ISSUE 3:
Nutrient and Contaminant Inputs

3.1 Overview and FRDC role

3.1.1 The issues

Like other nations, Australia's coastal lagoons, enclosed bays and are becoming increasingly subjected to anthropogenic inputs of dissolved and particulate materials that are having severe impacts on coastal food webs. The consequences of such inputs are potentially worse in Australian waters for several reasons:

- lack of significant upwellings of cool, nutrient-rich water
- few major river systems depositing materials in the coastal zone
- a large proportion of our coastal waters are subtropical-tropical , with characteristically low concentrations of nutrients (and hence low productivity)
- Australia's soils are ancient and greatly weathered, and low in available phosphorus
- temperate and subtropical coastal waters are very clear with a benthic flora geared to high light levels.

These characteristics maintain coastal and shelf waters that are naturally low in concentrations of dissolved and particulate carbon, nitrogen, phosphorus, and various trace elements. Natural estuarine and marine communities in Australia are therefore adapted to clear, low nutrient waters. Thus they are more susceptible to even moderate increases in nutrient and sediment concentrations than similar communities inhabiting many other coastlines.

The major sources of introduced nutrients, sediments and contaminants are:

- run-off from agricultural land of fertilisers, animal wastes, and soils;
- point source discharges from industrial plants, stormwater and sewage drains, and aeolian deposits;
- effluent run-off from mariculture ponds, racks and sea cages
- wind-blown agricultural chemicals (eg. from Yorke and Eyre Peninsulas in SA)

These inputs often accompany other impacts such as habitat modification and destruction, disruption of coastal hydrological cycles -- including river discharge-- shoreline erosion and siltation, and poor land-use practices (see Chapter 2). It is critical to note that a dynamic interaction exists amongst water, land, riparian zone and land use planning and management issues. We have separated some of these in this review for convenience only, in our mandate to evaluate the ranking of issues specified at the Cronulla 1994 workshop (Williams and Newton 1994). Acid drainage is a major contaminant of estuarine fisheries habitats, but we have discussed it in association with changes to drainage in Chapter 2.

Nutrient and contaminant inputs from point and diffuse sources were considered in the SOMER report to be the highest priority in all enclosed waters from Perth to Brisbane (eg. Edyvane 1996a, Winstanley 1996). However, in the North East of the country run-off and mobilisation of sediments may pose a greater threat to nearshore habitats - particularly in overgrazed catchments of the dry tropics. This threat is poorly documented and not understood well, because of a background of naturally high turbidity, and a lack of seagrass monitoring and other baseline data.

Many of Australia's coastal waterways have, in recent years, suffered from eutrophication caused by high concentrations of nutrients from sewage and runoff from agricultural land. Eutrophication (an increased rate of supply of nutrients leading to enhanced primary production) is caused mainly by loading of nitrates and phosphates, and secondarily by organic matter.

In marine systems, global reviews generally conclude that the response of "nuisance" phytoplankton and macroalgae are always in an opposite direction to benthic macrophytes such as seagrass. That is, the nuisance species always bloom and shade seagrass with combinations of epiphyte loads, water column chlorophyll and particulates.

The most infamous episode has been the 1992 blue-green algal blooms along more than 1000 km of the Murray-Darling. However, many sheltered marine waters in Australia have, to some extent, been affected by enhanced nutrient supply, including:

- Peel-Harvey Estuary, WA (phytoplankton and macroalgal blooms)
- Swan River, WA (phytoplankton and macroalgal blooms)
- Cockburn and Warnbro Sounds, Albany Harbours, WA (seagrass dieback, seabed anoxia)

- Barker Inlet (macroalgal blooms) and Port River, SA (dinoflagellate blooms)
- Holdfast Bay, Proper Bay, SA (seagrass dieback and blowouts)
- Derwent River, Tas. (dinoflagellate blooms)
- Port Phillip Bay and the Gippsland Lakes, Vic. (phytoplankton and dinoflagellate blooms, seabed anoxia)
- Botany Bay, NSW (seagrass decline)
- Hawkesbury River, NSW (phytoplankton blooms, excessive macrophyte growth)
- Tweed River, NSW (seagrass decline)
- Moreton Bay, QLD (phytoplankton blooms)
- Coastal Reefs, Great Barrier Reef, QLD (fears for macroalgal blooms - but little evidence ; coral decline)

The symptoms of advanced eutrophication at higher latitudes have been alarming -- with massive changes in the short and longer terms to the benthic and pelagic primary production of entire bays and estuaries. These changes characteristically involve:

- blooms of toxic cyanobacteria, dinoflagellates or other phytoplankton
- permanent or long-term dieback of very large areas of temperate seagrass due to shading or epiphyte growth at the scale of tens of thousands of hectares
- destabilisation of sediments after seagrass loss, leading to "blowouts" and sediment smothering of other seagrasses
- blooms of nuisance macroalgae at the scale of entire bays and estuaries, in biomass of tens of thousands of tonnes
- changes to denitrification cycles in sediments and bay-scale bottom anoxia
- choking of mangrove pneumatophores and excessive biological demand of rotting drift-algae, leading to anoxia of shallow waters.

There are also tertiary effects of loss of seagrass from sediment loading - the spatial interaction between endangered dugong and east coast gillnets may be aggravated by "narrow-banding". The declaration of Dugong Protection Areas has resulted in exclusion of gillnetting from some bays (see Chapter 4).

There is a further linkage of the eutrophication issue to the introduction of marine pests (see Chapter 5). The Port Phillip Bay Study showed that the assimilative capacity of the Bay for nutrient and contaminant inputs depended on aerobic denitrification cycles deep in sediments. A rapidly escalating coverage of the seabed in Port Phillip Bay by the fanworm *Sabella spallanzani* poses an unknown hazard to these cycles, but the risks are enormous. There may be also aggravation of the establishment and blooming of the toxic introduced dinoflagellates in elevated nutrient regimes.

Whilst some authorities suggest that nutrient inputs could enhance our low coastal fisheries production they have overlooked the fact that sewage and stormwater inputs are invariably accompanied by contaminants, pathogens and bacteria to some extent. These components of the wastewater cycle pose the following threats:

- heavy metal, organochlorine and hydrocarbon contaminants are concentrated in food chains or "banked" in sediments
- coliform bacteria and other human pathogens (eg. hepatitis in Wallis Lake Oysters) can shut down shellfish mariculture with cascading effects on all sales of seafood due to human health scares.

Finally, there has been poor performance of the programs monitoring seagrass decline using aerial photography and underwater surveys. Many of them are merely documenting the loss of the resource without any clear procedures or triggers for action - there is an urgent need to apply biomonitors (Dennison 1994) that give information about the cause of stress to seagrass.

The overall threats from contaminants are not well understood, due to a lack of systematic monitoring of sediment, water and biota throughout the nation's waterways, but the present threats seem to be localised to the immediate vicinity of heavy industry (eg. Selenium and other heavy metals in Lake Macquarie) and particular types of agriculture. For example, contamination of rivers by endosulfan pesticides from cotton farming has caused repeated, large fish kills in some catchments. The best documented instances in the marine environment (Port Phillip Bay metal pollution; Mercury in Albany Harbour and tributyltin (TBT) in oysters) show that the hazards usually recede when sources of pollution are removed and contaminants are buried in sediments.

However, gastropod imposex is still widespread near ports, due to continued use of TBT on international vessels over 20 metres length, and may pose a threat to western rock lobster stocks near Fremantle (p.c.#1400 C. Simpson). TBT levels in Port Phillip Bay are reportedly still high and require monitoring.

The historic focus on water quality standards and water column sampling may have under-estimated the local threat of contaminants to fisheries. New studies on the waterair and sediment-water interfaces show much higher concentrations than in the water column. Innovative biomarkers of contamination show that the sea-surface microlayer is a zone of concentration of many organic and inorganic contaminants that may pose a threat to neustonic egg and larval stages of coastal fishes. The techniques to assess this threat are now available (eg. Klumpp and von Westernhagen 1996) and should be applied.

The existing "cross-gill" toxicity testing protocols to determine water quality standards have also been questioned by fisheries authorities - more informative testing can be done by looking at uptake of some contaminants through feeding trials. Some species (notably prawns and mud crabs) have naturally very high levels of cadmium in their digestive tissues, and at the time of writing the ASIC was proposing that maximum permissible levels in food standards be raised to accommodate this fact.

The management response to the threat of contamination has generally been temporary or permanent closure to harvesting of some organisms in some "heavy metal hotspots" (eg. upper Spencer Gulf, Albany) near industrial sites and temporary closure to harvesting of shellfish upon the appearance of human health risks. Sea ranching of fin-fish can occur in badly affected areas, such as Port Davey in Tasmania, because the captive fish are isolated from local food chains.

The incidence of pesticide application for biting insect control in fish and prawn nurseries is widespread in more tropical areas, and increasing as development encroaches on mangroves, floodplains and waterways. Public health concerns about arboviruses are also rising as epidemics of Dengue and Ross River virus and Japanese encephalitis occur. There is a lack of knowledge of the toxicity of the popular "Abate" mosquito larvicide to prawn, crab and fish larvae - laboratory studies underway at the University of Queensland show lethal effects of small doses on zooplankton (p.c.#920 J.Greenwood), but the actual field toxicity is unknown.

Oilspills have very high public profile. The limited literature in Australia suggests they pose a transient, episodic threat to fisheries - but the longer term effects of hydrocarbons on egg and larval stages in the sea-surface microlayer have not been investigated. There has been recent focus on the effects of oilspills on mangrove ecosystems. Recovery from oiling may take several decades, but the effects of chronic oilspills (eg. in Botany Bay) are much worse. Mangrove trees, seedlings, sediments and key infauna, such as burrowing crabs, are badly affected by this local threat. We could find no assessments of the effects of oilspill dispersants on fish or commercially important shellfish and crustacean larvae.

3.1.2 The literature

The breakdown of "eutrophication" literature cited in Table 3.1.1 shows that R&D effort has mainly followed four different but complementary avenues:
- documentation and monitoring of decline in seagrass and increase in macroalgae
- determination of cause of seagrass decline and macroalgal increase
- understanding phytoplankton blooms to provide capacity to predict and avoid the consequences
- direct study or correlations between macroalgal increase or seagrass dieback and changes in fisheries production

Major reviews of the subject show that phytoplankton and macroalgal blooms and loss of seagrass inevitably occur at some stage in the eutrophication cycle, but the paths and stages differ greatly amongst locations and between different nutrient regimes (see Nielsen and Jernakoff 1996, Gabric and Bell 1993, Hillman *et al.* 1990 for reviews). There are benefits for some taxa (and losses for others) in these cycles.

Ultimately light and oxygen availability become the major forcing functions for benthic and pelagic communities, but studies of phytoplankton dynamics have shown a complex interplay of nutrients, interspecific competition, trace elements and rainfall. In this regard there is not yet a sufficient understanding to precisely predict the occurrence of monospecific blooms destructive to mariculture.

Seagrasses are important fisheries habitats, nurseries and bases of detrital food webs. The literature shows vast spatial differences in the levels of understanding of the threat of nutrients and contaminants - the division falling roughly between tropical and temperate meadows and east and west coasts. For example:
- the extent of southern seagrass is well-mapped, but there is not yet a complete spot map of their northern occurrence from Brisbane to Perth
- seagrass decline has been mapped in all estuaries of NSW, in the Gulfs of South Australia, around the entire Tasmanian coast, in the entire south-west of WA, and in the Gulf of Carpentaria, but some of these inventories need updating
- the reasons for decline are best understood in SA, south-western Australia, Moreton and Hervey Bays and the Gulf of Carpentaria

- reasons for decline are suspected, but poorly known, for Tasmania, Victoria and NSW
- effects on fisheries have been published only for Westernport Bay , Cockburn Sound and Gulf of Carpentaria
- the most powerful biomonitors of the reasons for decline have been developed in southern Qld (see Dennison 1994).

There is consequently a mis-matched mosaic of national understanding of seagrass dynamics and anthropogenic threats, and seagrass loss and fisheries implications. For example, Clarke (1987) has documented well the causes of loss of seagrass in Holdfast Bay in St Vincent Gulf, yet no studies have been done there on the response of fisheries - that type of study is presently confined to dieback episodes in Spencer Gulf where the causes are not related to nutrient inputs.

Finally, the paradigms presented by Edgar and Shaw (1995c) allow some tests of predictions concerning food-chain responses to seagrass dieback, but to our knowledge those tests are not being pursued.

There have been relatively few studies of the effects on fisheries of eutrophication in Australia. Best documented are the benefits for fisheries at some stages in the eutrophication cycle in the Peel-Harvey estuary, followed by anoxia and fish kills. There has not been close coincidence of studies determining the causes of seagrass loss and studies of fisheries decline. Studies of fish communities and production associated with seagrass dieback have mainly occurred after the seagrass has declined (eg. Westernport Bay) or are far removed from the location of studies where the causes of seagrass dieback have been investigated. We discuss in this chapter and section 2.7 why some of these correlations have not produced intuitive results due to the “intermediate” nature of disturbance, the persistence of detrital pools, differences in fisheries targets and other factors.

Interviews with researchers suggested that some herbivore populations on the SA and NSW coasts (luderick, sea mullet, yellow-eye mullet, tarwhine) may have benefited from estuarine eutrophication, but we could find no confirmation of this intuitively attractive hypothesis in CPUE figures.

Our searches produced a large number of studies of contaminants in coastal ecosystems. The breakdown in Table 3.1.2 incorporates a relatively large body of literature on design of monitoring programs, measurement and assessment of contaminants, and an abundance of "one off" local studies that documented many cases of elevated levels of contaminants. We could not assess from the literature whether the numerous studies of metals reflects their true risks and hazards relative to the organometals and organic pollutants -- or mostly historical concerns amongst the public and ease of measurement and analysis.

We could find no literature on the effects of pesticides in fish and prawn nurseries, and very little information on pathogens in wastewater and their implications for shellfish mariculture. This may be due partly to our search strategies and the separation of ecotoxicological and medical literature from marine research databases.

A feature of the "contaminants" literature is the periodic focus on a particular problem or region followed by apparent periods of inactivity and lack of monitoring. This may reflect the lack of systematic monitoring in Australia identified by Ashbolt (1996) and Richardson (1996) in the SOMER reports, but also indicates the limitations of our literature searches. For example, we found mention of a Market Basket Survey by the National Health and Medical Research Council (NHMRC) for seafood contaminants but there was no record of this initiative anywhere in the indexes we searched - it may be documented in medical or other bibliographies.

Table 3.1.1. Selected literature on the effects of nutrients and sediments in the coastal zone, by broad region or habitat type

	seagrass dieback - causes	seagrass dieback - effects on fisheries	algal blooms- causes	algal blooms- effects on fisheries	sediment/water quality and effects on communities	innovative biomarkers and biomonitors
temperate zone	Bulthuis *et al.* (1984,1992), Bulthuis and Woelkerling (1983), Clarke (1987), Clarke and Kirkman (1989), Neverauskas (1988a,b), Nielsen and Jernakoff (1996), Shepherd *et al.* (1989)	Edgar *et al.* (1993), Peterson *et al.* (1994), Hamdorf and Kirkman (1995), Jenkins *et al.* (1993d, 1994), MacDonald (1992), Seddon (In Progress),	Bunn *et al.* (1996), Butler *et al.* (1995), Cannon (1990, 1993), Hallegraeff (1992a, 1995,1996), Harris (1994,1995), Heath *et al.* (1981),	Gwyther (1990), Hamdorf (1993), Nicholson (1992), Parry *et al.* (1989), Winstanley (1996),	Axelrad *et al.* (1981), Nielsen and Jernakoff (1996), Woodward (1989),	Anon. (unpubl.), Ahokas *et al.* (1994),Arnott (1990a,b), Brumley *et al.* (1995), Heggie *et al.* (1994), Leeming *et al.* (1994), Moverley *et al.* (1995), Neverauskas (1987a,b), O'Leary *et al.* (1994), Parslow (in press),
sub-tropics and tropics	Bastyan and Paling (1992, 1995), Cambridge *et al.* (1986), Cambridge and McComb (1984), Clarke and Kirkman (1989), Hastings *et al.* (in press), Hillman *et al.* (1990,1991), King *et al.* (1986), King (1988), Kirkman (1978,1994), Kirkman *et al.* (1991), Larkum and West (1990), Lee Long and Coles (1997a,b), McComb *et al.* (1991b), Shepherd *et al.* (1989), Silberstein *et al.* (1986), Walker (1990b), Walker and McComb (1992), West (1990a,b), Wnuczynski and Thorogood (in press)	Dybdahl (1979), Halliday (1995), Jonker (1993), Walker *et al.* (unpubl.),	Bunn *et al.* (1996), Birch (1982), Birch and Gabrielson (1984), Birch *et al.* (1983), D'-Adamo *et al.* (1992), Hillman *et al.* (1990, 1995a), Hodgkin and Birch (1982,1984,1986), Humphries *et al.* (1984), Lavery *et al.* (1991, 1995), Lavery and McComb (1991), Lukatelich and McComb (1986), McComb *et al.* (1981a,1984), McComb and Humphries (1991, 1992), McComb and Lukatelich (1986,1990),	Gehrke and Harris (1994), Growns *et al.* (1996), Humpage *et al.* (1994), Lenanton *et al.* (1984,1985), Potter *et al.* (1983b),	Bastyan *et al.* (1994), Bunn *et al.* (1996), Cullen (1995), Gabric and Bell (1993), Lord (1994), McCook and Price (1997), Nielsen and Jernakoff (1996), Otway (1993,1995), Otway *et al.* (1995a,b),, Smith and Simpson (1993),	Abal and Dennison (1995, 1996), Abal *et al.* (1994), Dennison (1994), Hosja *et al.* (1994), Lavery *et al.* (1993), Nichols *et al.* (1994), Perry *et al.* (in press), Udy and Dennison (1995)

	seagrass dieback - causes	seagrass dieback - effects on fisheries	algal blooms- causes	algal blooms- effects on fisheries	sediment/water quality and effects on communities	innovative biomarkers and biomonitors
mangroves					Cook (1996), Robertson and Lee Long (1991), Robertson and Phillips (1995), Robertson and Ford (1995), Rothlisberg and Barlow (1996), Soukup *et al.* (1994), Tam and Wong (1994),	
tropics - coral reefs					Bell (1992b), Brodie (1994,1996,1997)	

Table 3.1.2. Selected literature on the effects of contaminants in the coastal zone, by contaminant type and broad region or habitat type.

Zone/Issue	pathogens in mariculture	heavy metals	tributyltin	organochlorines and pesticides	Oil spills and hydrocarbons	innovative biomarkers of stress
temperate - fish	Langdon (1990), DPIE (1996)	Fabris *et al.* (1992), Glover (1979), Langlois *et al.* (1987), Mosse and Kowarsky (1995), Nicholson (1992), Olsen (1983), Phillips *et al.* (1992), Vas *et al.* (1990), Walker (1981,1982), Ward (1989)		Batley (1992), Nicholson *et al.* (1994), Phillips *et al.* (1992),	Langdon (1986), Nicholson *et al.* (1994), Phillips *et al.* (1992),	Ahokas *et al.* 1994), Brumley *et al.* (1995), Holdway *et al.* (1995), Volkman *et al.* (1994a,b),
temperate-shellfish	Ashbolt (1996), Anon. (1978), Herfort and Kerr (in press)	Coleman *et al.* (1986), Fabris *et al.* (1994), Kitching *et al.* (1987), Richardson *et al.* (1994), Ritz *et al.* (1982), Smith *et al.* (1981), Walker (1982), Wootton and Lye (1982), Cooper *et al.* (1982), Ward (1989)	Foale (1993), Nias *et al.* (1993), Scammell *et al.* (1991),	Richardson and Waid (1983),		Moverley *et al.* (1995)
sub-tropics - fish		Anon. (undated b,c), Airey (1984), Bebbington *et al.* (1977), Caputi *et al.* (1979), Chvojka *et al.* (1990), Edmonds and Francesconi (1987), Edmonds (1981), Edmonds and Francesconi (1981), Francesconi and Edmonds (1993,1995), Francesconi and Lenanton (1992), Francesconi *et al.* (in press), Hamdorf (1992b), Leadbitter (1992), Maher (1984,1987), Maher *et al.* (1992), McLean *et al.* (1991), Mills (1987)		Anon. (1993g), Miskiewicz and Gibbs (1992,1994), Hamdorf (1992c), Novak and Ahmad (1989), Nowak (1992), Powell and Fielder (1982,1983), Richardson (1996),	Connell (1996), Cullen and Connell (1992), Hawker and Connell (1986), Kayal and Connell (1995), Miller (1982),	
sub-tropics - shellfish	Roubal *et al.* (1989),	Anon. (undated b,c, 1993g, 1995f,i), Brown and McPherson (1992), Batley (1996), Francesconi (1989), Francesconi *et al.* (1991, 1993,1994, 1995), Le Provost and Chalmer (1983), Mortimer and Miller (1994), Talbot (1983, 1985, 1990), Talbot and Chigwidden (1982),	Batley *et al.* (1989,1992), Batley (1996), Peterson *et al.* (1993), Wilson *et al.* (1993),	Just *et al.* (1990), Korth (1995), Scanes *et al.* (1993), Shaw and Connell (1982),	Mortimer and Connell (1993),	

Zone/Issue	pathogens in mariculture	heavy metals	tributyltin	organochlorines and pesticides	Oil spills and hydrocarbons	innovative biomarkers of stress
mangroves/ seagrass		Harbison (1986), Lenet *et al.* (1992), Mills (1987),Tiller *et al.* (1989), Ward (1984, 1987), Ward *et al.* (1986), Ward and Young (1981, 1982)			Butler (1995), Connolly and Jones (in press), Clarke and Ward (1994), Grant *et al.* (1993), Hatcher and Larkum (1982), McGuiness (1990), Raaymakers (1996), Wardrop *et al.* (1987),	
tropics -fish		Hortle and Pearson (1990), Lyle (1984),				
tropics - shellfish		Darmono and Denton (1990), Denton (1986), Denton and Breck (1981), Denton and Burdon-Jones (1986a,b), Jaffree and Brown (1992), Klumpp and Burdon-Jones (1982), Klumpp and Peterson (1981), McConchie and Lawrence (1991), McConchie *et al.* (1988,1991), Peerzada and Dickinson (1988,1989), Peerzada *et al.* (1990,1992a,b,1993), Talbot (1986)	Kohn and Almasi (1993),			Klumpp and von-Westernhagen (1995), von-Westernhagen and Klumpp (1995),
tropics - coral reefs		Burdon-Jones and Denton (1985),		Smillie and Waid (1985), Shaw and Connell (1985)	Coates (1985), Smith (1985), Smith *et al.* (1987),	

3.1.3 FRDC action

The greatest strategic challenge facing the FRDC and its stakeholders with the downstream effects of nutrients and contaminants from agriculture and development is to identify and implement better ways to transform scientific expertise and knowledge into information relevant to natural resource management - and to ensure this information produces outcomes that safeguard fisheries values.

For example:

- studies on the wastewater-induced *Posidonia* dieback have not yet produced an outcome whereby sewage inputs are halted, reduced or improved in quality in St Vincent Gulf
- several seagrass monitoring programs (eg. Botany Bay, Holdfast Bay) are merely documenting the decline of this fisheries habitat - without any clear procedures in place or triggers for action to address the problem
- the Westernport Bay fish-seagrass studies have not been followed up by monitoring programs of recovery paths for seagrass and fisheries
- some “Fisheries Habitat Areas” in north Qld are protected from mangrove destruction, but receive acid drainage, nutrients and sediment from adjacent disturbances (eg. fish kills in Palm Creek FHA)
- dredging in northern NSW estuaries has been implicated in seagrass decline, but there is no R&D on which to base management options

Prevention and rehabilitation of the eutrophication cycle from diffuse sources are certainly feasible - but all situations require a coordinated approach in research and management to achieve outcomes. The most notable successes and approaches come from Western Australia, where the Estuarine Research Foundation of WA has State Government funding and has produced an admirable focus in the efforts of most of the relevant scientific community in universities and government departments.

These initiatives are couched within models (eg. COASEC) to balance the requirements of “drawing conclusions” (experimental approach) and “making decisions” (modelling approach). Steering committees ensure that the models have captured the right processes at the management scale and match the model to the decisions and questions required by managers and users (eg. Parslow 1992).

Disposal of wastewater is a national concern and a growing number of multi-disciplinary, model-based projects have addressed the issue of assimilative capacity in major bays and estuaries at the "landscape-scale" (see Lord 1994). Invariably these models require strong knowledge of hydrographic and biogeochemical processes, and uncertainty increases sharply when it comes to the first levels of secondary production. However, the modelling process also serves to identify key uncertainties and early research needs (eg. Spear and Hornberger 1980).

As pointed out by Robertson and Phillips (1995), key research questions need to be answered before predictive models can be constructed estimating the capacity of a system to tolerate nutrient loading:

- what nutrient loads can cause complete anaerobiosis of sediments and plant mortality?
- what is the long-term assimilative capacity of sediments for dissolved nutrients?
- how do different sediment types affect the retention and transformation of nutrients?
- what nutrient loadings have a detrimental impact on benthic fauna?
- what is the impact of loss of bioturbating benthic fauna, such as crabs?
- what combinations of nutrient loadings and hydrodynamic regimes cause anoxic/hypoxic conditions in estuarine and coastal waterways?

These questions reflect our current level of ignorance with respect to nutrient impacts and tolerances of ecosystems.

Our recommendations for FRDC action are outlined in Table 3.1.3. A first step will be to coordinate with the LWRRDC (Pesticides Program) and the CRC for Wastewater to identify common priorities.

At the large, bay and estuary scale there is a role for the FRDC in coordinating with, and adding value to, initiatives such as the Moreton Bay Wastewater Management Study through strategic R&D on parameters estimating the routes, rates and sources of secondary production. Our review has found a surprising lack of any comparative studies contrasting fisheries production in the bays and estuaries at similar latitudes to make inferences about the processes governing production. There is consequently a poor understanding of the potential and ceilings for our inshore fisheries, and a lack of informative hypotheses at this level to predict the effects of moderate nutrification.

At the smaller scale of effluents from mariculture operations the key questions and processes are still the same but the FRDC will have the lead role to invest in the multi-disciplinary research required to address them. Regional planning of the location and management of aquaculture is a high priority to ensure sustainable development of this industry and has proven successful in Tasmania and elsewhere (see McLoughlin 1997 and Preston *et al*. 1997). The Fisheries Environment and Health Committee (FEHC) has produced a definitive summary of the threats of nutrient inputs to shellfish mariculture (Hamdorf 1993).

The FEHC has produced fishery-contaminant matrices, prioritised risks, hazards and threats to fisheries habitats, and canvassed the States on their responses to issues raised in the SOMER report (see Appendix 2, Hamdorf 1994, 1995).

Maintenance of water quality underpins all aquaculture, yet prawn pond effluents and seafloor souring from sea cages can threaten adjacent fisheries habitats or reduce their own sustainability. We see a lead role for the FRDC in developing techniques to assess and manage the "effects of mariculture on the environment" as well as "effects of the environment on mariculture". This issue extends from monitoring viral, hormonal, faecal coliform and other contaminants in and around farms into development of pellet feeds with better food : biomass conversion ratios and less waste and faecal matter. Risks occur from viral contamination of mariculture sites, but these are not detected by "traditional" monitoring of faecal bacteria levels. There are also R&D opportunities to study the use mangrove habitats in a dual role as nutrient sinks and scrubbers and fisheries habitats in association with tropical prawn aquaculture.

It is not possible for us to recommend specific R&D that will aid all integrated modelling approaches. Instead, we recommend that the FRDC continues to:

- invest in close coordination with FEHC and other R&D Corporations on catchment-scale issues
- identify processes and structures (eg. Integrated Catchment Management Committees) with common visions for fisheries outcomes, and effectively communicate existing R&D knowledge to them
- coordinate with and respond to the R&D needs identified by Adaptive Environmental Assessment and Management projects (AEAM) , such as the Tuggerah Lakes project run by Wyong Council.

The review by Webbnet (FRDC# 95/172, Webbnet 1996, p. 71) has outlined how research proposals can be evaluated to assure their impact in regard to the need for coordination and integration. Boehmer-Christiansen (1994) has shown how political forces can be harnessed to bring about better implementation of R&D results in environmental management, and Creighton *et al.* (1997) provide an outline of the scale of catchment management involved now in minimising nutrient and sediment export into the GBR lagoon.

This approach is rapidly being adopted to confront catchment-scale problems throughout Australia (see Chapter 2) and the production of "Natural Resource Management Toolkits" (Walker *et al.* 1997) has been a major product of the CSIRO Coastal Zone Program. There has been investment in this area by the FRDC to explore options on the northern NSW floodplains (Webbnet 1996) and in the "Huon Healthy Rivers Project" (FRDC #96/284).

However, we do strongly recommend that strategic R&D is needed to encourage and further develop biomarkers and other innovative surveillance techniques to :

- *assess*, *predict* and *avoid* problems associated with declining water and sediment quality
- *identify* and *monitor* stress and stressors
- *trace* trophic links and movement of nutrients and particulate matter (eg. away from mariculture sea cages; through food chains).

This would immediately aid in safeguarding mariculture and could, ultimately, assist in *prevention* of the upstream causes of such pollution - but only if such R&D is couched in Integrated Catchment Management and sound regional planning. Such an approach could be coordinated with the current development of Estuarine Indicators under "State of the Environment" Reporting.

As marine plants such as seagrass and mangroves fall specifically under Fisheries Acts in several States there is a clear role for the FRDC in addressing gaps in knowledge about the stressors, dynamics and potential for restoration of these habitats in the face of increased nutrient, sediment and contaminant loads through:

- employing and developing newly emerging biomonitoring techniques to allow an assessment of stressors of seagrass beyond the sensitivity of traditional monitoring
- identifying natural dynamics and ecophysiology of tropical seagrasses, and avenues for restoration
- better definition of seagrass-fisheries relationships, especially in the tropics, would help understand the implications of dieback (previous FRDC studies initiated development

of paradigms about secondary production that are the first available for any Australian fisheries habitat).

Unfortunately we can not clearly identify paths for linking such R&D results to management outcomes for the *Posidonia* dieback issue because the scale of the problem is outside the spatial boundaries of existing management structures such as Integrated Catchment Management and Fisheries Legislation. There are clearer opportunities through R&D for conservation and restoration of seagrass in estuaries and canal estates in the sub-tropics and tropics.

Our literature searches uncovered insufficient information to make comprehensive recommendations for R&D on contaminants. For this reason we recommend that the FRDC work closely with the Fisheries Environment and Health Committee to prioritise and identify R&D in this field. The FEHC has produced a "fishery-contaminant" matrix and a review on the threat posed by organochlorine termiticides (Hamdorf 1992).

We have identified a need for the FRDC to help develop and apply innovative techniques to identify and assess the sub-lethal effects of various contaminants on wild fish stocks, especially early egg and larval stages, which may live in the surface layers (neuston) where hydrocarbons, organochlorines, tributyltin and other contaminants are in highest concentration. Such pollution is not detected by traditional water column sampling. Interrogation of multifunction oxidases (MFOs) in adults and embryonic abnormalities in early life stages show promise to help understand the true threat of contaminants. Unexplained declines in the Port Phillip Bay anchovy fishery, for example, may be explained by egg and larval mortality induced by neustonic pollution.

There are also challenges in relating laboratory toxicity testing to field situations for some pesticides and herbicides. Traditional "cross gill" exposures to determine water quality guidelines tell nothing of cumulative impacts through food chains, and the threat to estuarine fauna of supposedly "safe" pesticides, such as "Abate" is inadequately known. Mosquito larvicides and other "vector control" chemicals need particular attention from the FRDC, as they are being applied more widely as human inhabitation of lower catchments increases.

Table 3.1.3. Summary of Major Opportunities for FRDC investment in addressing R&D Gaps in knowledge of "Nutrient and Contaminant Inputs" (*PMCWS = Perth Metropolitan Coastal Waters Study, MBWWS = Moreton Bay Wastewater Study, PPBES = Port Philip Bay Environmental Study)

R&D Role for the FRDC	Main Habitats	Main Fishery	Key Reference	Initiatives
Explore techniques by which existing and new scientific expertise can be transformed into information relevant (and acted on) by natural resource management - the Adaptive Environmental Assessment and Management initiatives	all coastal catchments and their deltas	estuarine and riverine fisheries	Preston *et al*. (1997), Walker *et al*. (1997), Webbnet (1996)	CSIRO Coastal Zone Program, ICM (Qld) and TCM (NSW)
Understanding algal blooms - development of techniques to predict and manage the threat to mariculture (eg. water quality sensors) -- and testing hypotheses on effects on fish harvests of macroalgal blooms	temperate bays and estuaries	all mariculture	Arnott (1990), Parslow (in press),	Huon Healthy Rivers Project FRDC #96/284
The need for Biomonitoring and Bio-indicators -- the integrated approach to identifying and assessing environmental impacts of sediment and nutrient flux on primary producers	Tropical and temperate seagrass; mangroves	all estuarine; prawn nursery	Dennison (1994)	Moreton Bay Wastewater Management Study
Lack of knowledge of nutrient, carbon and contaminant cycling in mariculture - the need for development and maintenance of locally relevant water and sediment quality standards and monitoring techniques to identify and manage impacts of effluents and contaminants (eg. viruses)	sea-cages and racks in temperate bays and estuaries; prawn ponds	SB Tuna, Atlantic Salmon, shellfish and prawn mariculture; oysters	Butler *et al.* (1995)	Tas. Shellfish Quality Assurance Program, FRDC# 96/284
Lack of understanding of water quality role in oyster dieback due to diseases and acid runoff- predicting and avoiding the symptoms	NSW estuaries	oysters		
Egg, larval and adult health in contaminated plumes and fishing areas - development of techniques for surveillance and assessment of the emerging risks and hazards, and the need for a move from "cross gill" to "food uptake" tests in assessing toxicity	polluted bays (eg. PPB) and sewage plumes	egg and larval stages of inshore species	Klumpp and von-Westernhagen (1995)	FRDC #97/217
Ecotoxicology of mosquito larvicides and oilspill dispersants	mangroves and saltmarsh	egg and larval stages of prawns, mud crabs, fish	Beumer *et al.* (1996)	

R&D Role for the FRDC	Main Habitats	Main Fishery	Key Reference	Initiatives
Seagrass and Mangrove Dieback and Restoration - some dieback situations are still not understood; others may be amenable to transplants and restoration of profiles -- R&D is needed (See also Chapter 6)	*Zostera*, *Heterozostera* seagrass; mangroves	Garfish, King George Whiting; east coast estuarine	Soukup *et al.* (1994), Kirkman (1990)	Cockburn Cement Pty Ltd Seagrass Transplants - also see Table 2.8.1
What are the trophic links between fisheries and estuarine and nearshore habitats -- a role for marine chemistry to distinguish amongst natural and artificial sources of primary production	Tropical and temperate seagrass, mangroves and algae	all estuarine fisheries	Leeming *et al.* (1994), Loneragan *et al.* (in press)	
Understanding secondary production in sheltered waters - life-history, trophodynamic and demographic parameters to add value to Landscape-scale Models of the processing of nutrients	WA estuaries, SA, Tas and Vic bays, Moreton Bay	fin and shellfish mariculture; coastal finfish	Lord (1994), Gwyther (1990)	PMCWS*, MBWWS*, PPBES*, Swan River
Fisheries significance of tropical seagrass, and understanding of the roles of multi-species patches and mosaics versus "stands" of temperate seagrass	*Posidonia* and *Amphibolis* seagrass	Garfish, King George Whiting	Halliday (1996),	Walker *et al.* (unpubl.) in Cockburn Cement shellsand mining project

Our interviews suggested that there may be scope for including the addition of silica in late stages of sewage treatment to grow diatoms that are useful in fisheries food chains. Silica limits growth of these organisms in the presence of excess nutrients and they are out-competed by monospecific blooms of nuisance or toxic dinoflagellates and blue-green algae. There may be a role for the FRDC in encouraging such R&D.

Finally, there has been a trial of a map-based, coastal marine bibliography "CAMTEXT" that links scientific publications to catchments, to allow catchment managers and other groups to easily find site-specific information (see CSIRO, DWE 1995). CAMTEXT and other tools have been developed under the "CoastNet" pilot study to make marine and coastal information more freely available on the Internet (see http://www.erin.gov.au:80/sea/sea.html). These platforms would be a very effective way of extending the findings of the FRDC final reports in the "Ecosystem Protection" Program.

3.2 Effects on ecosystems - seagrass dieback, algal blooms and the need for biomonitors

General changes to benthic communities in bays and estuaries in response to eutrophication include a shift in primary producers from large macrophytes, which are capable of nutrient storage and are more competitive at low ambient nutrient concentrations, towards ephemeral algae and phytoplankton which are more competitive at high nutrient loadings. In the case of secondary producers there are generally shifts from large fauna towards small opportunists - generally dominated by deposit-feeding polychaetes.

A review of all relevant Australian and international literature by Nielsen and Jernakoff (1996) has shown the following patterns for benthic community response.
For seagrasses:

- there are no consistent links between nitrogen concentrations and either seagrass shoot density, biomass or production
- seagrass shoot density can show a negative log-linear relationship with pore-water ammonium concentrations - but relationships between other growth parameters and water and sediment nitrogen concentrations are not clear
- seagrass growth parameters show strong positive relationships to irradiance, and hence negative relationships to light attenuation

- epiphytes have demonstrable, negative effects on seagrass production by blocking light access to the leaves
- nutrients are more likely, therefore, to have indirect effects on seagrass growth by promoting epiphyte growth and/or water column turbidity - both of which would reduce light reaching the seagrass leaves (see also reviews by Hillman *et al.* 1991, Kirkman *et al.* 1991b, Shepherd *et al*. 1989, Walker and McComb 1992)
- measuring the relationships between nutrients, epiphytes and light attenuation may be more important than direct observations of nutrient-seagrass relationships when trying to determine the likely effects on eutrophication on seagrasses.

For macroalgae, which are either attached to hard substrata (eg. *Enteromorpha*), free-floating (eg. *Ulva*) or epiphytic on seagrass blades (eg. *Asparagopsis*):

- all nutrients must be obtained from the water column (and cannot be stored or recycled in the case of ephemeral algae) - they therefore have higher nutrient demands than seagrasses, and are not competitive at low ambient nutrient levels
- as nutrient concentrations increase, fast-growing macroalgae and phytoplankton are more competitive because they capture and use light more efficiently
- positive correlations between macroalgal biomass and production and nutrient concentration are not always present - they are confounded by processes such as luxury uptake and storage and nutrient release during decomposition
- biomass and production are strongly related to irradiance, but this response is influenced by other factors too - in particular seasonal differences in physiological conditioning (not just temperature).

A superficial glance at the eutrophic estuaries around Australia shows striking differences in the visible symptoms - *Ulva* in Barker Inlet, cyanobacteria in the Peel-Harvey and no visible symptoms in Trinity Inlet in Cairns (see also King and Hodgson 1995). Current research on the dynamics of macroalgae in WA estuaries is yielding knowledge on the differences in these symptoms, which are largely enforced by a suite of physical factors and inter-specific differences in physiology.

For example, Peel Inlet in WA is unusual in that it is "light limited" and has no significant sewerage inputs. The primary rivers flow in winter in WA, so the Peel Inlet receives a once-per-year plug of terrigenous inputs through river flow events, which drive all subsequent changes in the amount of humic substances (and hence light) and also nitrogen and phosphorus. There are very rapid shifts from *Ulva* to *Chaetomorpha* and the disappearance of *Cladophora* that can be explained by:

- *Ulva* invasion needs constant eutrophication (hence their prevalence in Barker Inlet which receives sewage effluent all year)
- *Chaetomorpha* out-competes all others when there is intermittent eutrophication
- *Ulva* cannot cope with low winter salinities and therefore "catches" only the tail end of nutrient availability afforded by river flow
- *Cladophora* is a ball-forming species that sinks and embeds into the sediment, so as to build up a thick rotting layer. The balls rise up and are blown into shore where they build up in foul-smelling mats. The mats have since disappeared - perhaps because of cyclonic disturbance, a virus or bacterial infection, or grazing
- in WA the estuaries are shallow (2-3m deep) and daily sea breezes and heating and cooling cycles produce resuspension of macroalgae, and stratification causes short-term bottom anoxia - international research results are not appropriate for predictions of local dynamics (p.c. #1350 P. Lavery).

There are also long-term cycles in the response of primary producers to eutrophication which have important implications for fisheries. The history of the problem in the Peel-Harvey was firstly vast increases in *Ruppia* production, (and also the seagrasses *Halophila* and *Heterozostera*), then a predominance of macroalgal biomass followed by an increase in blue-green algal blooms. Whilst the early changes were considered to be beneficial to fisheries production, the cyanobacterial blooms were probably negative. The changes are still occurring - the intermittently open Wilson's Inlet is probably in the state now that the Peel-Harvey system was in 20 years ago (p.c.#1360 R. Lenanton).

The effects on fisheries of these cycles will in some part depend on the original types of primary producers present in estuaries and bays. For example, permanently open systems in WA have a much higher diversity of primary and secondary producers that range from "colonising" (*Heterozostera*) and old, "permanent" (*Posidonia*) seagrass beds to *Cladophora* and *Ulva*. In contrast, the intermittently open estuaries have *Ruppia, Polyphysa, Lamprothamnion* as the major benthic primary producers.

Nielsen and Jernakoff (1996) report that increases in fish abundance, growth rate, biomass and productivity have been documented in areas experiencing eutrophication but :

- increases in yield have generally been linked with greater fishing effort rather then to the direct influence of eutrophication
- empirical links between nutrient loads and fish abundance, biomass and production are difficult to quantify due to the high degree of variability associated with measurements of these parameters
- changes in community size-structure and species composition have resulted as a result in changes to the quality of benthic habitats or as a result of periodic anoxia
- declines in fish biomass have been empirically linked to low water column oxygen concentrations.

Anoxia may affect most the eggs and larval stages of important fish and crustaceans, as these are least able to avoid such stress and may migrate vertically into anoxic layers -- unfortunately studies are lacking in Australia on these life-history stages. Low, but non-lethal, oxygen tension is known overseas to lead to increased predation on fish larvae by scyphomedusae and decreased predation on larvae by planktivorous fish.

Anoxia does occur here, even in large bays such as Cockburn Sound where there is a 1 m deep anoxic layer above the sediments in the main basin due to stratification. For example, a mass-mortality of the cockle *Katelysia* occurred in Princess Royal Harbour at Albany due to anoxia (Peterson *et al.* 1994). Adult abundances crashed, but recruitment of young *Katelysia* was also negligible, at levels two orders of magnitude less than previously observed. These dramatic declines in abundances of a previously dominant component of the fauna of Princess Royal Harbour co-occurred with eutrophication, seagrass die-off and macroalgal blooms, suggesting that the environmental problems of this harbour have cascaded through the ecosystem to alter its ability to sustain natural secondary production and ecosystem function.

There are few Australian studies on the effects of eutrophication on fisheries production, and we have discussed some of these in detail in sections 1.3.2, 1.4.4.1, 2.7 and elsewhere. The gaps in knowledge of natural dynamics of fisheries and habitats have hindered prediction of the effects -- Gwyther (1990) concluded that "*habitat requirements of all the species in Port Phillip Bay are not known sufficiently for accurate prediction of species interactions and effects if nutrient loading caused increased phytoplankton and seagrass dieback*".

The long-term comparisons of community structure and trophic links in Port Phillip Bay have not produced any clear patterns that can be attributed to the input of nutrients. Rather, competitive interactions have been proposed as the mechanism behind the few, unexpected changes in numbers of some taxa (eg. small rays), and shifts in food chains have been caused by consumption of introduced crabs and bivalves (see Hobday *et al.* 1996, Officer and Parry 1996, Parry *et al.* 1995).

Gwyther (1990) proposed that nutrient enrichment would have to be very high to detect an increase in fish production in Port Phillip Bay, because carbon transfer efficiencies are generally 0.1-1%. Adverse effects would be seen with water quality before signals could be detected in fisheries production. Apart from general declines in landings for some species, and peaks in others, Gwyther (1990) could find evidence of change only in increased growth rates of scallops, and a higher growth rate of young snapper in Port Phillip Bay compared to other parts of their south-eastern range.

Nutrient inputs have caused algal blooms, seagrass dieback and anoxia in Cockburn Sound but relatively high fish production has been reported there in the review by Gwyther (1990) (see Table 1.3.2.3). However, two planktivores (*Sardinops sagax* and *Sardinella lemuru*) formed the bulk of catch and these are not directly dependent on seagrass. Dybdahl (1979) warned that seagrass detrital material is at the base of the food chain there and takes a long time to decompose. Therefore the effects of seagrass loss will not be immediately evident. There may even be local and short-term increase in diversity and abundance as habitat diversity increase in seagrass patches and dieback causes more detritus to pool in sediments.

The studies by Lenanton *et al.* (1985) and Potter *et al.* (1983b) have shown the importance of anoxia in the effects of eutrophication on fisheries production. The most prolific and prolonged blooms of the cyanobacterium *Nodularia spumigena* occurred in Harvey estuary and the western half of Peel Inlet. Blooms there were so intense that secchi disk readings were as low as 2cm. The blooms were highly seasonal, but also peaked after large river discharges of freshwater and nutrients.

Chlorophyll (*chl a*) measurements were good indicators of *Nodularia* abundance and the threshold for visible affects on fish abundance was 100 micrograms *chl a* per litre. Comparisons of fish community structure found 4 species responsible for the difference in "*Nodularia*" and "non-*Nodularia* years" when sampling was done by Potter *et al.*

(1983b) in the same places. These were the mouth-almighty *Apogon rueppelli,* the trumpeter *Pelates sexlineatus, Gymnapistes marmoratus* and yellow-eye mullet *Aldrichetta forsteri.*

Declines in bottom oxygen tension were associated with blooms and it was therefore most notable that benthic species died, and the recruitment of the demersal *Apogon rueppelli* was suppressed during blooms. Hundreds of dead blue swimmer crabs (*Portunus pelagicus*) and "cobbler" *Cnidoglanis macrocephalus* were found in summer when temperatures were at their maximum and blooms were intense. Several lines of evidence showed fish were moving away from the blooms and out of the estuary. Fishermen suspended operations and made good catches in unaffected areas. More active and mobile teleosts such a yellow-eye mullet did not suffer conspicuous mortality during blooms -- they moved away and the fishery shifted to follow them.

Potter *et al.* (1991) reported that the macroalga *Cladophora montagneana* coated much of the substratum in the Peel-Harvey estuary during the late 1960's until 1979 and commercial catches of western king prawns (*Penaeus latisulcatus*) were very low. They inferred from this that the preferred sandy substratum of juvenile stages of this species was lost and that this affected abundance. The biomass of macroalgae was estimated to have fallen from 27 thousand tonnes in 1978 to 2.6 tonnes in 1981-1988.

The massive growth of macroalgae (*Cladophora* and *Chaetomorpha*) were accompanied by greatly increased fish catches - a feature that Potter *et al.* (1990) suggest reflected a reduction in predation from avian piscivores as a result of greater shelter from predators provided by the algae.

During the era of macroalgal and cyanobacterial blooms the Murdoch University environmental studies group sampled the Peel-Harvey in comparison with the Swan estuary (relatively non-eutrophic) with a focus on community structure and distribution of fish, crabs and prawns. They noted:

- a dramatic increase in fish catch in the 1970's due to amphipod and copepod production in algal beds (amphipods *Melita* do not feed on the *Ulva*, instead they use it as shelter and graze on the epiphytic diatoms that live on *Ulva*)
- decline in western king prawns because of loss of nurseries in sandy substrata
- a State-wide increase in tarwhine numbers has been perceptible - these are herbivores as juveniles and recruit to vegetated habitats

- in the Swan estuary CPUE developed, peaked and then declined in association with macroalgal blooms - but shifts in targeting confounds looking at species shifts (eg. demand for yellow-eye mullet as rock lobster bait decreased)
- the Dawesville Channel option was chosen to reduce the residence time of phosphorus by increasing flushing -- marked changes in access by marine species have occurred
- in winter the Peel Inlet was hyposaline, but freshwater is now quickly flushed away
- this enables year-round access of blue swimmer crabs, tailor and herring *Arripis georgianus*
- juvenile western king prawns are very abundant, because there are better, sandy areas for recruitment now -- anglers have perceived improvement in catches but the strong currents in the channel have prevented proper sets of commercial gear and catches have declined
- high productivity of bacterial films remaining on sediment surfaces after the bloom episodes may provide food later for prawns, crabs and some shellfish.

In South Australia, there have been no measurable changes in fish production associated with *Ulva* blooms that appeared, seasonally at first, in the early 1970's although:

- the year class strength of recruits of yellow-eye mullet rose since 1980-1985, and this may be related to *Ulva* abundance
- the biomass of *Ulva* prevents use of jet-nets to sample post-larval western king prawns and repeat surveys done before blooms prevailed
- Barker Inlet remains the most important nursery for King George whiting in St Vincent Gulf (see Jones *et al*. 1996 and p.c.#1560 K.Jones, p.c.#1550 M. Kangas, p.c.#1520 A.J. Fowler).

Of all finfish species fished commercially, we would expect to see signals of eutrophication in greater production of omnivorous yellow-eye mullet and herbivorous sea mullet and luderick, yet there are no definitive studies for these species.

3.2.1 Regional variability

The impact of excess nutrients are greatly complicated by a combination of physical, chemical and geological characteristics of a given system. Most simply, an enclosed water body with long residence times would be more affected than an open embayment with short residence time of water. Indeed, coastal lagoons are among the water bodies most badly affected. Coastal lagoons such as the Peel-Harvey system and Moreton Bay make up 11% of Australia's coastline and are especially susceptible to eutrophication.

Most of our coastal rivers and embayments receive elevated nutrients from population centres and land uses within their catchments. For example, treated sewage enters the Richmond River at 8 point sources and enters the Clarence River at 7 point sources. Water quality measurements in the Clarence River by the SPCC (see West 1993) reported 30-40 micrograms of phosphorus per litre -- only slightly below the values considered to define eutrophic waters (40-60 micrograms per litre). The poorly flushed Tuggerah Lakes and Lake Illawarra have a problem with nutrient inputs and there is a proposal to make a cut (similar to the Dawesville Channel) to flush nutrients.

Similar problems with sewage inputs and low flushing have also occurred at Mallacoota Inlet and the Gippsland Lakes -- there are annual cyanobacterial blooms there, and fish kills have occurred due to low oxygen levels (see Longmore *et al.* 1990).

In SA, windblown nutrients from superphosphate use on the two peninsulas are thought to be a "sleeping giant" in terms of enhancing algal growth in epiphytic communities on *Posidonia* and *Amphibolis*. For example, early monitoring of seagrass and epiphyte biomass started in 1970's in SA and at the "control" sites in Port Victoria there are significantly more epiphytes now. On south-east Yorke Peninsula near Edithburgh there is a seasonal (summer/autumn) burst in algal growth in a narrow band - almost as if a nutrient slug has occurred- but there are no freshwater or sewage inputs. It may be that wind-driven, seasonal resuspension of sediment loads of phosphorus are responsible for this bloom. Cadmium is a tracer for superphosphate and may be used to explore the cause of unexplained epiphyte outbursts (p.c.#1500 J.Johnson).

Some systems are unique from a global perspective. The Great Barrier Reef lagoon is such a system and is thought by some to be increasingly affected by human encroachment. Catchment areas have been greatly modified by sugarcane farms, clearing for housing and tourism developments and prawn ponds, grazing, and urbanisation.

Approximately 77,000 tonnes of N and 11,000 tonnes of P per year are transported into the GBR lagoon (Alongi 1997). These amounts have been estimated to be nearly four times greater than pre-industrialisation. There is current debate that coastal reefs such as the

Whitsunday Isles, Low Isles, Green Island and Magnetic Island are deteriorating in live coral cover, coincident with increases in macroalgal (*Sargassum*) standing crops and turnover.

Unfortunately, the data are conflicting -- water-column and sediment nutrient concentrations do not suggest that eutrophication is occurring, and long-term data are lacking, as well as information on the capacity of coastal muds and muddy sand areas to assimilate and adsorb excessive nutrients, if any. Preliminary experiments on the responses of *Sargassum* to nutrient and sediment have produced counter-intuitive results - they have responded negatively to additions of these materials (see McCook and Price 1997). Biogeochemical studies to construct nutrient budgets may help to estimate the capacity of the lagoon and its reefs to withstand nutrient inputs above natural levels. Such estimates would in any event be complicated by effects of cyclones and summer monsoons that would tend to mask any deleterious impacts by humans.

3.2.2 Biomonitors and the symptoms of eutrophication - the need for innovation

Nielsen and Jernakoff (1996) and Ward (1989) have outlined the weaknesses of prevailing monitoring methods that focus on water column concentrations of nutrients. Some of the methods such as bay-wide measurements of nutrients and macroalgal biomass are so coarse that by the time a signal is perceived there will already be a serious threat from algal blooms and anoxia. They have proposed alternatives that may be more useful and quantify better the responses of primary producers to nutrients. Examples for macroalgae include the use of tissue nutrients and long-term changes in macroalgal depth distributions.

In this regard the laboratory of Dr W.Dennison at the University of Queensland has produced an innovative, comprehensive package of techniques for interrogation of biomonitors, to determine the source and proximity of nutrient and sediment stressors (see Dennison 1994, Abal and Dennison 1995,1996, Udy and Dennison 1995, Perry *et al.* in press).

These techniques deploy cultured phytoplankton and macroalgae bio-indicators, and examine isotopic ratios and depth range in seagrass tissues and beds, to trace the source, transport, fate and impacts of nutrients. This has provided a cohesive, powerful approach to enable inferences to be made over a range of spatial and temporal scales. The suite of techniques has been used in the sub-tropics and tropics, but will be applicable to temperate systems too, because nutrient inputs are not as pulsed and episodic as they are in tropics.

The measurement of phytoplankton productivity defines limiting nutrients. The method involves *in situ* inoculation of bags of local seawater with nutrients. The premise is that there is very little stimulation by the inoculation for phytoplankton in habitats where high levels of nutrient enhancement are not usually experienced -- therefore a sharp response to an inoculation shows that the community has developed in past conditions of nutrient enhancement.

This approach satisfies the need for measurement of rates and dynamics of primary productivity - in stark contrast to the traditional measurement of static water quality parameters. In the laboratory, phytoplankton are pushed to their physiological limits to get tolerance profiles for nutrients, then these dose/response curves are applied in a predictive manner to measurements obtained in a field situation.

Static measurements tell very little about the nutrient regimes - a small value or concentration of a nutrient can reflect high turnover, rapid uptake and low residual levels. Over time phytoplankton assemblages shift to be dominated by those with increasing ability to take up nutrients as nutrient levels increase (p.c.#650 M.O'Donohue).

A macroalgal bio-indicator has tissue pigments that act as sentinels for nutrient levels when the alga is deployed in the field. *Gracilaria* is used and is euryhaline, but the marine *Laurencia* also has potential. The *Gracilaria* tissue-nitrogen tracks water column nitrogen - it is sensitive even to immeasurable levels of nitrogen. The procedure involves keeping laboratory cultures in low nitrogen regimes so they are "nitrogen-starved". The algae are then deployed in the field.

Pigments, tissue nitrogen and phosphorus and amino acids are measured after exposure and enable the type of nitrogen source to be identified. There is visible change in pigments from transparent to deep red-brown correlated with nutrients.

Seagrass depth range is correlated with a suite of water quality parameters. Laboratory and field experiments have calibrated the decrease in depth range with increasing "Kjeldahl Number", increasing nitrogen and increasing light attenuation. Local correlations can be applied elsewhere (work is underway at Albany), and a model linked with GIS can be constructed to predict where seagrass should be found on the basis of the calibrations.

Vegetation isotopic ratios can be studied to assess the physiological health of seagrasses, mangroves and other marine plants. Nutrients from sewage also have characteristic isotope signatures. The N_{15} isotope is anthropogenic and can be used as a good bio-indicator. The C_{12} : C_{13} ratios can vary with plant stress. There is less discrimination between them when plant activity is very high, but when activity slows down, the plant takes up the lesser weight molecules selectively, and the ratio in tissue changes. The same process occurs with delta N (N_{14}: N_{15}). Delta N can change from 10 to 2 within a range of 30 km -- this has serious implications for food web studies inferred from isotope work (also see Bunn *et al*. 1995). Delta N is very high in the Logan River, and West Moreton Bay and near Tallebudgera sewage outfall, but low at Currumbin where there is no effluent.

Nitrogen is limiting in marine waters, and comes in the forms of ammonia, nitrate, urea, and amino acids. The ability of plants to take up nitrogen from sewage depends on the medium and mediators. For example, Trinity Inlet is eutrophic and poorly flushed, but it is turbid and therefore light limited. The major symptoms of the nutrient inputs are therefore confined to a downstream gradient in phytoplankton production and a heavy epiphytic load on mangrove pneumatophores (p.c. #650 W. Dennison).

In general terms there is a very important role for of applications of marine chemistry in studying the fate and effects of sewage and mariculture effluents and papers by Heggie *et al.* (1994), Leeming *et al.* (1994), Nichols *et al.* (1994) and O'Leary *et al.* (1994) give excellent examples.

It is also somewhat surprising that an early lead by Nichols *et al.* (1985, 1986) in identifying seagrass bases in food-chains using isotope signatures has been poorly followed up in this country (see Hemminga and Mateo 1996 for review). Notable recent exceptions include Loneragan *et al.* (in press) and Bunn *et al.* (1997).

3.3 Effects on ecosystems - de-nitrification cycles and phytoplankton blooms

The most comprehensive studies of nitrification (eg. Port Phillip Bay Study) show a natural “assimilative capacity” for nutrients in bays and estuaries - but also warn of high uncertainty of thresholds and major hazards if denitrification cycles in sediments are disrupted. These studies show the need for bay- and estuary-scale modelling of major ecological, chemical and hydrodynamic processes to understand nutrification - and a better recognition of the importance of sedimentary processes (eg. Lavery and McComb 1991).

Port Phillip Bay is arguably the best-studied coastal bay in Australia, with predictive models now available to estimate critical nutrient loading levels into the system (see Port Phillip Bay Environmental Study Final Report, Harris 1996).

Major sources of nutrients are sewage treatment plants, the Yarra and Maribyrnong Rivers, and smaller rivers, creeks and drains, groundwater, and the atmosphere. In 1994-95, 52% of the nitrogen (N) and 67% of the phosphorus (P) entering the bay came from the Western Treatment Plant, the major site for treatment of wastewater from Melbourne. The remaining P and N comes from the above-mentioned rivers. These inputs are balanced by major losses via denitrification (70-90%) and minor export of roughly 1000 tonnes N yr^{-1} to Bass Strait. Further inputs are predicted to result in net accumulation in bay sediments. In contrast, the P budget is balanced by precipitation and burial in sediment and some export to Bass Strait.

The study revealed that the main pathways of nutrient flux were through the sediments -- an abundant and actively bioturbating benthic fauna is responsible for rapid recycling and return of nutrients and other solutes to the water-column where they can again be taken up by pelagic and benthic photoautotrophs.

Thus the concentrations and fluxes of major elements in Port Phillip Bay waters are controlled by biogeochemical processes in the sediments. One of the main conclusions of the study was that in order for water quality in the bay to be maintained, the benthic ecosystem must be protected from excessive disturbance such as dredging and deposition of solids. In future, N loads to the bay should not exceed present levels -- a reduction of 6500 tonnes yr^{-1} would result in a dramatic improvement in water quality in the bay. However, introduced fanworm beds pose a major threat to the denitrification cycles in the sediments beneath them in the bay (see section 5.2.2).

3.3.1 Mangroves as nutrient scrubbers

Estimating the extent to which subtropical and tropical ecosystems, such as mangroves and seagrasses, would be more sensitive to excessive nutrient loading require more information on biological productivity, nutrient concentrations and fluxes in overlying waters and sediments than currently available.

A good example is the estimate by Robertson and Phillips (1995) of the amount of nutrients from aquaculture ponds that mangroves can utilise without detrimental effects. Using budgets of nitrogen and phosphorus output for prawn ponds combined with estimates of total net primary production in *Rhizophora* forests, they were able to estimate the ratio of mangrove forest to prawn pond area necessary to remove nutrients from the pond effluent.

Their calculations showed that for a 1 Ha pond, between 2 and 22 Ha of mangrove forest are needed to assimilate all of the effluent N and P -- the wide range of forest area reflects dependence on pond management practices. More importantly, they stated that before mangroves can be used in such a manner, more information is urgently needed on nutrient transformation processes in mangrove sediments, and the extent to which tree growth is nutrient limited in undisturbed forests. Data from an AIMS monitoring study near Port Douglas indicate that pond effluents have a greater short-term impact on creek hydrochemistry and plankton processes than on within-forest processes. This may be due to the adsorption of nutrients to clay particles, assimilation by trees, denitrification, and drainage into the creeks via porewater seepage.

3.3.2 Key uncertainties

Similar estimates have not been made for Australian seagrasses or macroalgal beds due to lack of information on basic nutrient recycling processes, especially in sediments. However, studies from other regions have indicated possible impact of excessive nutrient inputs. Most plants respond positively to nutrient additions because most plants are nutrient-limited. However, species richness declines and biomass of the most tolerant or most rapidly growing species increases at the expense of the others. Small nutrient additions are beneficial, but larger additions promote epiphytic growth on seagrasses, shading light and causing seagrass demise. What amounts constitute "small" and "large" are difficult to estimate unless plant productivity, sediment adsorption capacity and other such factors are known. As pointed out by Robertson and Phillips (1995), key research questions need to be answered before predictive models can be constructed estimating the capacity of a system to tolerate nutrient loading:

- what nutrient loads can cause complete anaerobiosis of sediments and plant mortality?
- what is the long-term assimilative capacity of sediments for dissolved nutrients?
- how do different sediment types affect the retention and transformation of nutrients?
- what nutrient loadings have a detrimental impact on benthic fauna?
- what is the impact of loss of bioturbating benthic fauna, such as crabs?
- what combinations of nutrient loadings and hydrodynamic regimes cause anoxic/hypoxic conditions in estuarine and coastal waterways?

These questions reflect our current level of ignorance with respect to nutrient impacts and tolerances of ecosystems, and they are of profound importance to sustain aquaculture without causing seafloor souring and other environmental hazards in the ponds and under the racks and cages. The major threats of nutrient fluxes to molluscan mariculture have been reviewed by Hamdorf (1993).

For example, in Tasmania 11 areas are zoned for aquaculture and there about 150 aquaculture farms including 15 salmon cage operations. Farm developmental plans for each area are being developed now to cope with :

- effects of the farms on the environment - oyster farms take out nutrients, but salmon farms put nutrients into the system
- effects of catchment use on farms -- relationships between catchment use and mariculture operate at small scales (even low numbers of dairy cows in a NZ catchment have been known to prevent oyster harvests because of *E.coli* contamination).

Seafloor souring under salmon cages is visible as a white bacterial mat that bubbles with methane and hydrogen sulphide. Preliminary studies have shown sediments to be organically enriched within <=5 m of cages, with some influence measurable at 5-10 m away and enrichment finishes at 10-40 m distance. However, use of isotopes to trace nutrients has shown influence of the cages up to 80 m away (p.c.#1280 J. Moverley).

The problems associated with sea-cage fish farming and seafloor souring have been reviewed by Trendall (1992) in response to demand for coastal sites for tropical barramundi farming. However, seafloor souring due to faeces and uneaten pilchards is also an issue for the southern bluefin tuna farmers in Boston Bay. The main R&D objective there is to determine what is the best way to assess the degree of souring, the recovery rates of the benthos and the farm-management requirements to move cages. Development of artificial feeds with better assimilation ratios would also be desirable to reduce seafloor souring. This is yet another example of the possibilities for cross-linking between the various FRDC Programs to achieve desirable outcomes for the environment.

3.3.3 Toxic and nuisance phytoplankton blooms

Hallegraeff (1992a, 1993,1995,1996) has reviewed the risks and hazards posed by blooms of phytoplankton and dinoflagellates in Australian coastal waters. He proposes that there has been an increasing awareness of the problems rather than an increase in occurrence of the blooms.

Important points to note are:

- overall they are natural events (eg. the bloom in Jervis Bay was a coccolithophorid - Blackburn and Cresswell (1993); *Trichodesmium* fixes atmospheric N)
- captive fish are extremely sensitive to blooms because they cannot escape them - some blooms produce slime or chemicals that clog or destroy gills
- the issue of ballast water introductions is a serious one, but it is extremely difficult to prove a species is introduced -- DNA fingerprinting will help
- there are over 2000 species of dinoflagellates in Australian waters, and about 40 of these could create nuisance blooms
- only *Gymnodinium catenatum*, and possibly a strain of *Alexandria* (*catenella*), are known to have been introduced
- *Gymnodinium catenatum* produces cysts, and cores showed that it came in to Australian in 1973, but the sources of other species have not been examined so closely yet
- it is not easy to measure the toxin producing paralytic shellfish poisoning (PSP) -- artefacts of acidification in assays can cause over-estimation of toxin power; the threat in our waters is not as severe as that posed by PSP toxins in USA and Japan.

There are three main types of nuisance and toxic algal blooms:

- slimy algal blooms - eg *Thalassiosira* see Griffin *et al.* (1997)
- exuders of chemicals that destroy gills - eg the 1995 bloom in Coffin Bay that killed rays and bivalves
- creators of toxins responsible for shellfish poisoning - eg paralytic shellfish poisoning (PSP), amnesic shellfish poisoning (ASP), neurotoxic shellfish poisoning (NSP) and diarrhetic shellfish poisoning (DSP).

Fish larvae of some species are very sensitive to blooms, and blooms have been identified as the cause of disappearance of whole year classes of fish overseas.
Overseas, picoplankton blooms can persist for 5 yrs and have killed off whole seagrass beds in Texas and Long Island Bay in the USA.

Blooms are unexpected in well-flushed areas, but enclosed bays and estuaries receiving nutrients and subject to calm, stratified conditions are the areas most likely to have blooms

Coastal algal blooms are driven by nitrate enhancement, but there is also much more to the process that makes blooms poorly predictable. For example:

- terrigenous runoff is a major factor -- in Port Phillip Bay and Tasmania blooms occur after major rainfall events, probably because of some micronutrient that is not related to nitrogen or phosphorus
- recent research has shown that iron and humic substances interact with nutrients, to sometimes make nitrate more, or sometimes less, available.

Key uncertainties and threats of blooms concern the reasons why monocultures develop. For example, in a stable water column, the diatoms will sink while the dinoflagellates migrate vertically after taking up nutrients at depth. Sometimes species are avoided by grazers (especially cyanobacteria) and so there is also a release from predation. Other species grow very fast because they can take up and utilise nitrate better than other taxa.

In many situations of coastal eutrophication (not all) there is more algal biomass, but our present knowledge is inadequate to explain whether the resultant biomass will be toxic or a nuisance, or beneficial diatoms that support food chains. It is also apparent that blooms can remain relatively benign until certain thresholds in concentration are reached.

Turbidity is also a major factor in determining the frequency and composition of blooms. For example, there are very high tannin loads and resuspended sediments in the Derwent , so despite excessive nutrient loads - phytoplankton are light limited there. The Huon estuary is even more coloured by tannins from button-grass plains, and hence is a very good choice for the location of fish farms, as phytoplankton are light-limited there too.

Salt-wedging at the interface of freshwater and the sea makes turbidity rise in estuaries to suppress blooms, so freshwater diversion and river regulation can have profound effects on later frequency of algal blooms. Land-uses in catchments such as deforestation can also have indirect effects on algal community change by causing enhanced supply of iron and other micronutrients.

Dinoflagellate cysts are tolerant of anoxia, and they have a dormancy period. Burial in anoxic sediments keeps them "asleep". Cues for breaking of dormancy are oxygen supply which causes germination, but then temperature, light, and nutrients govern survival and bloom dynamics. Dredging (such as for scallops) awakens dormant cysts (p.c. #1300 G. Hallegraeff).

These are further examples of the interactions of habitat disturbances.

Australian research is attempting to put blooms into the context of different sources of nutrients and pin down the key causes of blooms. For example, in Port Phillip Bay nutrient levels are high, but other factors are involved in limiting blooms - monitoring has shown a series of events involving temperature, stratification of water column, rainfall and then a quiescent period, plus and unknown chemical trigger. These are now almost regular, annual blooms of *Gymnodinium catenatum* in Tasmania, and the shellfishery has to be closed.

Sanitation procedures are in place with a notification scheme under the "shellfish quality assurance programs" in Tasmania and Victoria (Arnott 1990a,b), but at the time of writing several respondents suggested involvement of the FRDC in extending these programs to a national standard in biotoxin surveillance programs (p.c.# 1020 G.Arnott, p.c. #1270 C. Crawford).

In Victoria, there is now a major concern for predicting and managing the effects of toxic dinoflagellates that involves monitoring both the water column and testing for biotoxin in products. In Port Phillip Bay the MAFRI monitors 15 stations on a fortnightly basis, as the phytoplankton community can change very quickly. The dinoflagellate *Alexandrium catenella* is the greatest threat and it blooms about one week after heavy rain in the Yarra catchment. The spores may need both turbulence and freshwater from storms to hatch, and the development of blooms requires suitable temperatures, nutrients, and a calm stable water column. Blooms reach densities of up to 1-2 million cells per litre.

In January 1992, PSP was up to 125 times the health limit in the northern end of the Bay, and eating 6 mussels could have proven fatal, but there has been insufficient appreciation or funding of the problem at top Ministerial levels. Planktivorous pilchards and anchovies also affected by PSP, and the toxin has been measured in both rock lobster and abalone, but pilot surveys of major seafood industries are needed as a baseline. There is a precedent for concern in that Japanese markets rejected Spanish abalone imports because of PSP.

Rhizoselenia chunii leaves an intensely bitter taste and there were 3 major blooms in August in 1987,1993,1994, in PPB. This makes mussels inedible, but the toxin is mainly in the gut, so shucked and gutted scallops are marketable. Domoic acid is a toxin produced by diatoms (*Pseudonitzschia* and *Nitzschia*), which causes amnesic shellfish poisoning overseas -- there have been blooms of *Pseudonitzschia* in the Gippsland Lakes system. In Tamboon Inlet, a neurotoxic shellfish poison (NSP) came from *Gymnodinium comparbrevi* and this has now been found in Port Phillip Bay blooms. *Alexandrium catenella* has now spread to Sydney Harbour (p.c. #1020 G. Arnott).

The threat of ciguatera poisoning is a concern for recreational and commercial fishing interests along the Great Barrier Reef and especially Hervey Bay. Gambiertoxins from the epiphytic dinoflagellate *Gambierdiscus toxicus* (and other toxins) are transferred through the food chain to predators such as spanish mackerel and coral trout. There have been repeated claims that anthropogenic disturbances to corals aggravates the problem by creating ideal habitat for *Gambierdiscus* (Bagnis 1994), but such a hazard is not supported by Australian research (see Lewis and Holmes 1993 for review).

3.4 Contaminants and pathogens

The risks and hazards to fisheries of contaminants and pathogens appears to be localised to some coastal areas, particularly those with heavy industry, transport, and highest human population densities. From a fisheries perspective, the most commonly reported symptoms are "fish kills" from pesticides in coastal rivers (eg. Anon. 1993g), "kerosene tainting" or off-flavours in sea mullet, and closures to harvesting (see Leadbitter 1992). It was difficult to find the results of any results of systematic monitoring of coastal organisms and their environment in Australia, but the need for long-term programs has been indicated for some time (eg. Martin and Richardson 1991, 1995, Miskiewicz 1991). Instead, the literature comprises an abundant collection of "one-off" reports of contaminants in localised areas and development and testing of sentinels and protocols (see Table 3.1.2).

We also found evidence of high risks of disease in cultured organisms when water quality is lowered due to contamination, but the hazards have been poorly documented (eg. Roubal *et al.* 1989). The introduction of cholera in ballast water is a major risk for shellfish mariculture (see section 5.2.3).

3.4.1 Hydrocarbons

Surveys around the Australian coastline of concentrations of residual petroleum hydrocarbons (PAHs) in most seawater and sediment have found levels at or near background (< 1 μg litre^{-1} total hydrocarbons) (see Connell 1996). Localised areas of contamination include the Parramatta, Yarra, and Brisbane Rivers, and some parts of Port Phillip Bay and Western Port. The level of contamination in birds and marine organisms is more difficult to assess due to naturally produced hydrocarbons. Nevertheless, there appears to be some localised contamination (eg. some fish and birds in southern Queensland), but no large-scale pollution. Most PAHs are thought to enter coastal ecosystems via urban runoff, sewage and some leakage from container ships and petrochemical instillations (eg Edyvane 1991, 1995a, Liston and Maher 1986).

Mangroves are classified as being particularly susceptible to damage by oil pollution (Volkman *et al.* 1994b). Mangrove trees are killed by oil when floating oil deposits on their exposed roots and stems and contaminates sediments as tide levels drop. They die from either a toxic or suffocating effect, and from the result of oiling of burrowing animals. These animals, including crabs and worms, usually die within a day after oiling, whilst trees die after one or two months (Duke 1996).

Oil can persist in mangrove sediments for decades (Burns *et al.* 1991) and, in these circumstances, there is little degradation or change in composition of oil in the usually anaerobic sediments. Oil penetrates into mangrove sediments by diffusion from the surface, but the main mechanism for oil penetration is through crab holes and old root castes during low tides. Once the crabs die, the crab holes close over and the oil becomes trapped beneath the surface, affecting living roots and fauna in the vicinity.

Recovery of oiled areas largely depends on the degradation of oil, the re-establishment of the burrowing infauna, and the root development and growth of mangrove plants.
In Australia, mangroves have been killed and affected by large oil spills in at least seven sites around Australia (Grant *et al.* 1993, Volkman *et al.* 1994b). In Botany Bay, land and ship-based oil spills over the period 1979-1987 caused widespread mortality of seedlings and defoliation of lower foliage of *Avicennia marina* trees. Many contaminated areas have been recolonised by seedlings, but recurrent oil spills make it difficult to predict how long the mangrove habitat will take to fully recover. In the absence of more spills, it was estimated that the population structure would take several decades to recover.

The total amount of damage caused by oil spills is expected to remain small in view of the extent of mangroves in Australia. However, the impact at a local-scale is likely to major, effecting not only the mangrove habitat but also the neighbouring habitats which depend on mangroves.

3.4.2 Metal contamination

Like PAHs, heavy metals find their way into coastal waters and biota via urban and industrial effluents, explaining why localised contaminated areas are restricted mostly to coastal areas in proximity to the large cities and industrial installations. In most estuaries, while water concentrations of heavy metals are at or near background, much lower than concentrations in coastal areas of the Northern Hemisphere, metal levels in sediments are less than those in most other industrialised nations, but higher than in overlying waters and in dredge spoil.

Of much greater concern is the bioaccumulation of metals in coastal biota (eg. Ward 1989, Phillips *et al.* 1992). A variety of small-scale studies have indicated that tissue contamination can be attributed to point-sources in proximity to urban and industrial sites. For instance, in Port Phillip Bay, mercury levels in fish have been found to sometimes exceed international guidelines. Similarly, in the Georges River in NSW, copper in oysters exceeded guidelines and was attributed to antifouling paints. Some evidence suggests high levels of mercury in sharks and cadmium in crustaceans, particularly prawns. Metal levels, haemosiderosis and other disease in fish has been studied in areas of Port Phillip Bay polluted by metals (eg. see Fabris *et al.* 1992, Langdon 1986, Nicholson *et al.* 1994, Phillips *et al.* 1992). A limited review of the national outlook is given by Batley (1996).

Cadmium is perhaps of most concern to the national fishing industry, mainly in crustaceans, and the export trade could be most at risk due to levels exceeding food standards. Crustaceans (prawns, crabs, bugs) that feed on bivalve molluscs naturally accumulate levels of cadmium that are relatively high (or exceed) in comparison to the original Maximum Permitted Concentration (MPC) set by National Health and Medical Research Committee (NHMRC) in the 1960's. Indeed, some individuals and species far exceed the MPC in areas remote from any industrial sources of metal pollution.

In view of the high levels of cadmium naturally accumulated by crustaceans (particularly in the hepatopancreas, or "brown meat"), and other factors, the Australian Seafood Industry Council (ASIC) applied in 1995 to the National Food Authority to have the MPC for cadmium raised to 2 milligrams per kilogram (equivalent to molluscs), with an exemption for products comprising crustacean hepatopancreas material.

The best documented episode of mercury pollution in Australia occurred with widespread pollution in Princess Royal Harbour (see Hancock 1990, Francesconi *et al.* in press for review). The area was closed to all fishing, and even pelagic planktivores that are known to be migratory (herring *Arripis georgianus*) had unacceptably high levels of methyl mercury in their tissues. The source of pollution was removed and, after more than a decade, fish tissue levels have fallen to limits safe for fishing. Selenium often naturally occurs in fish flesh at levels around the MPC, but in Lake Macquarie the higher liver values were quoted in the media as high flesh values, in part of a political argument where anglers wanted commercial netters removed from the lake (p.c. #680 I. Hamdorf).

The best documented contaminant budgets exist for Port Phillip Bay as part of the Port Phillip Bay Environmental Study. Overall, all metals are well below water quality criteria when averaged over the whole Bay waters, but there is a problem with scales in measurement, and some ranges at localised sites do exceed the criteria. For example, in flathead, mercury and arsenic are highest at stations near Werribee outfall (0.3 ppm vs MPC of 0.5 ppm). In sediments, Corio Bay generally has high cadmium, lead and zinc close to existing or old industrial point sources, but not as severe as both Lake Macquarie and Sydney Harbour where extremely high zinc (1000's ppm) prevent life of any infauna in some sediments (p.c. # 990 G. Batley).

"Heavy metal hotspots" exist in Spencer Gulf near a lead smelter in Port Pirie where seagrasses are contaminated by zinc, cadmium and lead (see Ward 1984, 1989, Ward *et al.* 1986). In a review of the occurrence of metal accumulation and its impacts on seagrass and associated fauna, Ward (1989) developed clear recommendations for biomonitoring of metals in seagrass habitats and the use of sentinel accumulators and indicator species. We did not ascertain whether or not these monitoring studies have been pursued, but there have been recent closures to mollusc (*Pinna bicolor*) harvesting in parts of Spencer Gulf. Ward (1989) outlined the complexities in determining the impacts of the three metals, and concluded that seagrass species are moderately resistant to the direct effects of metals, but that the fauna inhabiting the seagrass meadows are much more likely to be sensitive and they are at risk.

3.4.3 Organochlorines and organometals

Prior to a ban imposed in 1988, tributyl tin from antifouling paints was a contaminant problem, usually in southern waters -- levels in waters, sediment and biota are now within the guideline concentration of 2 nanograms litre^{-1} (Batley 1996)-- but there is still evidence of widespread gastropod imposex (eg. see Nias *et al.* 1993) so the hazard has not been removed. There may be a threat to western rock lobster pueruli in the Fremantle area, as gastropod imposex is known to extend for a radius of about 30km in either direction of port facilities there (p.c.#1400 C. Simpson).

Organochlorines may be the most dangerous chemical compounds introduced into the marine environment. Although concentrations in Australian waters and in coastal sediments are low, these compounds are preferentially solubilised in tissue fats, and can accumulate in very high concentrations above environmental concentrations.

Localised studies indicate that pesticides are present in tissues of many estuarine and marine organisms, especially in hot spots in proximity to urban areas and agricultural land. Much research has focussed around the Sydney sewage outfalls (see below, and Otway

1992, Miskiewicz and Gibbs 1992,1994). It was found that fish such as the red morwong (*Cheilodactylus fuscus*) contain lindane and heptochlor in concentrations exceeding permissible levels by 50-120 times. This situation has improved since fishing was banned within 500 m of the outfalls, and continues to be closely monitored. Today, use of organochlorines such as DDT, aldrin, chlordane, heptachlor and dieldrin is not permitted, and use of other compounds, such as lindane are restricted. Nevertheless, no national surveys or monitoring programs are being conducted to determine the extent of the problem in fisheries products (but see Hamdorf 1992).

Best studied from a fisheries viewpoint is the assessment and identification of impacts of endosulfan pesticides leaching into upper catchments from cotton growing areas, for which the LWRRDC has a national R&D program (see Arthington 1995, Korth 1995, Novak and Ahmad 1989, Novak 1992 and section 2.1.3).

3.4.4 Sewage plumes

Until 1991 sewage was discharged into the coastal waters off Sydney through seven cliff-face outfalls. The effluent consisted of a cocktail of domestic and industrial wastes, and -- although freshwater was the major constituent of the discharge -- it contained contaminants in solution and suspension, as well as varying concentrations of pathogens, bacteria and toxic substances. These included metals such as cadmium, chromium, zinc, mercury and lead.

Gray *et al.* (1992) sampled larvae in and below plumes and compared these with sites >8km away. They could not detect any significant differences in densities of fishes in plume and non-plume waters, but did suggest that differences may exist between water masses of the plume, plume front and adjacent ocean. The scale of sampling has been shown to be very important in detecting differences amongst plumes and other water bodies.

Gray (1996) sampled in the effluent plume, along the frontal edge of the plume and just outside (approximately 500m) the plume in clear shelf water. He found that sewage plumes form a turbid, 1-5 m deep lens of lowered salinity overlying clear, shelf waters. Many fish were concentrated in plume fronts and advection or active attraction influences distribution of pre-settlement fish at scales <1km - this may prolong exposure of these stages to pollutants.

In fact, Kingsford and Gray (in press) and Kingsford *et al.* (1994) looked for effects of the plume on condition of larvae and rates of abnormality in the larvae. They concluded that bending of the notochord was caused by the plume - but this has been disputed by others who consider it may be more an artefact of capture (damage by fibres and other debris).

In any case, Otway (p.c.# 450) has pointed out that this observation may tell little about the source of stressor. Identifying impacts is a much different process than assessing impacts (see also Smith 1994, Keough and Quinn 1991). For example, effluent is a complex mixture -- the cause of some observed effects could be just the freshwater in the plume. Experiments must proceed after such observation of effects to isolate causes, and the experimental treatment should be delivered in the same form as the field effluent.

A problem with such impact assessment also concerns the lack of direction of precision and power by users of the information. Managers should communicate the level of change that is "unacceptable" (eg. <= 50%) -- politically or ecologically -- then experiments and monitoring can be designed accordingly. Power and precision analyses can then be done to address the level of change that needs to be detected.

There is also concern that there has been a relatively intense focus on the effects the five ocean outfalls off Sydney yet there is little consideration of the vast "background" plume of contaminated sediments coming out of Sydney Harbour - the legacy of 150 yrs of industry. Storms rework sediments on the Sydney shelf down to 80 metres depth and at these times the Sydney Harbour source swamps the relatively meagre budgets of contaminants from the outfalls

Slicks on the sea surface are caused by the aggregation of large organic molecules and there is the potential for contaminants of a variety of types to be concentrated in these structures, especially in the sea surface microlayer (see Volkman *et al.* 1994a for review). There is also a similar boundary layer at the sediment-water interface. The elevated levels of contaminants in these layers casts some doubt on the adherence to water quality standards that measure only water column concentrations. Many species have egg and larval stages that are neustonic in the sea surface microlayer, or epibenthic. The threats of contamination are poorly known for these stages, but a new project (FRDC#97/217) will be assessing the utility of some innovative techniques to identify the risks for eggs and larvae (see Klumpp and von Westernhagen 1995, von Westernhagen and Klumpp 1995).

There could be more widespread use of measurement of multi-function oxidases (MFOs) (see Holdway *et al.* 1995 for review) to assess the risks and hazards associated with contaminants that will help overcome the poor power of traditional surveys of abundance in assessing impact of oil-spills and other contamination (eg. Connolly and Jones in press).

Perhaps of more immediate concern to managers of mariculture and fisheries are the introduction of pathogens associated with sewage pollution, and the proliferation of litter such as plastics, glass and other garbage in our waters. Seabirds, turtles, cetaceans and fish may ingest this material or may become entrapped in nets, six-pack yokes and other synthetic debris leading to suffocation and a variety of injuries (see section 4.7).

Moreover, the occurrence of bacterial and viral pathogens, parasitic protozoa and worms, and toxic algae is increasing in our waters (Ashbolt 1996) -- these pathogens pose a health risk not only to humans, but to marine organisms as well (see section 5.2.3). Unfortunately, the magnitude of the problem is unclear due to the lack of studies and monitoring programs around Australia. The Standing Committee on Agriculture and Resource Management (SCARM) held a series of "Aquatic Pests and Diseases" Workshops in September 1996 and the proceedings covered these threats.