson (1996) concluded that even basic information such as distribution, abundance or basic control options are non-existent. They report that major weeds such as water hyacinth, *Salvinia* and alligator weed have had only incidental study of their impact upon habitat. The ASFB published workshop proceedings on the issue of “introduced and translocated fishes and their ecological effects” in Australia (Pollard 1990). The dearth of marine literature in that document may reflect that not many fish species are transported in ballast water or on hulls, but it may also illustrate the recent nature of concern for, and rapid rate of spread of ship-vectored introductions.

Table 5.1.1. Summary of Australian literature on effects of introduced and translocated pests on fisheries and mariculture.

Pest/Issue	Effects on mariculture	Effects on fisheries habitats	Taxonomy, biology and ecology	Surveys of introduction and spread	Management Methods
Dinoflagellate blooms	Hallegraeff *et al.* (1988), Hallegraeff (1992a), Shumway and Cembella (1994), Parry *et al.* (1989b)		Cannon (1993), Furlani (1996), Hallegraeff (1987, 1992a,b, 1993, 1995, 1996), Hallegraeff *et al.* (1989, 1991)	Anon. (1992b), Hallegraeff and Bolch (1991), Hosja *et al.* (1994)	Arnott (1990a, b), Arnott *et al.* (1991), Reichelt *et al.* (1994), Rigby *et al.* (1993),
Seastars, molluscs, fanworm, crabs	Clapin and Evans (1995), Davenport and McLoughlin (1993), McLoughlin and Thresher (1994, 1997), Rees (1996), Winstanley (1996)	Clapin and Evans (1995), Hobday *et al.* (1996), Lewis *et al.* (1994), Officer and Parry (1996), Parry *et al.* (1995), Peterson (1994), Thresher (1997)	Bruce *et al.* (1995a), Clapin and Evans (1995), Furlani (1996), Oshima *et al.* (1989,1993), Thresher (1997)	Clapin and Evans (1995), Davenport and McLoughlin (1993), Rainer (1995), Thresher (1997)	Clapin and Evans (1995), Hutchings (1992), Thresher (1994b, 1997),
Algae	Rees (1996),		Furlani (1996)	Pollard and Hutchings (1990), Rainer (1995), Sanderson (1990), Sanderson and Barrett (1989)	
Weeds		Finlayson *et al.* (1996), Lukacs and Pearson (1996)	Finlayson *et al.* (1996), Furlani (1996)	Cowie *et al.* (1988), Finlayson *et al.* (1996)	Finlayson *et al.* (1996)
Introduced Fish		Arthington (Undated), Ault and White (1994), Finlayson *et al.* (1996), King *et al.* (1997), Lake (1994), Robertson *et al.* (1997)	Finlayson *et al.* (1996), Furlani (1996), Lloyd (1984, 1986, 1990a), Lloyd and Tomasov (1985),	Burchmore *et al.* (1990), Cadwallader *et al.* (1980), Pollard (1990),	Bluhdorn *et al.* (1990), Grewe (1996)
Diseases		Langdon (1990)	Wolf (1977)	Furlani (1996), Gibson *et al.* (1991), Herfort and Kerr (in press)	Crane and Rawlin (1997)
Translocated fish		Bell (1992a), Beumer *et al.* (1996), Sheridan (1995),	Keenan (1996), Russell (1996)	Hogan (1996), Russell (1996)	Cadwallader (1996), Rimmer (1996)

5.1.3 FRDC action

There have been a large number of peak bodies and Task Forces recently set up to organise R&D on the avoidance, study and management of pest and disease invasions. We have not been able to draw together their recommendations, but there is clearly a key role for the FRDC in filling R&D gaps in the areas of both *reducing the role* of industry in causing pest and disease spread, and *reducing the effects* of pests and diseases on industry, by:

- determining the role of the fishing and aquaculture industries as a vector and source of exotic marine pests (eg. by vessel movements, intentional spread, live seafood shipments, bait and feed imports, escape of feral aquaculture species)
- developing codes of practice, technologies, education programs and other activities to reduce this role and avoid translocation and introduction of pests and pathogens
- liaising with international fleets and joint venture partners to ensure research is undertaken to reduce the risk of them introducing pests and diseases
- for new introductions deemed beneficial for aquaculture, encourage and if necessary support assessment of impacts on fisheries and aquaculture, in order to prepare impact mitigation strategies
- identifying the effects of existing pests on “wild” fisheries habitats and mariculture - a short-list of designated pests has been prepared by the Australian Ballast Water Management Advisory Committee (ABWMAC)
- developing cost-effective techniques (including industry “best practise”) to minimise impacts of all introduced species assessed to pose threats to harvesting
- developing mariculture surveillance protocols and technologies to avoid hazards caused by toxic algal blooms and introduction and spread of pathogens (eg. continuous-recording water quality buoys, disease test kits).

Close coordination with the national initiatives such as CRIMP, ABWMAC, LWRRDC and Environment Australia would serve the FRDC best in refining R&D priorities in this area, in ensuring that fisheries issues are included in their considerations and to facilitate effective use of FRDC funds. Further R&D on the aggravation of algal blooms by nutrients and effects of mariculture on the environment is outlined in Chapter 3.

The need to watch and prepare for disease introduction is crucial, but somewhat outside the scope of our review. Reviews of the subject are available in Crane and Rawlin (1997), Herfort and Kerr (in press), Humphrey (1995), Langdon (1990) and Munday *et al.* (1994)

The Land and Water R&D Corporation has prioritised the R&D needed to address the threats posed by aquatic weeds, woody weeds, pasture grasses, noxious fish and feral animals in its scoping review for the LWRRDC Wetlands R&D Program. These pests pose major threats to freshwater fisheries, Australian bass and barramundi in large parts of their range. Integration of the FRDC and the LWRRDC activities for these issues is essential to rehabilitate these fisheries.

We believe that there are R&D opportunities to expand and develop sportfisheries in impoundments based on stocked fishes. There is also demand to stock open estuaries and coastal lagoons (eg. mulloway in NSW, sand whiting and dusky flathead in Qld), but in all cases there is need to provide R&D on “best practice” in restocking and translocations to :

- safeguard local genetic biodiversity
- develop genetic and physical tags to distinguish stocked fish
- develop appropriate brood-stock turnover rates
- assess appropriate stocking levels
- assess the risks and hazards of disease dispersal.

Table 5.1.2. Summary of major opportunities for FRDC investment in addressing R&D gaps in knowledge of “Introduced and Translocated Pests”

R&D Gaps	Key Threat	Main Habitats	Main Fisheries	Key Australian Reference	Initiatives
Toxic dinoflagellate blooms and shellfish poisoning -- the need for development of national biotoxin surveillance and bloom management protocols for mariculture	Toxic and nuisance species of cyst-forming dinoflagellates	temperate bays and estuaries	Mariculture of shellfish and finfish in all States	Arnott (1990a,b), Arnott *et al.* (1991), Hallegraeff (1992a,b, 993,1995,1996)	Port Phillip Bay Shellfish. Sanitation Program., Tas, Shellf.Qual. Assur. Progr.
Need for development of genetic and ecological “best-practice” in restocking impoundments and open systems	inbreeding and genetic pollution	impoundments, disturbed freshwaters; SE Qld estuaries	east coast sportfisheries for translocated species (eg. catadromous bass and barramundi) ; estuarine barramundi, whiting, flathead	Benzie (1994), Rimmer (1996), Russell and Rimmer (1997), overseas references eg. Blankenship and Leber (1997)	
Effects of introduced pests on fisheries --- Assessment of threatening processes of key existing and potential introduced pests - strategic biological research for integrated management of the threat and tactical R&D to minimise impacts	ABWMAC designated pests; aquatic weeds and pasture grasses; carp and tilapia	sheltered temperate coastal waters; disturbed freshwaters;	Tas., SA and Vic. shellfish culture; Tas. Abalone and Rock Lobster; Tas. Salmon culture; east coast freshwater sport and commercial fisheries	Bunn *et al.* (1996), Finlayson *et al.* (1996), Kerr (in press)	CRIMP, Environment Aust., LWRRDC Wetlands R&D Program, AQIS
Potential for new, harmful introductions of pests and disease that endanger fisheries elsewhere (eg. *Mnemiopsis, Pfisteria, Sargassum, Caulerpa*)-- what are the risks and hazards for Australia?	Sheltered waters, diverse overseas taxa	All States; all waters, mainly enclosed waters near ports, freshwaters now	Shellfish mariculture; fish translocations for mariculture; big threat posed by aquarium industry imports	Herfort and Kerr (in press), Munday *et al.* (1994), overseas references eg Carlton and Geller (1993), Bellan-Santini *et al.* (1996)	ABWMAC, AQIS Ports and Diseases Study

5.2 Ballast water and hull-fouling organisms -- ship-vectored threats to mariculture and temperate fisheries habitats

Recent recognition of the threats posed by dinoflagellate blooms and changes to ecosystem structure by introduced pests has sparked alarm over ship-vectored imports of fauna, flora and pathogens in ballast water or fouled on hulls.

The Australian Quarantine and Inspection Service (AQIS) is now the lead Commonwealth agency for the management of ballast water issues, including policy development, implementation of a strategic research plan, and quarantine operations. A full summary of their activities can be found on the Internet at http://www.dpie.gov.au/aqis/homepage/imadvice/bprogram.html

The Ballast Water Program which includes the Australian Ballast Water Management Advisory Council (ABWMAC) and Research Advisory Group (RAG) is administered by AQIS in Canberra. The Strategic Ballast Water Research Program has been developed and is being implemented by ABWMAC on advice from its Research Advisory Group. AQIS provides administrative support for the implementation of the Research Program. The outcomes of the Strategic Ballast Water Research Program are central to the development of effective ballast water management policies. The Program is focused on the development of a risk assessment based Decision Support System (DSS) as an effective ballast water management tool for AQIS and other relevant government agencies and port authorities.

The DSS will provide a sophisticated risk assessment tool for application to each vessel voyage, and will allow authorities to more effectively manage ballast water discharges from international and coastal vessels. The Research Program also examines the issue of hull and sea-chest fouling as a vector for harmful marine pests.

The Coastal Zone Inquiry (RAC 1993) focussed early attention on the problems and costs associated with marine pests and the Centre for Research on Introduced Marine Pests (CRIMP) was established in the CSIRO Division of Marine Research in 1994. The objectives of CRIMP are to:

- develop and promote the application of techniques for earlier detection, more accurate prediction of impacts, and effective assessment of risks and costs associated with marine pest species introduced into Australian waters

- develop new methods or improve existing measures to control the spread and minimise the impacts of introduced marine pest species (CSIRO unpubl.)

There is, however, less emphasis within the early priorities of both ABWMAC and CRIMP on management of the impacts of existing pests on fisheries and mariculture and these beneficiaries of such R&D will have to contribute an investment (p.c.# 1110 R.Thresher). We recommend a major role for the FRDC in this field -- Kerr (in press) reports that economic costs due to toxic dinoflagellates alone may be around 200 million dollars over the next decade.

There have been a multitude of Australian initiatives and peak bodies with core business, or recently formed, to combat the threat of introductions. These include:

- Biodiversity Group in Environment Australia (formerly ANCA) - live imports and management of aquarium fish trade
- AQIS - risk assessments for pathogen and live/dead imports of seafood products
- Harmful Algal Bloom Task Force
- National Seastar Task Force
- Australian Shellfish Sanitation Advisory Committee
- National Taskforce on Imported Fish and Fish Products
- the Task Force on Managing Incursions of Exotic Pests, Weeds and Diseases
- Working Party on Aquatic Disease Preparedness Assessment.

The International Council for the Exploration of the Sea (ICES) has an international focus of several working groups on the threat of pest and disease introductions.

It was beyond our resources to identify and compile the R&D recommendations of all these bodies for the purpose of this scoping review. A first step for the FRDC in investing in this area would be to align its priorities with the activities of these groups.

5.2.1 Toxic and nuisance dinoflagellate blooms - a threat to mariculture

The problems associated with algal blooms have been reviewed in detail by Hallegraeff (1993, 1995) and are discussed in section 3.3. The major pest is the toxic dinoflagellate *Gymnodinium catenatum*, but several other species of *Alexandrium* may also have been introduced.

5.2.2 Marine pests that alter ecosystem structure

The reviews of information on marine pests by Furlani (1996, 1997) show serious gaps in knowledge of pest ecology, dynamics of invasion and effects on fisheries and mariculture, and with the sparse literature at hand for the Australian situation we could not rank pests relative to one another. In the SOMER reports Lehane *et al.* (1996) indicated that fanworms, Northern Pacific seastars, and Japanese kelp pose the greatest long-term threat to benthic communities, but this is disputed by CRIMP and may reflect more their media profile than their impacts.

Information from CRIMP suggested that the main pests threatening benthic communities in Australia are the European shore crab, the New Zealand screwshell, the Japanese kelp, and a hybrid of *Caulerpa taxifolia* that may not yet have reached Australia.

Freshwater studies of "invasion ecology" suggest that habitat disturbance is the key to allowing invaders to become established at a site. However, some marine pests such as Japanese kelp and European shore crabs are known to become well established and spread in apparently healthy benthic communities. Once pests become established, there is a high risk that the fishing industry itself may transport them to new locations (p.c.#1110 R.Thresher), for example:

- fanworms are known to foul hulls in ports
- at least 12 species of phytoplankton can survive inside the valves of closed shells (eg. oysters) in the "live water" fish trade
- Japanese kelp may have been transported on gillnets and anchor lines amongst Tasmanian rocky shores, perhaps by abalone fishermen in the case of a recent outbreak
- seawater used in live fish shipments could potentially contain seastar larvae.

The Fanworm Sabella spallanzani

Sabella spallanzani is a native of the Mediterranean. The worms are about 20 cm long and live in flexible tubes up to 50 cm long. They settle on hard substrata, such as pilings, but can anchor onto shells and rocks in sand and soft sediments. New recruits then settle on these colonisers to form very large, dense colonies. High vanadium (350ppm) levels in their tissues make the worms inedible to fish (p.c.#1050 A. Longmore), and there is evidence that they have a well-developed capacity to regenerate damaged body parts, so dredging is not a control option (Clapin and Evans 1995).

Fanworms are very fecund broadcast spawners. Spawning occurs annually and the larvae are lecithotrophic with a duration of less than 2 weeks. Settlers die after exposure in the intertidal -- the fanworms prefer sheltered, subtidal environments. They have a wide depth distribution, governed by wave energy, and they are found in depths below about 1 m in calm conditions and below about 3-4 m in exposed conditions in WA (p.c.# 1350 R.Lavery), to at least 18 m (Clapin and Evans 1995).

Seagrass dieback in Cockburn Sound and Port Phillip Bay may have helped fanworms to become established as they are known to use the remnant rhizome mat as a holdfast. The fanworms then overgrow the former habitat of seagrass in some areas and the standing stock of epiphytes and epifauna is actually greater than on seagrass (p.c.# 1350 R.Lavery).

Fanworms were first recorded in Port Phillip Bay (in Corio Bay) in 1988, then spread rapidly to a patchy distribution throughout 30% of the bay waters. They are altering the epifaunal substratum and the levels of turbulence there. Only the weedy "whiting" *Neoodax balteatus* settles in *Sabella* as a juvenile, and there are indications that this species has become more abundant in Port Phillip Bay. There is good evidence that fish feeding success is significantly lower in regions of the bay colonised by worm beds (see Hobday *et al.* 1996).

There are also serious concerns for the effect of the fanworms on the benthic bioturbation and denitrification cycles (see Bird 1994) that are critical in the assimilative capacity of the bay for sewage nutrient inputs. Bioturbation extends down to at least 50 cm within the sediments there, and there is a very high risk that overgrowth by dense, monospecific stands of fanworms could disrupt the processing of nutrients within this oxic layer. This hazard is unknown, but presently under study (p.c. #1050 A. Longmore), and was identified as the greatest threat to the health of the bay by the Port Phillip Bay Environmental Study. The fanworms also filter out thousands of tonnes of phytoplankton and are thought to be competing with scallops and cultured mussels for food (p.c.# 960 M. Holloway).

In Western Australia the fanworm is well established throughout Cockburn Sound and in the harbours of Fremantle, Bunbury and Albany. In Cockburn Sound patches of the fanworm attached to shell fragments covered approximately 20 Ha of shallow sandbank (3-6m depth) and are clearly visible in aerial photographs, having existed there for at least

10 years. Elsewhere in the Sound the fanworm apparently prefers to attach to artificial substrata in the form of pier pilings, breakwaters, wrecks and navigation markers. The fanworm has been translocated on the hulls of dredges and other vessels within and amongst locations in WA (Clapin and Evans 1995).

A preliminary study found little evidence of direct impact of the fanworm on the fishing and mariculture in Cockburn Sound. This may be partly because most of the important commercial fisheries there are offshore and rely on pelagic planktivores. There is obviously a more severe threat to the Victorian and South Australian bay fisheries that employ haul-seines to catch King George whiting, sea garfish, southern calamari and other species amongst the shallow, patchy seagrass areas to which the fanworm may ultimately spread.

The Northern Pacific seastar - Asterias amurensis

This seastar poses serious threats to mariculture and wild mollusc fisheries in Tasmania (and perhaps Victoria) because of its local density and predatory habits. There is an intensive research effort at CRIMP on predicting and measuring its potential distribution, its dietary preferences and rates of consumption and developing management methods for shellfish farms (see Davenport and McLoughlin 1993, Furlani 1996).

At the time of writing, *Asterias* was restricted in its distribution and had not yet seriously affected shellfish farms. There are very high densities in the Derwent estuaries (estimated at about 27 million by CRIMP), and their rate of spread has not matched predictions from hydrodynamic transport models. The larval biology has been investigated by Bruce *et al.* (1995) and future modelling of dispersal will incorporate different scenarios in larval behaviour, such as diurnal migration, and preferential distribution near the surface and seabed (p.c. #1170 S.Walker).

The larvae are certainly dispersed widely -- *Asterias* benthic recruits are being found in scallop spat collector bags in Mercury Passage -- but no post-larval stages have been seen on the seabed in that region. The roles of settlement cues, competition and predation are unknown, but are being studied by CRIMP and at the University of Tasmania (p.c. #1260 G. Edgar).

A single individual of *Asterias amurensis* was found in Port Phillip Bay in 1994, and there is concern that this pest and the introduced *Astrostole scabra* starfish (up to 1 m wide) from New Zealand will prey on abalone (p.c. #1080 H. Gorfine).

Introduced algae - Undaria, Codium *and* Caulerpa

The Japanese kelp *Undaria* is an annual species that grows very rapidly and shades other native algae. In only ten years, Japanese Kelp has spread four kilometres along Tasmania's east coast. Thousands of plants up to two metres tall grow on bare rock to a water depth of eight metres. It may be impossible to eradicate this weed once it is established. It needs open spaces or a substratum of coralline algae to recruit and grow. It provides a good food source for abalone -- but only in summer - and dies back in winter. Other macroalgal species have been displaced in the meantime. There is consequently great potential for such forcing to modify interactions amongst herbivores and algae that produce urchin "barrens" habitat (see section 4.5.1). The distribution of the Japanese kelp has been documented by Sanderson (1990) and Sanderson and Barrett (1989) and studies of some of the ecological effects of this pest are underway at CRIMP, the University of Tasmania and the Victorian Institute of Technology. It spread to Victoria from Tasmania during the drafting of this review.

Beds and "gardens" of *Caulerpa scapelliformes* occur in Botany Bay and throughout the Sydney region and there is concern that this alga will displace seagrass - it is inedible to fish and was translocated from South Australia (p.c. #610 A. Larkum). Introduced species include *Caulerpa racemosa* and *C. filiformis*. Green algae in the genera *Caulerpa* and *Codium* pose major threats to Australian ecosystems (especially those supporting the rock lobster and abalone fisheries), and a very high priority for the FRDC and its stakeholders should be to keep them out of our waters.

In the Mediterranean a hybrid of *Caulerpa taxifolia* has invaded from an initial patch of $1m^2$ to over 3000 Ha and there has been extensive overgrowth of the seagrass *Posidonia oceanica* by chemical and physical competition. Chisholm and Jaubert (1997) attribute its spread in less than a decade to:

- abnormal size and growth rate
- strong chemical defence against herbivory and epiphytic overgrowth
- efficient vegetative propagation
- enhance tolerance of winter minimum seawater temperatures
- an ability to colonise widely varying substrata

- efficient absorption, conservation and internal recycling of nutrients
- peak frond length and productivity in autumn when the biomass of native species is at a minimum.

These properties allow it to grow in depths of at least 99m, in densities of 350 m of fronds and 14,000 leaves m^{-2} and to out-compete seagrass and shallow-water macroalgae. No doubt these same properties also endear it to marine aquarists, as this hybrid (reportedly bred as *Caulerpa* "*prolifera*") is sold widely in the international marine aquarium trade, and we believe there are high risks that it will reach Australia by this route (if it has not already). Vigilance is essential and CRIMP has advised AQIS of the problem.

Bellan-Santini *et al*. (1996) reported that it was still too early to formulate relevant conclusions about the impact of the alga on Mediterranean benthic faunal communities, although abundance of molluscs and crustacea (important fish food) were lower at infested sites when compared with reference sites. Monitoring is being continued to determine if the observed patterns of species richness represented stable or regressing benthic communities of invertebrates amongst the algae.

There is also potential for introduction of *Sargassum nudicum* -- an invasive self-fertilising hermaphrodite that forms large rafts of drift algae in Europe and the Mediterranean (p.c. #530 N. Andrew). This spread first by escape from mariculture enterprises.

Other introduced marine species

The predatory activities of the European shore crab *Carcinus maenas* have destroyed mussel fisheries in parts of the USA and threaten Tasmanian shellfish farms. This pest is the focus of research on demography, impacts and possibilities for biological control by CRIMP. The workshop on these issues held by CRIMP (see Thresher 1997) provides some important messages that may apply more generally to the pests in Australia:

- surprisingly little was known about the ecology of the species in its native range
- even in areas where the species is perceived to have had a large impact, data supporting this conclusion are sparse
- the spread of the species and the decline in some overseas bivalve fisheries has been simultaneous, but climatic changes, overfishing and other environmental disturbances have also occurred and confound historic comparisons
- range may not be readily explained by physiological tolerances and dispersal ability

- rapid and recent changes in distribution may be due to climatic change (eg. to Tasmania in a general response to a climate-induced shift in biogeographic provinces)
- regional differences in impacts, demography and behaviour - eg. major impacts perceived on bivalve and crab populations in Tasmania , but only slight impact (and lower densities) in Victoria and Tasmania
- the prospect for physical removal of the pest is attractive, but depends on a trade-off between effort and effectiveness
- establishing a fishery for the crab is superficially attractive, but once an industry forms its reliance on viable populations may cause resistance to eradication attempts or decimation of the population
- there are several options for biological control, but discussion of their prospects focussed on safety, effectiveness and the information needs to assess both.

The workshop also defined a number of priorities and opportunities for R&D, including study of the range expansion of the crab to construct “before-after” contrasts to assess and identify impacts.

Mention is also made here of other pests identified by our informants. The brevity does not reflect their threat to fisheries, but rather the lack of study and evidence of impacts.

On the shelf grounds of the SE fishery the New Zealand screwshell *Maoriculpis rosaceous* is rapidly spreading and occurs in densities over 1000 per m^2 in depths down to at least 50 m. It reportedly appeared first in the Derwent River and spread north to southern Queensland and west across the Great Australian Bight. It reportedly came from the live trade in oysters across the Tasman (as did the seastar *Patiriella*), and is a nuisance for scallop fishermen. It has been implicate by CRIMP in the demise of native shellfish and is routinely washed off the decks of scallop vessels and some trawlers in port. It has risen in abundance over the same 50 year time frame in which several species (see section 4.5.2) have declined in the SE fishery, but there is no knowledge of the links between these events.

Introduced crabs *Pyromaia tuberculata* and the bivalve *Corbula gibba* now form important parts of the diet of fishes in Port Phillip Bay, and may have encouraged a rise in the population of the spiky globefish (see Officer and Parry 1996). In San Francisco Bay a related bivalve *Potamocorbula* invaded and evidently suppressed the spring bloom by filter-feeding, causing larval fish to starve and local fisheries to collapse (p.c.#1110 R. Thresher).

5.2.3 Disease

A review of the threat to fisheries habitats by introduced diseases was somewhat beyond the expertise and resources of the review team. However, the mass mortality of pilchards in autumn 1995 demonstrated that the threat of disease to fisheries ecosystems is a major one, not necessarily confined to monospecific, high-density culture of aquatic organisms. This event also focussed attention on the very large volumes of frozen feed and bait that are imported for the fishing and tuna-ranching industry. For this reason we have made an attempt to review some of the current issues here.

Herfort and Kerr (in press) developed a simple methodology -- based on the rationale that high impact and high risk implies high threat - that took the “seriousness” rating from previous studies of pathogens, and the number of vessel visits, to rank the threat posed by various fish pathogens presently unidentified in Australia. This was based also on the premise that the amount of contact by ships between ports is a crude indicator of the relative risk of organism introduction by this means, but not necessarily establishment.

Japan had a 2 in 3 chance of being the source of any exotic fish pathogen introduced during 1991, as 41% of all shipping came from there and 16 fish pathogens are known to inhabit the region. The Asian region in general had a chance 9 times that of the rest of the world combined due to the origin of ships and the number of endemic pathogens.

The study concluded that the pathogens *Aeromonas salmonicida* (which causes furunculosis), infectious pancreatic necrosis virus (which causes infectious pancreatic necrosis), *Myxosoma cerebralius* (which causes whirling disease) and *Renibacterium salmonarum* (which causes bacterial kidney disease) are the pathogens of greatest threat to Australia (see DPIE 1996). The salmonids, prawns and oysters that comprise the majority of estuarine mariculture industry are the fisheries that would be most affected by such introductions, but a third group of small baitfish that contribute to food chains are also at risk.

The major recommendations were to:
- develop a testing protocol to detect pathogens at an agreed level
- apply this protocol to ports under risk of introduction

- conduct studies of the environments of “infected” overseas ports with the Australian ports at risk of receiving infected ballast water
- quantify the risk of translocations between domestic ports
- establish a system to link high-risk source ports with high-susceptibility points of discharge - eg bays near mariculture facilities
- establish biological sampling of high-risk ports overseas to confirm the presence of the suspected pathogens
- establish ship-board ballast water/sludge monitoring of pathogen presence form high-risk ports
- encourage ballasting overseas at points far from sources of pathogens, such as fish processing or mariculture facilities

Further research was recommended to better understand the factors involved in the introduction/establishment process, and to develop comprehensive inventories of existing and planned mariculture facilities in Australia to be pro-active in assessing risks. Hayes (1997) has provided a review of ecological risk assessment methodologies.

The threat of cholera (*Vibrio cholerae)* introduction is also a real threat to mariculture, as spores have been recorded in ballast-water sediments transported from South America to the USA. The ABWMAC has commissioned a study of this threat (see http://www.dpie.gov.au/aqis/homepage/imadvice/b9697rsch.html) to :

- conduct a literature review (including a review of the North American evidence) to assess the potential for *Vibrio cholerae* to survive translocation in ships’ ballast water, examining the effect of factors such as temperature and salinity tolerances, voyage duration, association with copepod skeletons, phytoplankton and other hosts
- evaluate possible ballast water treatments and their impacts on cholera, with reference to lethal temperatures and biocide concentrations (eg. hydrogen peroxide, chlorine, heat treatment of ships’ ballast water
- describe existing methodologies available and their effectiveness for monitoring cholera in ballast water and seafood products, including the distinction between toxic and non-toxic serotypes.
- outline *Vibrio cholerae*’s global and Australian distribution to identify its potential for both domestic and international translocation and for the establishment of cholera in Australian waters. Review the lessons learned from the history of past pandemic outbreaks

- determine to what extent the principles relating to cholera apply to other exotic bacteria of public concern such as those responsible for fish farm diseases and botulism
- undertake scientific trials (laboratory, simulated or on board) to determine the lethal temperature and incubation conditions of *V. cholerae*.

This range of objectives shows the focus of ABWMAC research projects on risk assessment and management. There are opportunities for the FRDC to aid ABWMAC in developing these measures, as well as taking a lead role in identifying impacts of existing pests and diseases on industry and ways to reduce them.

In 1995 there was an unprecedented, mass mortality of pilchards (*Sardinops sagax*) spanning the entire 6000 km range of the species. Griffin *et al.* (1997) have reviewed the physical an biological factors associated with the mortality and quite confidently rejected environmental stress as a causative agent. They could not reject the hypothesis that an introduced pathogen was responsible, and discounted the likelihood that fish-to-fish contact, ocean currents or ballast water were vectors - leaving predators (eg. seabirds, dolphins, predatory fish) as remaining candidates for vectors.

Fletcher *et al.* (1997) were stronger in their conclusions - “the most likely cause of the massive mortalities of pilchards in 1995 was from a novel Herpesvirus to which the Australian pilchard population was naive and whose origin was, therefore, most likely to be exotic”.

There was an early suspicion that the *Herpes*-like virus that was the aeteological agent was introduced in imported, frozen Californian pilchards fed to southern bluefin tuna in fattening pens in Port Lincoln. Over 10,000 tonnes of pilchards were imported for this purpose in 1995. Humphrey (1995) warned that the importation of bait and feedfish “constitutes a high risk of introducing exotic pathogens” with the risk escalating when importing, and using in an untreated state, hosts (species) that are also present in Australia.

The issue highlights the possibility of future disease introduction in bait and mariculture pellet food. The sources and consumption of frozen bait from overseas are widespread -- in the order of tens of thousands of tonnes annually. This ranges from regular use of *Scomber japonicus* by Japanese longliners in all waters of the EEZ where they are permitted to operate to imports of clupeids for rock lobster bait in WA and squid for the angling bait market in all States. Fish meal is imported for use in local pellet food manufacture, but imported pellets may carry viruses. The National Taskforce on Imported Fish and Fish Products is reviewing the protocols needed to manage these imports safely.

"Epizootic Ulcerative Syndrome" (EUS) first broke out amongst all age classes of Northern Territory barramundi in 1986. There were many fish killed from a variety of freshwater species and the syndrome was attributed not to water quality implications, but rather a Rhabdovirus. However, Pearce (1990) notes that that while Rhabdovirus-like particles have occasionally been found in lesions their role in EUS is unclear since they have never been isolated. We could find no record of whether the virus was introduced or endemic, and other informants suggested that the *Aphanomyces* fungus was also involved.

The EUS is now restricted to mainly barramundi. For example, in Corroboree billabong rates of ulceration were 54% in 1993 and 11% in 1994. In 1986 all age classes were dying but now 0+ juveniles are the only ones infected and the survivors grow to maturity. There is also variability in infection rates amongst billabongs. Quite a few of the older survivors have only one remaining eye - giving rise to a local name of "right eye disease" (p.c. # 1670 R. Griffin).

5.3 Translocated fishes and introduced pests in lower catchments

The R&D priorities for introduced pests in wetlands have been prioritised for the LWRRDC by Finlayson *et al.* (1996) and we have summarised their findings in Table 5.3.2.

5.3.1 The role of habitat disturbance

The culmination of decades of research on major freshwater pests has seen a recognition of the role of habitat disturbance in allowing pests and weeds to become established in catchments (see Arthington *et al.* 1983, 1990). A similar role is proposed for disturbances in our major ports and harbours (eg. dredging, pile driving) in allowing establishment of the newly recognised pests from ballast water introductions (p.c.# 1110 R. Thresher), but other scientists argue that "disturbance" is confounded with "shelter" in such comparisons.

Arthington *et al.* (1990) found that the reviews of effects of introduced fishes in Australia generally did not give sufficient attention the significance of habitat disturbance - and that significant R&D opportunities exist for pest management through integrated habitat restoration and enhancement. Habitat disturbances associated with successful establishment of introduced fishes most often occur in combination and lead to general degradation of habitat, loss of specific habitats or reduced habitat heterogeneity. These disturbances act also to threaten native species (see Pollard *et al*. 1990 for overview) and are listed in Table 5.3.1.

Table 5.3.1 Habitat Disturbances and their possible roles in establishment and transfer of introduced pests in freshwaters.

DISTURBANCE	POSSIBLE MECHANISM	EXAMPLES	REFERENCES
1. impoundment causes changes in the seasonal distribution of river discharge; flood amelioration; long-term trends towards reduction of average flows in the middle and lower reaches of rivers	• creates a more pool-like environment in and below dams that favours aquatic macrophyte growth and species preferring weedy, slow-flow, lentic habitats • removes the floods that periodically remove introduced species	European Carp, Redfin Perch, Tench, mosquito fish (*Gambusia); Oreochromis mossambicus*	Arthington *et al.* (1990), Bluhdorn *et al.* (1990), Lake (1994), Lloyd (1984), Pollard (1993a), Pollard and Burchmore (1986),
2. diversion and channelisation of rivers	• sudden changes in water level kills eggs of littoral spawners • inter-basin transfer spreads pests • loss of pools and habitat diversity	redclaw may have been spread by this means: Tilapia may reach Gulf drainages via new population in Lake Tinaroo	Davies *et al.* (1992), p.c. A. Webb
3. loss of riparian vegetation	• allows entry of C_4 plants that smother waterways, change food webs		Bunn *et al.* (1996, 1997),
4. bank erosion and sedimentation; desnagging	• niche compression may render native species unable to compete with introduced species		Ault and White (1994), Bales (1992), Burchmore *et al.* (1990),
5. thermal and chemical pollution	• heated waste-waters from power plants harbour warm-water • tolerance of low O_2 favours survival of *Gambusia* and *Oreochromis* in urban drains • pesticide resistance favours some populations of *Gambusia*	cichlids and poeciliids in temperate rivers	Cadwallader *et al.* (1980),
6. the presence of introduced plants (eg. Para Grass, *Hymenachne, Salvinia, Eichornia, Pistia)*	• shelter from Barramundi and other predators in Para Grass and amongst water hyacinth • introduced herbivores eat epiphytes or plants themselves • reduction of microhabitat diversity and niche compression of native fishes	*Oreochromis* and *Tilapia mariae* , poeciliids (eg. *Poecilia reticulata* and *G.holbrooki*)	Russell *et al.* (1996a,b), Beumer *et al.* (1996), Cowie *et al.* (1988), p.c. A. Hogan

5.3.2 Translocated fishes

In the past decade there has been a great advancement in development of techniques to artificially spawn and rear the young progeny of a variety of marine and catadromous species. The demand for this R&D may have come first from mariculture interests (eg barramundi, mangrove jack, snapper and mulloway), but more recently from recreational fishing interests for Australian bass, dusky flathead, sand whiting (*Sillago ciliata*), grunter (*Pomadasys kakaan*)to be stocked in "open" systems (see Palmer 1995 for review).

This translocation and restocking of fish is accompanied by a variety of risks and hazards associated with genetic "pollution" of local stocks, consumption of forage species, competition with other species, and spread of disease (eg Benzie 1994, Kearney and Andrew 1994, Langdon 1990).

The risk of inbreeding, or swamping of local gene pools with recessive alleles, is greatest when stocking occurs in small breeding populations with distinct genotypes. Such scenarios could easily occur with local strains of Australian bass and barramundi (see Sheridan 1995, Keenan 1996 for reviews). In the case of barramundi there are many difficulties for hatcheries to rotate brood stock - repeatedly obtaining permits to take brood fish in closed seasons presents problems, brood males quickly develop into females under the favourable conditions of captivity, and brood fish are large animals that require large facilities if they are to be kept in high numbers.

Aside from the genetic implications there are poorly known effects on the Australian environment of translocating large populations of "top" predators such as barramundi or burrowing benthic carnivores such as redclaw, yabbies and marron (eg. Kearney and Andrew 1994). The issue of disease dispersal with such translocations is also a considerable risk and hazard with recorded episodes in Australia (see Langdon 1990 for review). There is an opinion that the *Aphanomyces* fungus present in the lesions of fish suffering from epizootic ulcerative syndrome (EUS; see section 2.2.1) was introduced into Australia with goldfish in the aquarium trade during the 1970's (p.c. I. Anderson, QDPI Oonoonba Veterinary Laboratories, November 1997).

Harris and Battaglene (1990) indicated also that policy development and implementation was made difficult for translocations of freshwater native fish because of :

- the many established precedents

- the economic significance and varied standards of our numerous fish farms and hatcheries
- the paucity of Australian studies identifying and extending knowledge of specific problems
- the ill-founded public popularity of fish stocking as a panacea for freshwater fisheries management problems in general.

The last point is especially pertinent to the situation prevailing now in the face of increasing demand for stocking of open estuarine systems (see Tait 1996).

In reviews of the subject, Blankenship and Leber (1995, 1997) do not dwell on the risks and hazards, but instead provide the following ten points as a "responsible approach to marine stock enhancement":

1. prioritise and select target species for enhancement
2. develop a species management plan that identifies harvest opportunity, stock rebuilding goals, and genetic objectives
3. define quantitative measures of success
4. use genetic resource management to avoid deleterious genetic effects
5. use disease and health management
6. consider ecological, biological and life-history patterns when forming enhancement objectives and tactics
7. identify released hatchery fish and assess stocking impacts
8. use an empirical process for defining optimum release strategies
9. identify economic and policy guidelines, and
10. use adaptive management.

Whilst advances have been made in implementing many of these points (eg fish marking: Willett 1993,1994, Russell and Rimmer, 1997), we could find no studies of the effects on ecosystems of the restocking programs in Australian inland waters and estuaries. There is clearly a lead role for the FRDC to help develop various aspects of "best practice" in Australian restocking programs.

5.3.3 Noxious aquatic macrophytes, woody weeds and pasture grasses

There are major threats to the sub-tropical and tropical coastal wetlands by woody weeds (eg. *Mimosa pigra* and rubbervine *Cryptostegia*), aquatic weeds (eg. *Salvinia molesta* and *Eichornia crassipes*) and pasture grasses (eg. para grass, *Hymenachne*). There is surprisingly little knowledge of their effects of ecosystems (Finlayson *et al.* 1996) - despite their abundance and rate of spread.

For example, *Mimosa pigra* is an aggressive prickly shrub that can form dense monospecific stands on the floodplains of northern Australia. At present it is confined to the coastal floodplains of the Northern Territory in an arc extending from the Moyle River in the west to the Arafura Swamps in Arnhem Land. It covers an estimated 80 000 Ha. It is a prolific producer of seeds that are readily dispersed by water, vehicles and animal vectors. However there is no knowledge of its effects on barramundi nurseries.

The aquatic weeds *Salvinia molesta,* water hyacinth *Eichornia crassipes* and *Pistia* (water lettuce - translocated from natural populations in NT) form rafts that completely block light, heat and oxygen flux in north Queensland barramundi nurseries -- and also form support for the horizontal extension of introduced pasture grasses (para grass *Brachiaria muticum* and *Hymenachne* spp).

This allows complete overgrowth of small wetlands and channels in the space of several seasons. Electrofishing surveys in Herbert River floodplain lagoons have found differences in the proportions of 0+ and 1+ barramundi juveniles. In some Cattle Creek wetlands where weeds are overgrowing lagoons each season the juveniles recruit but die within the year during cessation of flow. The dieback is caused by overgrowth of weeds and then anoxia as the weeds decompose after being overturned in flood events.

Salvinia molesta has invaded some billabongs in Kakadu National Park in the past decade. An attempt at control of this weed by the Australian Nature Conservation Agency pulled out several thousand tonnes of *Salvinia* from Island Billabong on the Magela Creek Floodplain. Barramundi existing there at the time were in poor condition (p.c.#1670 R. Griffin)

Para grass was introduced as "improved pastures" in 1880 and *Hymenachne amplexicaullus* was introduced in the early 1980's. Both can grow in >=2 metres of water and are replacing native sedges. Invasions of both pasture grasses have clear interactions with destruction of riparian vegetation. Para grass is now a major weed in disturbed stream channels in northern NSW, Qld and the wet-dry tropics - but is still being promoted as an improved pasture grass (see Bunn *et al.* 1997).

Bunn *et al.* (1997) were the first to examine the effects on aquatic food webs of invasions of para grass, in comparison to sugar cane and riparian trees. There is high primary production by para grass, but very little of this is transferred into the aquatic food web, either directly through herbivory or indirectly through a detrital pathway. Sugar cane was found not to be contributing at all. These findings were consistent with previous studies that C_4[1] macrophytes play a relatively minor role in aquatic food webs despite their major contribution to primary productivity.

The only contribution of para grass production was through terrestrial prey (eg. insects, frogs) to snakeheads *(Ophieleotris aporos)* and the eel *Anguilla reinhardtii*. In-stream primary production appears to form the basis of the food web supporting invertebrates in wet-tropics creeks. Highly productive, inconspicuous epiphytes (eg. on macrophyte stems) are probably most important.

Restoration of riparian vegetation would provide C_3 carbon for benthic detrital food webs and arthropod prey for fish-shading is seen as the only long-term solution to para grass spread rather than mechanical and chemical control. These temporary measures invariably result in re-invasion or weed-by-weed replacements in riparian zones.

Without control para grass will continue to contribute to water quality problems by :
- high rates of respiration in detritus
- efficiently trapping sediments and destroying benthic habitats
- reducing channel capacity
- sheltering tilapia and making them unavailable to large fish predators such as barramundi and sooty grunter.

Simple removal may also cause serious downstream problems. Bunn *et al.* (1997) estimated that for one creek alone sediments trapped in amounts of about 20 000 tonnes km^{-1} will be released when para grass is lost. However, cane-land streams cannot be viewed as a permanent store for sediments - as high-discharge events inevitably will lead to scouring of channels and associated discharge of sediment and high plant biomass.

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[1] C_4 and C_3 refers to how plants fix carbon from the atmosphere into plant tissue. C_4 plants, like salt marsh grasses, utilise the c4 pathway in which oxaloacetic acid (OAA), a 4 carbon compound, is produced in the dark photosynthesis reactions. In contrast, mangroves and phytoplankton utilise C_3 photosynthetic biochemistry, in which phosphoglyceric acid (PGA), a 3 carbon compound, is produced in the dark reactions. C_4 plants have a specilized leaf anatomy that maximises internal CO_2 concentrations, thereby allowing the plant to maintain a higher rate of photosynthesis at higher temperatures and at stronger light intensities than C_3 plants. All woody plants are C_3 plants.

These conflicting issues emphasise the need for an integrated management of river systems and their receiving waters, and some of these needs are reflected in the R&D recommended to the LWRRDC in Table 5.3.2.

Table 5.3.2. Summary adapted from Finalyson *et al.* (1996) of priority pest species in the LWRRDC "Wetland R&D Program Scoping Review" and strategies for R&D.

Priority plant species	Mimosa - *Mimosa pigra* - NT Top End Para grass - *Brachiaria mutica* - north and NE Aust Alligator weed - *Alternanthera philoxeroides*- east Aust Lippia - *Phyla canescens*- Darling Basin Salvinia - *Salvinia molesta*- north, east and SW Aust.
Priority animal species	Feral pigs - *Sus scrofa* - ubiquitous Mosquito fish - *Gambusia holbrooki* - east, south and SW Aust European carp - *Cyprinus carpio*- south and SE Aust. Cane toad - *Bufo marinus*- north and NE Aust.
R&D Strategies	• Develop community awareness of and involvement in pest management and planning • Conduct risk assessments of introduced species and possible control techniques • Enhance biological control and genetic modification programs • Develop protocols for integrated pest management including Decision Support Systems • Economic incentives for land users to maintain the essential ecological features of wetland • Environmental pricing mechanisms to encourage the retention of wetland processes and functions • Inventory and survey of susceptible areas and potential pests

Despite their relatively harsh physico-chemical environment, saltmarshes are highly susceptible to invasion by exotic species (Adam 1995, 1996). Cord grass*, Spartina angelica*, was introduced in the early 20th century and has spread vigorously in Victoria and Tasmania but populations in New South Wales and South Australia have remained small. In Victoria, Cord grass has become established to seaward of *Avicennia marina* fringes, but its effects on nutrient transfer, fish access and adjacent seagrasses are unknown.

Other weeds invading saltmarsh are most notable in southern Australia and include: Pampas grass *Cortaderia selloana*; the rush, *Juncus acutus*, replacing the native *Juncus kraussii*; and groundsel bush, *Baccharis halimifolia*, forming dense stands in disturbed saltmarshes.

Introduced species also occur in mangrove habitats, including the European shore crab in Victorian *Avicennia* and an unconfirmed proposal by Saenger (1988) that the microbial soil fungus *Phytophora*, introduced in landfill soils, caused extensive dieback of *Avicennia marina* around Gladstone. All other species including the dominant *Rhizophora stylosa* appeared unaffected. Saenger (1988) proposed that the fungus was introduced to the area with construction of roads and earthen bunds, and was possibly enriched by high organic nutrients associated with sewage outfall. An alternative view suggested that the fungus might be latent and only affect trees already stressed for other reasons (Pegg and Foresberg 1982).

Introduced fishes - a much higher profile, but less of a threat to ecosystems than habitat destruction and weeds?

Introduced and translocated fishes, and their ecological impacts in Australia, were reviewed in a workshop held by the ASFB in 1989 (see Pollard, 1990). In summing up, Courtenay (1990) identified that :

- there is a paucity of information on interactions between non-native and native fishes and their food webs and habitats
- there were often earlier or simultaneous alterations to habitats or other anthropogenic disturbances that may have facilitated the establishment of alien species
- introductions and translocations are primary or secondary forces in declines or other perturbations to native fish populations, in synergy with other disturbances
- molecular genetics shows that there are measurable differences between populations within species and translocations can alter the natural course of evolution, through hybridisation
- habitat modifications such as impoundments often result in demand for introductions of species that can tolerate these modifications
- Australia's impoverished and depauperate inland fish fauna makes it particularly vulnerable to aquarium fish introductions
- allowing for any non-native aquatic species into a nation under legislation is, in effect, approving its possibility of becoming a part of the biota of that nation.

Our review of the literature comes to the same conclusions for freshwater systems. For example, European carp have possibly the highest public profile of any aquatic pest in Australia, and there are continual calls for spending on eradication programs. Yet only recently has there been wider public reporting of the views of biologists that water resource management regimes have created ideal habitat for carp in the Murray-Darling.

Morison and Hume (1990) reported that attempts to look at differences between habitats with different densities of carp, and at habitats before and after carp became established, and to conduct experiments in ponds where densities of carp were controlled, could still not resolve major questions about the effects of carp on the environment. They concluded that prevailing hydrological changes were more important in determining turbidity and macrophyte abundance during the period of a study which found strong circumstantial evidence that carp had reduced the density of shallow-rooted and soft-leaved macrophytes.

However, they warned that such findings were a feature of all such studies on carp introduced elsewhere, and that unequivocal demonstrations of adverse effects should not be required before restrictions on the importation, sale or possession of a species are implemented.

Gehrke and Harris (1994) provided key possible mechanisms of a role for carp in enhancing algal blooms, and billabong-scale exclusion/enclosure experiments that manipulate carp densities are in progress to better understand the effects of this fish pest (p.c. #350 A. Robertson). For example, King *et al*. (1997) found that carp had a significant effect on turbidity (also see Roberts *et al*. 1995) and intensity of algal bloom but this varied with carp biomass and billabong sediment type, and factors other than carp usually contributed to most of the variation in measured water quality. Robertson *et al*. (1997) concluded that the impact of carp on benthic and surficial processes was significant but the mechanisms of change differed between billabongs. The parameters measured were rates of particle settlement, biofilm development, sediment respiration, macrophyte detritus and decomposition, sediment nutrient concentrations and benthic algal biomass.

Eradication attempts have been successful in very small impoundments, but have failed at larger scales (sometimes because of deliberate re-introduction) , and a fishery for the species (mainly as rock lobster bait) has not seriously depleted their populations (Morison and Hume 1990). However, new products and markets for human consumption of carp are now being developed and electrofishing for carp will provide a part of any integrated management program for the species.

Unfortunately there is evidence that anglers and commercially motivated fishermen have been spreading or re-introducing carp, for instance from the mainland to Tasmania as live-bait. Similarly, Townsville anglers have been seen transporting tilapia from impounded freshwaters of Ross River to nearby estuaries for use as live-bait, despite the risk of heavy penalties. There is concern that tilapia will reach the Gulf drainages, and hence the lucrative northern prawn fishery, via a recent introduction to Lake Tinaroo and through inter-basin transfers of water. Tilapia have spread to estuaries in Townsville, but there is no knowledge (and evidently no study) of their predation on prawns there, so the threat to the northern prawn fishery is unknown. The Japanese goby *Acanthogobius flavimanus* is established in some bays in the eastern States, but also has unknown impacts.

Grewe (1996) has modelled the possibilities for transgenic incorporation of an inducible fatality gene (IFG) into the carp genome. He concluded that a combination of intermittent culling by triggering the action of the gene (eg. by a dietary supplement) and re-stocking with transgenic fish appears likely to result in eventual eradication of the carp from target systems.

The value of detailed ecological studies of introduced pests is illustrated by the work of Bluhdorn *et al.* (1990) who have proposed a series of management strategies for new invasions of *Oreochromis mossambicus* based on the ecology and biology of the species and size of the habitat being invaded. These include complementary use of manipulations of water flow regimes, predator enhancement and direct poisoning.