CHAPTER F. IMPACT ON THE BIOPHYSICAL ENVIRONMENT

The purpose of this chapter is to focus on aspects of the general environment of estuaries, beyond those fish and invertebrates that are caught as a result of the fishery. It broadly describes the major types and extents of habitats commonly found in NSW estuaries and describes how each of these, and the fauna and flora that depend on them, may be affected by the Estuary Prawn Trawl Fishery. It assesses the effectiveness of control measures outlined in the draft FMS to minimise these potential impacts, and the effectiveness of the monitoring and research programs proposed in the draft FMS to provide the information required to adequately assess the potential impacts of the fishery. Physical aspects, such as water and air quality, are also discussed both in terms of the impact that fishing has on them, and how they affect the fishery.

1. Biodiversity and Habitat Issues

There are 950 water bodies joining the Tasman Sea along the NSW coast, although the vast majority of these are rarely open to the sea (Williams *et al.,* 1998). Approximately 130 have a water area greater than 0.05 km^2. The estuaries in NSW cover a range of shapes, sizes and geological origins (see Appendix F1), and these factors are largely responsible for determining the distribution and abundance of physical habitats and ecological assemblages. Other factors such as the degree and rate of sedimentation and the water quality characteristics of an estuary are also important influences on the presence and abundance of the major habitats, particularly seagrasses, mangroves, saltmarsh and intertidal sand and mudflats.

Trawling is an active fishing method that directly disturbs seafloor sediment (Collie *et al.,* 1997). Any impacts from trawling activity in NSW estuaries will be limited to four estuaries, the Clarence, Hunter and Hawkesbury Rivers and Port Jackson. Prawn trawling activity in Botany Bay will cease in May 2002 as the bay has been gazetted as a recreational fishing area. An assessment of this fishery will be undertaken as part of the Recreational Fishing Area process. This section identifies potential impacts of the Estuary Prawn Trawl Fishery on the biodiversity and habitats of the four estuaries to be trawled under the draft FMS, and evaluates the effectiveness of proposed management measures in the draft FMS.

a) Major habitats of the trawled estuaries

The trawled estuaries in NSW have different geomorphological forms; the Hunter and Clarence Rivers are mature examples of a barrier estuary, while the Hawkesbury River/Broken Bay and Port Jackson are drowned river valleys (see Appendix F1). The distribution of habitats within these estuaries is influenced by physical characteristics associated with structure, geological maturity, climate, and human activities both past and present (see section 10 of this chapter).

There have been some attempts to map the distribution of major habitats within NSW estuaries (West *et al.,* 1985; Bucher and Saenger, 1991), although these were focussed on mapping vegetation communities rather than other habitats such as rocky reef and unvegetated sand. Table F1 summarises the area of the major vegetated habitats within each trawled estuary, based on information from a mapping program done by NSW Fisheries between 1981 – 1985 (West, *et al.,* 1985). Although more recent information exists for the Hunter River (Williams *et al.,* 2000), for reasons of comparison, only the information from West *et al.* (1985) is shown in Table F1. NSW Fisheries is currently reviewing and updating this information, which will also include the distribution of rocky shores. More recent data on the distributions of the major vegetative habitat are also available in Estuary Process Studies done as part of the Department of Land and Water Conservation's Estuary Management Program. However, this data is of limited use as the process studies only utilised field observation and did not provide any quantitative data. A summary of estuarine habitats, their importance in estuarine ecosystems and their distribution in trawled estuaries is discussed below (more detail is provided in Appendix F2).

Table F1. The area of vegetated habitats within trawled estuaries in NSW.

ESTUARY			HABITATS		
Name	**Type**	**Water area (km^2)**	**Mangrove area (km^2)**	**Seagrass area (km^2)**	**Saltmarsh area (km^2)**
Clarence River	3	89.243	5.208	19.072	1.954
Hunter River	3	30.421	15.481	0.153	5.409
Hawkesbury River	2	100.005	10.654	0.47	1.126
Port Jackson	2	49.667	1.475	1.286	0.073

Estuary Type Information (Roy *et al.,* 2001): 1 = oceanic embayment; 2 = tide dominated estuary; 3 = wave dominated estuary; 4 = intermittently closed estuary; 5 = freshwater (see Appendix F1 for a description of estuary types).

Other information was obtained from West *et al.* (1985).

i) Seagrasses

Brief description

Seagrasses are flowering plants that live and reproduce completely submerged in seawater (King, 1981a; West, 1989). They are rooted in the sediments, with the leaves appearing above the substratum and produce flowers and seeds, in a similar way to terrestrial grasses (Keough and Jenkins, 1995). Six species of true seagrass are found within NSW and there is a general increase in the number of species from north to south (West, 1989). *Zostera capricorni* is the most widespread species, occurring in most estuaries and for considerable distances upstream. Strapweed (*Posidonia australis*) is the other major species in terms of area but is found in only 16 estuaries and prefers areas where salinity is high and nutrient levels are low (Roy *et al.,* 2001).

Summary of importance

Seagrass is widely recognised as an important habitat for juvenile fish (e.g. SPCC, 1981a; Pollard, 1984; Bell and Pollard, 1989; Connolly, 1994), but it serves many more roles than the mere provision of food and habitat for species of economic value. Seagrasses are also reported to:

- prevent erosion by restricting water movement and binding sediment (Scoffin, 1970; Fonesca *et al.*, 1982)
- form the basis of food webs through high productivity and by providing detritus (Borowitzka and Lethebridge, 1989; Hillman *et al.,* 1989)

- provide surfaces for colonisation by epiphytes and periphyton (Harlin, 1975; Pollard and Morairty, 1991)
- restrict water movement which in turn allows for the settlement of plankton (Keough and Jenkins, 1995)
- trap and recycle nutrients (Hemminga *et al.,* 1991)
- provide foraging habitat for many species of birds, particularly cormorants, herons, swans and ducks.

Some studies have also reported the importance of detached seagrass in supporting abundant fish communities, particularly adjacent to beaches where it washes ashore to form accumulations known as wrack (Lenanton *et al.,* 1982). In northern Australia, seagrasses form a major component of the diet of dugongs and turtles, but in more temperate environments such as NSW, few animals actually consume seagrass directly (Klumpp *et al.,* 1989). Rather, as stated above, its importance to most fauna and other flora is in the provision of habitat and food from organisms it supports.

Distribution

Of the estuaries along the NSW coast, 82% have some seagrass. Most of the larger seagrass beds are contained within barrier estuaries, and four of these estuaries (Wallis Lake, Clarence River, Lake Macquarie and Tuggerah Lakes) account for more than 50% of the total area of seagrass in NSW. Of the trawled estuaries, the Clarence River has the greatest surface area of seagrass (21% of the water surface area in 1985) (Table F1). In the Hawkesbury River and Port Jackson, seagrass habitats are relatively minor when compared to the water surface area; 1% in the Hawkesbury and 2.5% in Port Jackson in 1985 (Table F1). Seagrass habitats are negligible in the Hunter River (Table F1) and have not been seen in the Lower Hunter River for at least the past three decades (Williams *et al.,* 2000). For details regarding the distribution of seagrass beds within these estuaries refer to West *et al.* (1985).

When assessing the regional distribution of these habitats, the seagrass of the Clarence River appears to be particularly significant, as there are no other substantial areas of seagrass habitat on the far north coast. The seagrass found within the trawled estuaries of the Sydney region is not as isolated as that of the Clarence. While these estuaries do contain a significant portion of the seagrass habitat within the Sydney region, adjacent estuaries such as Brisbane Waters, Pittwater, Botany Bay and Port Hacking also have relatively large areas of seagrass habitat.

Globally, the distribution of seagrass beds is known to fluctuate (e.g. Larkum and West, 1983) as a consequence of natural and human-induced factors such as storms, disease, dredging and/or pollution. Consequently, current distributions of seagrass beds in the trawled estuaries may vary from those mapped by West *et al.* (1985), and further mapping by NSW Fisheries is gathering more recent distributional data. Watford and Williams (1998) study in Botany Bay provided an example of how seagrass distribution varies over time.

ii) Mangroves

Brief description

Mangroves are trees and shrubs that grow in soft sediments within the intertidal zone of estuaries, generally in sheltered areas where silt can accumulate. They usually form dense forests when conditions are optimal, but can exist as small scattered trees on rocky areas in extremely sheltered areas (Chapman and Underwood, 1995). Mangroves usually spread their roots out widely in the upper layers of sediment, as opposed to vertically, in order to maximise exposure to oxygen and to enhance stability in otherwise unstable substrata (Chapman and Underwood, 1995). Other adaptations to survive in the intertidal zone include: having aerial roots (called pneumatophores) which arise vertically out of the sediment and absorb oxygen and other gases; increasing the number of pneumatophores in sub-optimal growing conditions; secreting salt through glands in their leaves; excluding salt via a filtering system; or accumulating salt in old leaves (Hutchings and Saenger, 1987).

Summary of importance

Like seagrasses, mangroves have been widely recognised as an important ecological community, and some studies suggest they are the most productive (in terms of organic matter produced per hectare per year) of all estuarine habitats (Larkum, 1981). Mangroves are reported to:

- provide organic materials that form the basis of detrital food chains (West, 1985; Robertson and Alongi, 1995)
- stabilise sediments (West, 1985; Robertson and Alongi, 1995)
- recycle nutrients (Robertson and Alongi, 1995)
- provide feeding and roosting habitat for numerous species of birds, particularly pied cormorants and mangrove honeyeater, a vulnerable species (Chapman and Underwood, 1995)
- provide habitat for a variety of fish and invertebrates (e.g. SPCC, 1981a,b; Pollard and Hannan, 1994; Robertson and Alongi, 1995)
- act as a filter system between the land and aquatic environment (NSW Fisheries, 1999a).

Distribution

Mangroves are not as widespread as seagrass along the NSW coast as they are more reliant upon tidal conditions. Mangrove habitat occurs in all of the trawled estuaries as their entrances are permanently open, allowing strong tidal influence. In particular, large areas of mangroves are found in the Hunter, Hawkesbury and Clarence Rivers (Table F1) and combined with that found in Port Stephens and the Macleay and Richmond Rivers, these represent 65% of the total area of mangroves recorded in NSW. For details regarding the location of mangroves within trawled estuaries refer to West *et al.* (1985).

Mangroves are common along the northern and central NSW coast. When assessing the regional significance of mangroves in trawled estuaries along the coast, there are large mangrove stands in other estuaries near those of the Clarence and Hunter Rivers. In the Sydney region, the mangroves located in the Hawkesbury River are accompanied by large stands in Botany Bay/Georges River and smaller stands in Port Jackson, Port Hacking and Brisbane Waters.

An increase in mangrove habitat over a large extent of Eastern Australia, from central Queensland to South Australia has been reported (Saintilan and Williams, 1999). An example comes from the Hunter River where mangroves have increased from 1310 ha in 1954 to 1711 ha in 1994 (Williams *et al.,* 2000). Consequently, the current distribution of mangrove habitat within trawled estuaries will most certainly differ from that mapped by West *et al.* (1985).

iii) Saltmarsh

Brief description

Saltmarsh refers to a collection of herbaceous plants and low shrubs that can tolerate highly saline soils and at least occasional inundation by seawater (King, 1981b; Morrisey, 1995). These plants are generally found on the high shore between the average high water marks of spring and neap tides. They therefore often remain exposed for long periods (Morrisey, 1995). Saltmarshes develop on shorelines in estuaries with soft sediments and along sheltered parts of the coast, and are more common in barrier and coastal lagoons than in other estuaries. Saltmarsh areas are relatively flat, with shallow pools separated by vegetated mounds typically consisting of grasses (Poaceae), saltbushes (Chenopodiaceae), rushes (Juncaceae) and sedges (Cyperaceae), and with most assemblages containing only a few species (Morrisey, 1995).

Summary of importance

There has been little work done in Australia on the value of saltmarsh and extrapolations from studies in the Northern Hemisphere are not possible because those relate to fundamentally different marshes. Not only is the species composition different, but the plants are much taller than their analogues in NSW (Adam *et al.,* 1988). In overall terms however, saltmarshes are thought to play a similar role to mangroves in that they are thought to:

- be used by a large variety of migratory and resident birds for feeding, roosting and/or breeding, including egrets, sandpipers, curlews, whimbrels, plovers, dotterels and banded stilts (Morrisey, 1995: Zann, 1995; Zann, 1996)
- provide habitat for some terrestrial species of birds, such as chats and parrots, and several birds of prey, such as brahminy kites, whistling kites and harriers
- filter water draining from the land before it enters estuaries (Adam *et al.,* 1985)
- be highly productive (Zann, 1996), although specific information on details such as energy pathways and the export of detritus to adjacent habitats is very limited, and invariably from overseas studies of different types of saltmarsh to those in NSW (Adam *et al.,* 1985; Morrisey, 1995)
- provide important habitat for juvenile fish and invertebrates, although judging by numerous Australian studies, perhaps not to the same extent as do seagrass or mangroves (Morton *et al.,* 1987; Williams *et al.,* 1995; Connolly *et al.,* 1997; Thomas and Connolly, 2001).

Distribution

Saltmarsh is widely distributed and is reported from 92 estuaries in NSW (West *et al.,* 1985). Saltmarsh habitat is found in all of the trawled estuaries. In 1985, the saltmarsh found in the Hunter River represented 10% of the total cover for the State, while that in the Clarence represented 3%, the Hawkesbury 2% and Port Jackson 0.1%. For details regarding the location of saltmarsh within trawled estuaries refer to West *et al.* (1985).

Stands of saltmarsh habitat are located near all of the trawled estuaries. Some of these stands are larger than others, for example large stands of saltmarsh are found near the Hunter River at Port Stephens, while in the estuaries surrounding the Clarence River only small areas of saltmarsh are found.

A decline of saltmarsh habitat of 1428 ha (67%) between 1954-1994 has been observed in the Hunter River (Williams *et al.,* 2000). Drainage works, reclamation and infiltration by mangrove are assumed to be the main reason for these losses. Considering the increase in mangrove habitat along the east Australian coast (Saintilan and Williams, 1999) and development activity along the NSW coast, corresponding declines in the saltmarsh habitats of other trawled estuaries may have occurred.

iv) Unvegetated soft substrata

Brief description

Unvegetated soft substrata, including intertidal and subtidal mudflats and sandflats, are the most common habitat in estuaries and yet are largely ignored because of their lack of physical structure. Unvegetated habitats have not been studied much in Australia (Inglis, 1995), possibly because of their lack of habitat complexity and readily identifiable features. Intertidal shores can comprise of both sandflats and mudflats, the major difference between these being the relative proportions of sand, silt, clay and organic matter in the sediment and deoxygenation within the sediments of mudflats. Sandflats are generally found near the mouths of estuaries, where there are stronger waves and currents, and a ready supply of marine sands. Mudflats are located further upstream in more sheltered environments, where silt and clay that has been carried downstream from the upper catchment settles out in response to a reduction in flow and mixing with more saline water (NSW DPWS, 1992).

Summary of importance

Soft substrata are inhabited by a large variety (often hundreds of species) of invertebrates including polychaete worms, crustaceans and molluscs; these being collectively termed benthos (Rainer, 1982; Jones *et al.,* 1986; Morrisey *et al.,* 1992a,b; CSIRO, 1994). Depth, salinity, sediment size characteristics, and the degree of sediment movement are among the physical factors that determine benthic community composition (Jones and Candy, 1981; CSIRO, 1994; Zann, 1996). Benthic organisms can be broadly classified by their method of feeding and include suspension-feeders, deposit-feeders, browsers, predators and scavengers (Morrissey, 1995). Bare substrata are also utilised by a variety of larger invertebrates, such as crabs and prawns, as well as by invertebrates such as fish and birds. Shallow intertidal sediments are particularly important for wading birds. Despite being broadly referred to as unvegetated sediments, soft substrata can also include microscopic and drifting macroalgae, which provide important food and refuge for fauna.

Distribution

The distribution of unvegetated habitats has not been directly included in past inventories of NSW estuaries; rather, it has been implied during the mapping of estuarine vegetation (e.g. Bell and Edwards, 1980; West *et al.,* 1985; Bucher and Saenger, 1991). This habitat is prevalent in all estuaries, including those trawled, and would probably consist of a mosaic of sandy to muddy areas in each case, as mapped in Botany Bay during a previous study (SPCC, 1979).

The distribution of major intertidal sandy and muddy shores can be inferred from a mapping program by the EPA (formerly the SPCC). This mapping showed that sandflats are common in the lower parts of trawled estuaries and mudflats are found in the upper reaches of these estuaries (Thompson and McEnally, 1985; McEnally *et al.*, 1989, 1992; Allen *et al.*, 1992 a,b; Carter, 1994, 1995).

v) Rocky shores and reefs

Brief description

The other key habitat within estuaries is that of intertidal rocky shores and subtidal rocky reefs, although it is far less common than the other habitats. Rocky shores include both natural reef and human-made habitats such as breakwaters and seawalls (SPCC, 1981a; Pollard, 1989). Other human-made structures that provide a source of hard substratum and are abundant within estuaries include oyster leases, piers, marinas, bridge footings, channel markers and jetties.

Summary of importance

Subtidal and intertidal areas of hard substrata provide structurally complex habitat and suitable sites for settlement and recruitment by marine and estuarine species, particularly algae. Diverse assemblages of brown, red and green macroalgae, along with sponges, ascidians and other sessile invertebrates further enhance habitat complexity of rocky shores and reefs and provide many opportunities for specialisation (e.g. Jones and Andrew, 1990; Lincoln Smith and Jones, 1995). The large macroalgae (such as kelp) that partially cover most rocky reefs enhance overall species diversity by providing patches of shaded habitat favoured by distinct assemblages of organisms (Kennelly, 1995b). Artificial hard substratum, such as pontoons and piers, also provide alternate types of substratum and are reported to support different assemblages of epibiota compared to adjacent rocky reefs (Glasby, 1999; Connell and Glasby, 1999). Rocky reefs and other such habitats:

- provide extensive refuge and feeding opportunities for a variety of fish and mobile invertebrates, plus attachment sites for sessile invertebrates such as soft corals, bryozoans, ascidians and sponges (e.g. SPCC, 1981b; Jones and Andrew, 1990; Lincoln Smith *et al.,* 1992; Butler, 1995; Lincoln Smith and Jones, 1995)
- may be utilised on a seasonal basis by juveniles of tropical species of fish that are swept southward by the East Australian Current each summer and autumn (Kailola *et al.,* 1993; Kuiter, 1993). These juveniles rarely survive the winter, and even if they do, would fail to establish breeding populations (Lincoln Smith and Jones, 1995)
- are important to the lifecycle of many of the protected fish species found in NSW, including grey nurse shark, blue devil fish, elegant wrasse, black cod, estuary cod, blue groper, Australian bass and estuary perch. Rocky reefs would also probably have provided habitat for the species of algae thought to be extinct, Bennetts seaweed (*Vanvoorstia bennettiana*).

Distribution

As with soft substrata, the locations of rocky shorelines and reefs within estuaries are generally unknown as these habitats have not been mapped in previous inventories. Natural rocky shores are most common in the drowned river valleys (Morrisey, 1995), including the trawled Port Jackson and Hawkesbury River estuaries. Artificial rocky surfaces, including breakwaters, retaining walls and bridge pylons, are common in all of the trawled estuaries.

b) Marine protected areas within trawled estuaries

Marine protected areas and similar such areas are discussed here as they form part of the ecosystem and habitat section of the draft FMS.

Marine protected areas are coastal, estuarine or oceanic areas that are managed to conserve marine biodiversity. They range from small highly protected areas that focus on species or community protection to large multiple-use areas that include complex linkages of ecosystems and habitats. Marine protected areas may include reefs, seagrass beds, rocky platforms, mangroves, estuarine waters, mudflats, saltmarshes, shipwrecks, archaeological sites and coastal and offshore areas of airspace, seabed and water. Internationally, marine protected areas are considered an important tool for achieving conservation objectives in the marine environment. Marine protected areas in NSW consist of Marine Parks, Aquatic Reserves, Intertidal Protected Areas and marine components of National Parks or Nature Reserves. Coastal parks and reserves sometimes incorporate the beds of adjoining lakes and estuaries, and may include extensions to the high water mark of ocean beaches.

Although not referred to as marine protected areas, wetlands listed as internationally significant under the RAMSAR convention are expected to be preserved, and the importance of migratory bird habitat listed under the JAMBA and CAMBA agreements should be considered when making management decisions. These latter areas are generally referred to as JAMBA (Japan-Australia Agreement for the Protection of Migratory Birds, Birds in Danger of Extinction and their Environment) and/or CAMBA (Agreement between Australia and the People's Republic of China for the Protection of Migratory Birds and their Environment) habitat.

Marine Parks, aquatic reserves and intertidal protected areas

Within the trawled estuaries of NSW only Port Jackson presently contains marine protected areas: an Aquatic Reserve located in North Harbour and an Intertidal Protected Area covering the entire estuary. These existing marine protected areas were chosen opportunistically in the absence of clear definitions and studies. Prawn trawling is not allowed in this conservation area, although some other forms of commercial and recreational fishing are permitted.

Future marine protected areas will be selected on the basis of the National Representative System of Marine Protected Areas (NRSMPA), a strategy that has been endorsed by the States and Territories for the conservation of Australia's marine resources. The Interim Marine and Coastal Regionalisation for Australia report (ANZECC, 1998) provides the general planning framework for developing the NRSMPA. Using that report, a Marine Park and numerous Aquatic Reserves will be established within each of the following areas: the Tweed-Moreton Shelf, Manning Shelf, Hawkesbury Shelf, Batemens Shelf, Twofold Shelf bioregions, and the Lord Howe province. Candidates for marine protected areas in these bioregions are currently being chosen by NSW Fisheries, the NSW NPWS and the Marine Parks Authority based on the criteria for selection of marine protected areas established by ANZECC (1999) (see Table F2).

Table F2. The criteria used by NSW Fisheries to select candidate estuarine marine protected areas.

Criteria	Definition	Measurement
Comprehensiveness	First order geomorphological classification	Estuary type
Representativeness	Second order geomorphological classification	Estuary age
Ecological Importance/Uniqueness	Habitat health; Species diversity	Size, health and number of habitats; Species diversity
International/National Importance	Identified species and associated habitats	JAMBA/CAMBA listing; Threatened species sightings
Productivity	Biomass within each habitat type	Size and number of habitats; Commercial fishing statistics
Vulnerability	Degree of urbanisation	CMA maps
Naturalness	Degree of catchment protection	State Forestry maps

The criteria have been established by ANZECC (1999). The definition and measurements applied to those criteria by NSW Fisheries to select candidate sites for estuarine aquatic reserves in NSW (Frances, 2001) are also given.

At the time of writing this report, sites for estuarine aquatic reserves in the Hawkesbury and Batemans Shelf regions had been identified. The Hawkesbury Shelf region includes all of the trawled estuaries in the State except the Clarence River which occurs in the Tweed-Moreton Shelf region. Of the seven identified candidate estuarine aquatic reserves (NSW Fisheries, 2001b), one (Fullerton Cove at the Hunter River) occurs in a trawled estuary. This area is already part of the Kooragang Nature Reserve. Details regarding how this aquatic reserve will be protected cannot be provided until the reserve has been finalised. To maximise their effectiveness, future marine protected areas should include areas of no harvesting, both commercial and recreational.

Marine components of national parks or nature reserves

National Parks and Nature Reserves are found along the shores of trawled estuaries. Such conservation reserves protect estuarine foreshores, including mangroves and saltmarsh.

Ramsar wetlands

The Convention on Wetlands of International Importance, signed in the Iranian town of Ramsar in 1971, aims to halt the loss of wetlands and to conserve the remaining wetlands. Countries that are parties to the Convention nominate wetlands to be listed as Wetlands of International Importance, and following acceptance they become known as Ramsar Wetlands. Countries are expected to manage their Ramsar sites to preserve their unique ecological characteristics. In Australia these sites are protected under the EPBC Act 1999. Within the four trawled estuaries in NSW, the Kooragang Island Nature Reserve (Hunter River) is a Ramsar Wetland.

JAMBA and CAMBA bird habitat

The JAMBA and CAMBA agreements were established to protect the habitat of migratory birds. There are approximately 90 species of birds covered under these agreements, but only 44 of those are likely to occur within and adjacent to trawled estuaries (see Appendix F3). These birds include species of curlews, sandpipers, godwits, terns, plovers, shearwaters and skuas. The majority of these birds migrate to NSW estuaries during spring and summer and return to the northern hemisphere to breed at other times. The few exceptions include wedge-tailed shearwaters and little terns, which arrive in spring to breed and may remain on our coast all year. Other nomadic species (i.e. occur all year and breed in Australia) include white-breasted sea-eagles, caspian terns, crested terns, painted snipes and white egrets.

The JAMBA and CAMBA treaties require that the occurrence of listed migratory birds in an area be given special consideration when making management decisions. Specific sites do not have to be conserved because of the periodic occurrence of such birds. The trawled estuaries thought to be most significant for JAMBA and CAMBA birds are listed in Table F3. The listed waders are mostly found on the intertidal sandflats and mudflats located in the lower parts of trawled estuaries (refer to Thompson and McEnally, 1985; McEnally *et al.*, 1989, 1992; Allen *et al.*, 1992 a,b; Carter, 1994, 1995 for maps of these areas). When listed birds are found within the confines of the North Harbour Aquatic Reserve, Kooragang Island Nature Reserve and areas where trawling is not permitted, they would receive some protection from trawling activities.

Table F3. Trawled estuaries in NSW which have international significance in that they support more than 1% of the estimated Australian population of a given species protected under JAMBA and CAMBA or the TSC Act 1995.

Location	Important species or population
Hunter River	7000-10,000 migratory waders; > 5% of world pop. of eastern curlews and golden plovers
Clarence River	3000 waders; important for lesser golden plovers, bar-tailed godwits, grey-tailed tattlers, curlew sandpipers, red knots, red-necked stints, Terek sandpipers and sharp-tailed sandpipers
Port Jackson	Grey-tailed tattlers, golden plovers and red-necked stints; little penguin population at North Harbour

(Source: Thompson and McEnally, 1985; McEnally *et al.*, 1989, 1992; Allen *et al.*, 1992 a,b; Carter, 1994, 1995).

c) Effects of the fishery on estuarine habitats

It is difficult to assess the actual impacts the fishery could have on estuarine habitats, as the impacts of the fishery on such habitats have not been directly studied. However, potential impacts can be inferred from relevant studies investigating the impacts of trawling activity on habitats in marine environments, including tropical areas. These studies generally were based on larger and heavier trawl gear, and therefore impacts from trawling in estuarine environments may differ. Consequently there is some uncertainty associated with the assessment of trawling on the biodiversity and habitats of estuaries.

Trawling has been shown to cause severe physical disturbance of the seafloor as a result of direct net contact (e.g. Jones, 1992; Collie *et al.*, 1997; Engel and Kvitek, 1998; Schwinghamer *et al.*, 1998; Watling and Norse, 1998). Such disturbances have been classified by Collie *et al.* (1997) as scraping or ploughing, sediment resuspension, physical destruction of bedforms, and the removal or scattering of non-target benthic species.

While trawling is restricted to certain areas within four estuaries in NSW (for maps of trawlable areas refer to section 7 of Chapter B), there is no information on which parts of these areas are trawled nor how frequently. In the absence of data to the contrary, and in accordance with the precautionary principle, it will be assumed in this assessment that all parts are trawled at some stage. In all trawled estuaries, except the Hawkesbury where trawling can occur at any time of the year, disturbance from trawling is limited to certain seasons and times of the day (refer to Appendix B6). However, without information on the frequency of trawling within the designated seasons, an assessment of the magnitude of trawling impacts is impossible.

Given the assumption that all of the designated areas are trawled, an assessment of the extent of trawling impacts on estuarine habitats is still difficult, owing to the uncertainty of habitat distribution within the trawled estuaries. As stated previously in this chapter, the distribution of vegetated habitats within the trawled estuaries may have changed considerably since the mapping by West *et al.* (1985) in the early 1980s. Also, the exact distribution of unvegetated and rocky habitats in the trawled estuaries is unknown and can only be inferred from the maps produced by West *et al.* (1985). With such uncertainty, it is impossible to accurately determine which habitats are trawled. However, the habitats that are likely to be trawled can be determined by considering the proposed management of trawling activity, the operational constraints on trawling equipment and the distribution of estuarine vegetation mapped by West *et al.* (1985).

The four likely consequences of trawling in estuaries are:

- disturbance of seafloor sediments and any associated benthic infauna
- inputs of nutrients such as sedimentary nitrogen and silica into the water column (Pilskaln *et al.,* 1998)
- damage to and/or removal of any epibenthos and associated macroalgae
- damage to seagrasses.

These are discussed in the following sections.

i) Unvegetated soft substrata

Disturbance to seafloor sediment from trawling is likely to vary according to the nature of the sediment and the seafloor topography. A trawl net will 'dig into' soft sand or mud more readily than (say) a firm gravel bottom, and will tend to scrape the top off any humps on the seafloor. Sediment disturbance is likely to include its resuspension. Pilskaln *et al*. (1998) found evidence of trawler-induced sediment resuspension 25 metres off the bottom within a heavily trawled area of the Gulf of Maine. It is possible that, under some circumstances of heavy trawling, resultant resuspended sediment loads may significantly increase turbidity and thereby effect seagrasses and macroalgae.

The degree of disturbance is also likely to depend on the frequency of trawling. For example, Engel and Kvitek (1998), in a comparison of different levels of trawling effort off central California, found that the heavily trawled area had more trawl tracks, exposed sediment and shell fragments, but fewer rocks and mounds, and less flocculent material than did the lightly trawled area.

The depth and persistence of sediment disturbance are likely to depend on the above factors, in addition to the type of trawling gear used, speed of towing and the strength of currents or tides in the area fished (Jennings and Kaiser, 1998). No data on these aspects of sediment disturbance are available from NSW estuaries. However, Schwinghamer *et al*. (1998), in a study of the effects of otter trawling on sandy sediment off Newfoundland, estimated that the trawling altered sediment structures to a depth of nearly five cm. They also observed that disturbance of the seafloor remained clearly visible after ten weeks, and in some cases was faintly visible after a year.

Concerns regarding the effects of trawling on benthic communities have a long history (Cappo *et al*., 1998), and most of the relevant overseas studies have detected significant effects on both infauna and epifauna (e.g. Hall *et al*., 1993; Kaiser and Spencer, 1996; Collie *et al*., 1997, Tuck *et al*., 1998; Kaiser and de Groot, 2000).

Whilst some types of benthic infauna would be able to burrow below such disturbances, many species would be displaced and, if not killed outright, rendered vulnerable to predators and scavengers. In general, however, the physical disturbance from trawling will be short-lived in benthic infauna communities that are adapted to frequent natural disturbances (Jennings and Kaiser, 1998). A study done in a Scottish loch upon a mud substrate showed that trawling altered that state of benthic communities by decreasing evenness and diversity (Tuck *et al*., 1998).

Trawling is widely recognised as causing the damage/removal of epibenthos (Gibbs *et al*., 1980; Hutchings, 1990; Laurenson *et al*., 1993; Sainsbury *et al*., 1993; Moran *et al*., 1995; Cappo *et al*., 1998; Engel and Kvitek, 1998). The effects of such removal are likely to include:

- loss of biodiversity, particularly with respect to larger longer-lived species of epibenthos
- loss of species dependent on epibenthos for food or shelter
- a range of species shifts.

Trawling is particularly damaging to larger epibenthos, with studies in tropical areas generally showing high mortality rates of benthos larger than 20 cm in height, especially after repeated trawls over the same bottom (Cappo *et al*., 1998). Using underwater video, Moran *et al*. (1995) estimated that a demersal trawl destroys about 16% of large epibenthos in its path in a single pass. They also expressed concern that some studies under-estimated the effects of a trawl by not considering the damage caused by bridles and sweeps. Even higher estimates of destruction have been made by Sainsbury *et al*. (1993), in a study off the North West Shelf. They estimated that the probability of epibenthos in the path of a trawl being destroyed was between 40 and 90%, depending on the best/worst case scenarios for mortality after disturbance. Furthermore, they found that the quantity of epibenthic fauna caught in trawls dropped substantially during the course of the local fishery's development

Unfortunately, little is known about the ability of epibenthos to recover from the effects of trawling (Cappo *et al*., 1998). Currie and Parry (1995) suggest that studies of benthic recovery should last at least as long as the longevity of component species, although frequently this too is unknown (Cappo *et al*., 1998). Recovery for each benthic species would depend, in part, on available reproductive modes (Hutchings, 1990). Whilst many colonial species (e.g. sponges and coral relatives) can reproduce asexually from fragments, most species (including all molluscs and crustaceans and most echinoderms) only reproduce sexually, and would therefore not be able to regenerate if broken up by the passage of a trawl net. Recovery is also likely to depend on factors such as the size of the trawling ground, the distance from nearby untrawled areas (which might act as a source of larval recruits), the type and frequency of the trawling undertaken and the time of year at which the fishing occurs (Hutchings, 1990). Whatever the case, serious long-term ecosystem damage is very likely where the trawling return interval for a particular patch of seafloor is shorter than the associated recovery time (Watling and Norse, 1998). Such a situation may occur within heavily trawled estuaries in NSW, although no data to confirm this are available.

Recovery of so-called "megabenthos communities" on the North West Shelf has been reported to occur within ten years of a cessation of trawling, though to a level that bears an unknown relationship to original (untrawled) conditions (Sainsbury *et al*., 1993, Cappo *et al*., 1998). Watling and Norse (1998) suggest that recovery after trawling disturbance is often slow because recruitment is patchy and growth to maturity may take years or even decades, particularly in the case of structure-forming species. It is likely that recovery of benthic (and fish) communities is slowest in environments infrequently disturbed by natural phenomena (Kaiser, 1998). Within NSW estuaries, such environments would include deep sheltered marine-dominated areas, rather than shallow wave-exposed areas or places subject to large salinity variations. In the trawled estuaries, such areas may be found in Port Jackson and Broken Bay.

As stated previously, the distribution of unvegetated habitats within trawled estuaries in NSW can be inferred from maps of estuarine vegetation in West *et al.* (1985). When comparing this with the area allowed to be trawled in estuaries (refer to maps in Chapter B), it is evident that unvegetated sediments are trawled. The type of gear used by the fishery is suited to soft unvegetated sediments, and perhaps has even been specifically developed to work on such substrate. However, the impacts of this gear have not been studied. The extent and magnitude of potential impacts by the fishery on unvegetated substrate, and all estuarine habitats for that matter, would be linked to the distribution and frequency of effort exerted by the fishery. This information is also unknown.

From the above description of studies done in other fisheries, it can be inferred that trawling in NSW estuaries could have the following impacts upon unvegetated habitats:

- resuspension and destabilisation of sediments, with subsequent increases in turbidity and release of contaminants
- exposure and destruction of benthic infauna
- damage and removal of epibenthos, with a subsequent reduction in habitat complexity
- changes in benthic community structure, favouring those species adapted to frequent disturbance.

Trawling has existed for over 60 years within the four estuaries used by the fishery, and it is probable that any relevant major changes in habitat distribution and condition would have taken place early on and that any subsequent changes would have been less visible or dramatic. Furthermore, any further changes may no longer be readily identifiable due to the variety and extent of other factors affecting estuarine habitats, e.g. sand and gravel extraction, dredging, urbanisation and pollution (see section 10). A study investigating the impact of trawling on the benthic communities of the Clarence River is currently being undertaken.

ii) Seagrasses

Because it has a more severe impact on the seafloor than hauling, trawling is likely to have greater effects on seagrass than those found by Otway and Macbeth (1999) in relation to hauling. In particular, seagrass meadows are vulnerable to physical disturbance as trawls can reduce plant biomass and abundance by shearing off fronds, exposing rhizomes, digging shoots from the susbtratum and increasing local turbidity through sediment resuspension (Fonesca *et al.*, 1984). Guillen *et al.* (1994) reported that trawling damaged 45% of a *Posidonia* meadow in SE Spain. Trawling activity could also remove epiphytes, periphyton or epifauna from seagrass blades. Many indirect effects of trawling on seagrass habitat are also likely because of the role seagrass plays in providing nutrients for estuarine food webs, stabilising sediments and restricting water movement.

In times past, the Estuary Prawn Trawl Fishery may have damaged seagrass beds, possibly even influencing the distribution of seagrasses within trawled estuaries. However, there are no data available on the extent or magnitude of such historical impacts. In the three trawled estuaries where seagrasses occur (there is no seagrass in the Hunter River), fishers usually avoid operating over areas where seagrasses grow. When comparing the areas that can be trawled (see maps in section 7 of Chapter B) with the maps produced by West *et al.* (1985), it is apparent that some of the seagrass beds within these estuaries have been protected from direct trawling impacts by their occurrence in areas closed to trawling. Although the potential for the fishery to damage seagrass beds will always exist, the risk of this happening will be removed with the implementation of a total ban of trawling over seagrass habitat, as proposed in the draft FMS.

iii) Rocky shores and reefs

Fishers in the Estuary Prawn Trawl Fishery generally avoid operating over rocky habitats, primarily to avoid damaging their gear. The extent of this habitat in trawled estuaries is unknown. If trawling did occur over rocky habitats (such as over flat rocky areas), possible impacts would include damage or removal of epibenthos and flora, reduced habitat complexity, the exposure of previously discrete species, and a range of flow-on effects on dependant species.

iv) Mangroves and saltmarsh

The effect of the Estuary Prawn Trawl Fishery on the mangrove and saltmarsh habitats occurring in all of the trawled estuaries is unknown. As prawn trawling is a boat-based activity, any resultant impacts on mangroves or saltmarshes are most likely to occur when adjacent areas are trawled. By comparing the area that can be trawled (refer to maps in section 7 of Chapter B) with the distribution of mangrove and saltmarsh habitat as mapped by West *et al.* (1985), it is apparent that trawling does occur adjacent to these habitats, particularly in the Clarence and Hunter Rivers. However, provided prawn trawler operators act responsibly when adjacent to these habitats, by leaving a buffer area and by limiting vessel wake so to avoid shoreline erosion, there would be few potential impacts from this activity. Perhaps the trawlers could disturb the fauna of these habitats, particularly birds. As the otter trawling method requires a minimum water depth of 1-2 m, prawn trawl fishers are likely to leave a buffer area when working adjacent to these habitats and the proposed implementation of a code of conduct should ensure this. However, the width of these buffers would vary around the trawled estuaries, and the extent to which these buffers would protect against impacts is not known.

v) Marine protected areas

Of all the marine protected areas, the intertidal sandflats and mudflats where JAMBA and CAMBA listed species occur would seem most likely to be impacted by trawling. On comparing the maps of migratory bird habitat produced by the EPA (Thompson and McEnally, 1985; McEnally *et al.*, 1989, 1992; Allen *et al.*, 1992 a,b; Carter, 1994, 1995) with the areas that can be trawled (see maps in section 7 of Chapter B), it is evident that some of the areas closed to trawling also help protect migratory bird areas, especially in the Hawkesbury and Clarence Rivers. However, trawling activity adjacent to these areas could still occur in all of the estuaries trawled by the fishery. As migratory birds are mostly found in NSW estuaries during spring and summer (when trawling occurs in all estuaries of this fishery), there is potential for the fishery to have an impact upon migratory birds. As stated previously, trawling gear easily disturbs soft seafloor sediments. Although, the extent of trawling adjacent to these habitats is unknown, it would presumably be minimised as these areas are generally too shallow for trawling activity. Provided trawler operators take care to limit vessel wake around these habitats, the fishery should not have a direct impact on these areas. However, trawling operations fishery could indirectly disturb migratory birds. The proposed code of conduct should minimise trawling impacts on migratory birds and their habitat.

Trawling should not impact upon the Aquatic Reserves located within the Hunter River and Port Jackson as it is not permitted within these areas. While trawling could occur adjacent to land-based National Parks and Nature Reserves, the possible impacts on these areas would be minimal and similar to those described for mangroves and saltmarshes above.

d) Proposed habitat management in the draft FMS

The outcomes of management measures in the draft FMS relating to habitat issues are summarised in Table F4. There is a commitment in the draft FMS to prevent the expansion of trawling activities into new areas and to implement further closures if areas of environmental sensitivity are identified within the currently trawlable areas (management responses 1.2a & b). Also, all trawling over seagrass will be banned (management response 1.1f) and a code of conduct for operating adjacent to river banks and migratory bird habitat and ramsar wetlands will be established (management response 1.2e). In the absence of data concerning the impacts of trawling on estuarine habitats, such management measures are considered precautionary. They should protect known seagrass areas, limit any direct impacts to areas where trawling already occurs and minimise disturbance to estuarine shoreline habitat.

The draft FMS seeks to reduce uncertainty in the management of habitat issues through a commitment to undertake research on the impact of trawling on both the biodiversity within the trawled area (management response 1.3e) and the general environment (management response 1.3b) and the identification of the distribution of habitats and untrawled areas within the trawled estuaries (management response 1.2a). This research could be improved by investigating how trawling affects the biodiversity of the whole estuarine ecosystem, and mapping the frequency of trawling within the trawlable area. Through knowledge of which habitats are trawled and the associated impacts, the draft FMS proposes to reduce trawling impacts by the development of more environmentally sensitive fishing gear (management response 2.1a) and closures (management response 1.1f). The research results should also be used to establish a performance indicator for biodiversity as soon as possible. Such measures should be adequate to reduce the impacts of trawling in estuaries, provided they are based on results of the proposed research.

The draft management responses focus on removing the impact of the fishery on seagrass and understanding and reducing its impact on unvegetated sediments. This approach can be justified by the likelihood, as previously discussed, that the fishery would not directly impact upon mangrove, saltmarsh or rocky habitats. The proposed scientific observer program, however, should be used to determine if further action is required. For example, it may be observed that fishery operations adjacent to mangrove and saltmarsh habitats are widespread and possibly causing more damage and/or disturbance than perceived in this assessment. Subsequent actions could include reviewing the code of conduct for operating near these habitats and/or studying these impacts. On this basis, the draft FMS should propose an annual review of the code of conduct.

The observer program should also investigate whether trawling is impacting upon migratory bird habitat. Considering that trawling by the fishery occurs at times when migratory birds are generally found in NSW estuaries, the draft FMS (under the JAMBA and CAMBA treaties) has considered migratory bird habitats via a code of conduct. While this measure should reduce any impacts by the fishery on migratory birds, the observer program should help establish if further action, such as closures or a review of the code of conduct is required. The code of conduct is a good precautionary measure, while the potential impact of the fishery on these species are determined, and should be reviewed annually. For the development of this code of conduct, the mapping of habitats within trawled estuaries should specifically identify the important areas of migratory bird habitat and this information should be checked with the NPWS. To minimise disturbance on migratory waders it will also be important to establish appropriate buffer zones (Paton *et al.*, 2000).

The proposed management measures also provide for the fishery to have more input into the management of habitat issues that are not directly related to fishing activities (objective 2.5). There is also a commitment for the fishery to be consistent with other estuarine habitat management initiatives (management response 6.4a). Such measures should help achieve more integrated and effective management of estuarine habitats.

Table F4. Proposed management measures in the Estuary Prawn Trawl draft FMS directly relating to estuarine habitat and biodiversity issues.

Management response	Summary of response	Predicted outcome(s) of the response
1.1a	restrictions on gear dimensions, construction materials and modes of operation	Degree of habitat disturbance controlled and/or minimised
1.1b	modification of fishing practices to reduce impacts of trawling upon non-retained species	Biodiversity disturbance reduced
1.1f	prohibition of trawling over seagrasses and key habitats	Seagrass habitat protection
1.1g	prohibition on the use of firearms, explosive or electrical devices in the fishery	Habitat protection
1.2a	areas of habitat types, environmental sensitivity and non-trawled areas within trawlable area defined	Habitat protection; uncertainty reduced; improved management
1.2b	no increase in area that is trawled within the boundaries of the fishery	Habitat protection; disturbance minimised
1.2c	wilful damage of marine vegetation prohibited	Habitat protection
1.2d	removal of woody debris from river bed prohibited	Habitat protection
1.2e	code of conduct minimising impacts to river banks, closed areas and JAMBA and CAMBA habitat	Disturbance minimised
1.3a	incidental catch ratios in each estuary	Biodiversity impacts reduced
1.3b	study of trawling impacts on environment	Uncertainty reduced; improved management; trawling impacts reduced
1.3c	collaborate to better understand ecosystem function	Uncertainty reduced
1.3d	performance indicator for trawling impacts on biodiversity	Improved management
1.3e	study of impact of trawling upon biodiversity within the trawled area	Uncertainty reduced; improved management; trawling impacts reduced
1.3f	fishery comment on the selection and management of Marine Protected Areas in estuarine waters	Integrated habitat management
2.1a	maintain size and dimensions of gear in fishery, subject to any changes made under any other response in this strategy	More environmentally sensitive gear; trawling impacts reduced
2.3a	separate management rules for each trawled estuary	Effective habitat management
2.5a	NSW Fisheries to contribute to development applications	Integrated habitat management
2.5b	external impacts on estuarine habitats brought to management attention	Effective habitat management
2.5c&d	involve the estuary prawn trawl MAC in the development of habitat management policies and habitat rehabilitation works	Effective habitat management
6.4a	manage the fishery consistently with other programs managing marine resources and habitats	Effective habitat management
8.1a	observer program to collect information on interactions with threatened species and discard composition	Uncertainty reduced; improved management

i) Level of confidence in achieving predicted outcomes

There are no reliable data about the effects of the fishery on estuarine habitats and fauna. Most of the impacts are inferred, generally on the basis of studies conducted in oceanic environments where heavier trawl gear is used. Considering the potential impacts inferred from this information, the draft FMS has taken a precautionary approach to conserve estuarine biological diversity. The confidence in achieving this outcome varies with different habitats and is ultimately linked to the timely inception of and compliance with the proposed management measures.

Through prohibiting trawling over seagrass, there is a high confidence that the draft FMS will effectively conserve the biodiversity of seagrass habitats, at least in the absence of any detrimental external influences such as catchment-related pollution. The management responses should also effectively conserve the biodiversity of mangrove, saltmarsh, rocky or migratory bird habitats, provided external impacts are minimal and the observer program examines trawling impacts on these habitats. There is an acceptance within the draft FMS that the fishery has probably impacted upon the biodiversity of unvegetated sediments over the 60 years of its operation in all of the four trawled estuaries. Consequently, the species found within the trawled areas are probably adapted to frequent disturbance from trawling activity. However, by limiting trawling to only four estuaries along the NSW coast, and by prohibiting the expansion of trawling activities into new parts of these estuaries, the draft FMS should effectively conserve the current biodiversity of unvegetated sediments.

With respect to NSW estuaries, there is no information on the recovery of unvegetated sediment habitat, especially that which has been regularly disturbed over a long period of time. Also, whether or not trawling activity prevents the rehabilitation of estuarine habitats is unknown. If the impacts of trawling on the unvegetated sediments of the Clarence River, currently being studied, are detectable and conclusive, alternative fishing gear that minimises biodiversity impacts may need to be developed, and further closures may need to be established. It is not known whether such closures would guarantee the rehabilitation of impacted habitat, or increase associated biodiversity. However, the cessation of trawling in Botany Bay in May 2002 (as the bay has been gazetted as a recreational fishing area) will provide an opportunity to study the potential recovery of previously trawled estuarine habitats, assuming they were affected.

e) Alternate mitigation measures

This section discusses alternative habitat management measures to those proposed in the draft FMS. As there are no data concerning the effects of the fishery on the biodiversity and habitats of estuaries, it is difficult to accurately determine how the measures proposed in the draft FMS, or any alternate management measures, would reduce these effects. It is, however, possible to consider the relative likelihoods of success (in terms of reducing impacts) for both the proposed and the alternative mitigation measures.

i) Timing of fishery activities to minimise disturbance

When aiming to minimise the impacts of the fishery on habitats, and hence fauna, the draft FMS includes responses such as temporary and permanent closures and gear modifications. Closures are particularly effective because they recognise the patchy nature (both in space and time) of fish communities, habitats and resource use (whether by commercial fishers, recreational anglers or other waterway users). With respect to the timing of fishery activities, the key responses are those that relate to minimising the impact on species during particular periods of their lifecycle, minimising bycatch at times of high abundance, and sharing of resources and estuarine waterways. Trawling within all trawled estuaries except the Hawkesbury River is subject to seasonal, weekly and daily time restrictions. In the case of the Hawkesbury only parts of the estuary are closed to trawling during the evening and on weekends. Seasonal closures were implemented to protect the small prawns generally found in estuaries during winter, prior to their moving to sea over summer and autumn (Racek, 1959; Ruello, 1973a; Glaister, 1978b). As prawns of marketable size were found year round in the Hawkesbury River (McDonnall and Thorogood, 1988), the Hawkesbury trawl fishery is allowed to operate all year.

A possible alternative to the current and proposed closures would be to have one set of rules applicable across all estuaries. However, this approach would inevitably lead to greater conflict, inefficiencies due to lost fishing opportunities and/or a higher risk of local resource depletion or habitat damage. Having only one set of rules would not allow the flexibility to work efficiently within the different sustainability constraints provided by each estuary. Another alternative, to remove all closures in the fishery, would create similar problems and does not consider the life cycle behaviour of prawn stocks. Given that a wide variety of issues effect each of the trawled estuaries, and do so in different ways, the use of a single set of rules or the removal of all rules are clearly not appropriate for the Estuary Prawn Trawl Fishery.

A more appropriate alternative, however, would be the implementation of a seasonal closure in the Hawkesbury River. The study by McDonnall and Thorogood (1988) has not been peer reviewed and was intended for internal use only. Due to an inadequate graph, data from this study are difficult to interpret and does not seem to support the claim that marketable sizes of prawns are caught in the Hawkesbury River during winter. During this study (1986-1987), catches of prawns in the Hawkesbury were greater in summer, however, the figure purporting to show this is upwardly biased due to their being more commercial fishing during this season, perhaps an indication of the available prawn stocks. Information provided in Appendix B5 suggests that the Estuary Prawn Trawl Fishery in the Hawkesbury River does land some school prawns of marketable quality over winter, although in lower quantities than in summer. Eastern king prawns over the 1997/98 to 1998/98 period were not caught by the fishery over winter (see Appendix B5). Furthermore, by being allowed to operate over winter, the Hawkesbury River fishery continues to disturb habitat and take bycatch throughout the whole year. McDonnall and Thorogood (1988) found two peaks in the abundance of commercially and recreationally important finfish in the Hawkesbury, one of which was over winter. While most of these catches were taken in areas closed to trawling and perhaps illustrate the effectiveness of these closures, the presence of high quantities over winter, suggests that there is a greater potential for these species to be captured as bycatch at this time. On the basis of the sustainability of prawn stocks, bycatch reduction and a reduction in the frequency of trawling-induced habitat destruction and disturbance, the implementation of a seasonal closure in the Hawkesbury River should be seriously considered in the FMS.

ii) Location of fishing activities to minimise impacts

The impacts of the Estuary Prawn Trawl Fishery are currently limited to five estuaries in NSW. The declaration of Botany Bay as a recreational fishing area will limit these impacts to four estuaries after May 2002 (an assessment of this fishery will be undertaken as part of the Recreational Fishing Area process). These four estuaries are spaced along the northern half of the NSW coast, but are most concentrated within the Sydney-Newcastle region. Any regional effects from trawling activity are therefore most likely to occur in this area. Trawling within these four estuaries will only be permitted in designated areas and not over seagrass or in Aquatic Reserves. It is also proposed to prohibit trawling from any other defined areas of environmental sensitivity that may become apparent within the trawlable areas. This proposal has an associated trigger point that should ensure the protection of environmentally sensitive habitat within trawlable areas (see the second trigger point in Table C3). This trigger could be improved by determining the proportion of each habitat type protected from direct trawling activities at all times.

The reasons for existing locational closures and Aquatic Reserves are not clear, however, protection of habitats from the direct impacts of trawling is a consequence of such closures. The protection of such areas also accommodates those species which are dependant upon these areas. These species include those which undertake seasonal migrations between freshwater and estuarine or brackish environments (e.g. Australian bass).

The alternative of having no locational closures within trawled estuaries is not feasible, given that trawling is perceived to be an active and destructive fishing method. Trawling by the fishery may have already impacted estuarine habitats, and the proposed measures appear adequate to limit these impacts to areas already potentially affected. As stated previously, the alternative of providing buffer zones with respect to mangrove, saltmarsh and migratory bird habitat should be incorporated within the proposed enforceable code of conduct. In the case of impacts being found on unvegetated habitats, another alternative is to implement closures. This is already covered in the management measures, however, as previously discussed, the result of such closures cannot be predicted.

iii) Closures in key habitat areas

As discussed above, there are numerous time and locational restrictions on trawling activities proposed for key estuarine habitat areas. These pertain specifically to protecting Aquatic Reserves, Nature Reserves and key habitat areas, restricting the area that can be trawled within an estuary, prohibiting trawling over seagrass and implementing temporary closures during times of high juvenile fish abundance. The proposed restrictions are also backed by performance indicators that will monitor the declaration of newly protected areas and interactions with threatened species. The closures would probably protect a proportion of each key estuarine habitat type, although the actual figure for each trawled estuary can not be given. As some of the threatened species that could be affected by the fishery are birds (including those of international significance) that occupy intertidal habitats, it will be important for future closures to consider those areas as key habitats. These closures, whether gear, time or location specific, need to encompass as many habitats as possible, beyond those historically reserved because they have large areas of aquatic vegetation. Closures and/or marine protected areas that include areas of no harvesting, whether commercial or recreational, are considered to be the most effective large-scale management tool with which to ensure that the fishery has as little impact on biodiversity and habitats as possible.

Given the concern over *Caulerpa taxifolia* (see section 4 of this chapter), and the ease with which it can spread, appropriate closures should be implemented if it were to establish within the trawled estuaries. It is the opinion of this assessment that just marking infested areas and closing them to only some forms of fishing is inadequate. This approach does not make sufficient provision for the control of removal and dispersal caused by other user groups of estuaries. Marking the areas of highest density is appropriate for general awareness, but should not be used as an isolated measure. Other measures including total closures and operational procedures should also be implemented.

2. Threatened and Protected Species

a) Threatened species that may be affected by the Estuary Prawn Trawl Fishery

The concept and legal application of threatened species legislation is still only a relatively recent phenomenon. The NSW NPWS introduced the concept in 1991 through the *Endangered Fauna (Interim Protection) Act*, which became the *Threatened Species Conservation (TSC) Act 199*5. In 1997, NSW Fisheries included threatened species amendments to the *Fisheries Management (FM) Act 1994*. Largely because this legislation is a recent concept, many species that are considered threatened do not yet have recovery plans, even though such plans are a requirement of all threatened species legislation. These plans would describe threatening processes along with management measures to mitigate these processes.

For this assessment, 'threatened species' refers to any species, populations or ecological communities and their habitats as defined and listed under Schedules 4 or 5 of the FM Act, Schedules 1 or 2 of the TSC Act, or Subdivisions C or D of the *Environment Protection and Biodiversity Conservation (EPBC) Act 1999*. This assessment also includes any species of fish listed as protected under Sections 19 (totally protected - not to be taken) or 20 (not to be taken by commercial fishers) of the FM Act. Species are listed as protected as there is concern for their vulnerability and rarity but they are not necessarily in decline or directly threatened. If this were so, the species would be considered threatened.

Descriptions of the habitats and distributions of the species considered in the following general assessment under the FM Act, the TSC Act and the EPBC Act, are given in Appendix F4. Tables F5 and F6 provide summaries of this information, highlighting the habitat types where the species are most likely to be caught or affected, the main age groups liable to be affected (Table F5 only) and the most likely effects to the species by the fishery (Table F6 only).

Based on the various legislatures noted above, and on an analysis of the distribution and ecology of threatened and protected species, the Estuary Prawn Trawl Fishery has the potential to impact 39 species that are considered either threatened or protected and one endangered population. Of these species, very few are truly estuarine and many only inhabit estuaries for a limited period either annually or throughout their life. The species listed have been included because some of their preferred habitat occurs within estuaries and so they could be affected in some manner by the fishery. Potential impacts could include direct impacts such as capture or habitat disturbance and/or damage, and indirect impacts such as removal by the fishery of a species' preferred food source.

Table F5. List of threatened and protected fish species protected under the *Fisheries Management Act 1994* and *Environment Protection and Biodiversity Conservation Act 1999* that could be directly or indirectly affected by the Estuary Prawn Trawl Fishery.

Species/group	Types of habitat where most likely to be caught or affected	Main age groups liable to be affected	Protective legislation
Engandered Species			
green sawfish	Lower reaches of estuaries, particularly on far north coast	All	FM
grey nurse shark	Lower reaches of large estuaries and bays subject to strong marine influence	All	FM EPBC -critically endangered
Vulnerable Species			
black cod	Rocky reef, particularly where caves and/or large drop-offs are present, especially lower estuarine areas	All, especially juveniles	FM
great white shark	Lower reaches of large estuaries and bays subject to strong marine influence	All	FM and EPBC
Protected Species (Section 19)			
Australian grayling	Brackish to freshwater areas within south coast estuaries	Juveniles	FM EPBC -vulnerable
elegant wrasse	Algal beds and reefs in lower estuarine reaches	All	FM
estuary cod	As above, but more prevalent in north of State	All	FM
eastern blue devil	Rocky reef near estuary entrances, particularly in south of State	Adults	FM
Queensland groper	Rocky reef near estuary entrances, but more prevalent in north of State	All	FM
weedy seadragon	Rocky reef and kelp beds near estuary entrances subject to strong marine influence	All	FM
Protected Species (Section 20)			
Australian bass	Brackish to freshwater areas; during winter further downstream in estuary proper, particularly after heavy rain	All	FM
blue groper	Seagrass and rocky reef near estuary entrances	Juveniles	FM
estuary perch	Upper estuaries, sometimes in lower freshwater reaches; during winter may be found well downstream towards estuary entrance	All	FM

Table F6. List of species protected under the *Threatened Species Conservation (TSC) Act 1995* and *Environment Protection and Biodiversity Conservation (EPBC) Act 1999*, which could be affected by the Estuary Prawn Trawl Fishery.

Species/group	Types of habitat where most likely to be caught or affected	Most likely effects	Protective treaties or legislation
Endangered Species			
Birds			
beach stone-curlew	North of Nambucca River; open beaches, sandflats and mudflats	Disturbance - feeding	TSC
bush stone-curlew	Central coast; saltmarsh, mangroves	Disturbance	TSC
little tern	Sand-spits, islands and beaches near estuary entrances	Disturbance - feeding Disturbance - nesting	TSC
Plants			
Zannichellia palustris	Tributaries of Hunter River (Lake Macquarie?)	Could be trawled over	TSC
Endangered Populations			
little penguins (population)	North Harbour Aquatic Reserve, entrance to Port Jackson	Disturbance - feeding Disturbance - nesting	TSC
Vulnerable Species			
Plants			
Wilsonia backhousei	Saltmarsh, esp. in Jervis Bay, and north to Wamberal Lagoon	Trampling	TSC
Reptiles			
green turtle	Seagrass beds of northern and central NSW	Disturbance - feeding	TSC and EPBC
leatherback turtles	Mouths of major rivers, primarily oceanic	Disturbance - nesting	TSC and EPBC
loggerhead turtles	Seagrass beds, estuarine and coastal reefs	Disturbance - feeding	TSC - vulnerable EPBC - endangered
Birds			
Australasian bittern	Saltmarsh	Disturbance - feeding Disturbance - nesting	TSC
black bittern	Northern half of coast, wetlands and mangroves	Disturbance - feeding Disturbance - nesting	TSC
black-tailed godwit	Sp. and Su.; sandspits and mudflats, especially Hunter River	Disturbance - feeding	TSC, J and C
broad-billed sandpiper	Sp. and Su.; Hunter to Shoalhaven Rivers, sand and mudflats adjacent to mangroves	Disturbance - feeding	TSC, J and C
comb-crested jacana	Tweed to Bermagui; upper estuaries	Disturbance	TSC
freckled duck	Coastal brackish lakes	Disturbance - feeding	TSC
great knot	Sp. and Su.; sandflats, mudflats, sandy beaches	Disturbance - feeding	TSC, J and C
greater sand plover	Su.; sandflats and mudflats	Disturbance - feeding	TSC, J and C
lesser sand plover	Su.; beaches, sandflats, mudflats and mangroves south to Shoalhaven River	Disturbance - feeding	TSC, J and C
mangrove honeyeater	Mangroves from Tweed to Macksville	Disturbance - feeding Disturbance - nesting	TSC
osprey	Areas of extensive open water	Disturbance	TSC
pied oystercatcher	Sandflats, mudflats, beaches	Disturbance	TSC
sanderling	Su.; mudflats, sandspits, coastal lagoons	Disturbance - feeding	TSC, J and C
sooty oystercatcher	Rocky shores, beaches	Disturbance	TSC
Terek sandpiper	Sp. and Su.; mudflats near mangroves, lagoons and creeks	Disturbance - feeding	TSC, J and C
Marine Mammals			
humpback whale	Entrance of larger bays and harbours	Disturbance	TSC and EPBC
Indo-Pacific humpbacked dolphin	Far North Coast, mouths of larger rivers	Disturbance - feeding capture	TSC - vulnerable; EPBC - insufficiently known
Southern right whale	Entrance of larger bays and harbours	Disturbance	TSC and EPBC

Sp = spring; Su = summer; J & C = threatened species also protected under JAMBA & CAMBA

b) Impact due to direct capture or disturbance

As discussed in previous sections, the Estuary Prawn Trawl Fishery uses otter trawling in a limited number of estuarine habitats. Under the draft FMS, these habitats would primarily include unvegetated sediments and, to a far lesser extent, perhaps low-profile rocky reef. As stated in section 1 of this chapter, the exact distribution of these habitats within the trawled estuaries is unknown. This section will focus on how the method of otter trawling is thought to impact on threatened and protected species through either capture, disturbance, or by altering their habitat. For brevity, generalised statements will be used for species that utilise similar habitats, except where it is apparent that trawling activity or its timing may adversely impact a particular species.

i) Capture rates and mortality

Otter trawling, being relatively non-selective catches a variety of incidental species, which could include threatened or protected fish, reptiles and mammals. There is no information on the capture rates of threatened and protected species by the fishery. However, those aquatic species that spend a large part of their life cycle in estuaries are more likely to be caught.

Given the distribution, abundance and occurrence in estuaries of protected species of fish, the Australian bass, eastern blue groper, estuary perch, elegant wrasse, estuary cod, Queensland groper and weedy seadragon are likely to occur in some or all of the four trawled estuaries in NSW. These species all have wide distributions and are found along most of the NSW coast in either freshwater and estuarine and estuarine and marine habitats. The eastern blue devil and Australian grayling are highly unlikely to encounter estuary trawl operations. These species are normally found in marine and freshwater habitats respectively, in estuaries where trawling does not occur. Thus the fishery can be assumed to have no impact on these species.

With respect to the protected fish species likely to be found in trawled estuaries, incidental capture rates by the fishery would be greatest amongst those that feed on prawns (Australian bass and estuary perch). Studies on bycatch from the fishery, conducted before the introduction of bycatch reduction devices (BRDs), identified species protected from commercial fishing under Section 20 of the FM Act amongst the fishery's bycatch. Liggins and Kennelly (1996) reported occasional captures of Australian bass in the Clarence River, and estuary perch in Lake Woolooweyah, with average catch rates for these species being between 0 and 1 individuals per fisher day during 1989-1990. Although a catch rate was not determined, Gray *et al.* (1990) noted captures of Australian bass (1,851 in total) and estuary perch (118 in total) in the Hawkesbury River between 1986 to 1988. Ruello (1971) also identified Australian bass in the bycatch of the Hunter River trawl fishery, but did not provide any estimates of numbers or tonnage. No protected species were found in trawl bycatch at Port Jackson during 1990-1992 (Liggins *et al.*, 1996). Although Botany Bay will no longer be a part of the fishery after May 2002, Liggins *et al.* (1996) found otter trawling techniques to catch eastern blue groper in the bay at a rate of 0 to 1 individuals per fisher day. No other threatened or protected species were found in the catches from these bycatch studies.

The captures of Australian bass and estuary perch, identified above, suggest that these species are commonly found in trawled areas and are consistent with information about the biology of these species. Where capture rates were determined in the bycatch studies, these could be described as occasional (Liggins and Kennelly, 1996), although this may vary between estuaries and/or seasons. These species are found in estuaries mainly during winter when trawling in all zones (except the Hawkesbury River) is banned, thus reducing the risk of trawling placing the species under sufficient pressure to warrant listing as a threatened species. However, the winter-time trawl fishery in the Hawkesbury River can potentially capture these species, especially in the upper and mid estuarine reaches. Most of the bass observed amongst bycatch in the Hawkesbury were juveniles, and most were taken in areas currently closed to trawling (C. Gray, NSW Fisheries, pers. comm.). Regardless, the observer program should look at this issue further, to determine whether a winter and/or area closure in the Hawkesbury is warranted. It is unknown whether these protected species survive after being released from capture, however, a precautionary approach would assume that the survival of these species may be significantly reduced following capture. Other factors thought to be responsible for the decline of Australian bass include river regulation, catchment alteration and general harvesting of fish (Harris, 1984; Pollard and Growns, 1993).

The fishery could potentially capture threatened or protected species occurring on unvegetated estuarine sediments. A possible example would be the endangered green sawfish in the Clarence River, although the last confirmed sighting of this species was 30 years ago. Estuary cod, along with several of the other threatened and protected species of fish, could be caught in the lower reaches of estuaries wherever there is rocky reef, other suitable hard substrata or seagrass. However, trawlers generally avoid operating over these habitats, greatly reducing possible incidental captures by the fishery.

Grey nurse sharks could occur in the marine reaches of estuaries where, especially in the Hawkesbury River and Port Jackson, they could be captured by the fishery. However, this species was not captured during bycatch studies in any of the trawled estuaries (Liggins and Kennelly, 1996; Liggins *et al.*, 1996; Gray *et al.*, 1990) and captures by the fishery were not reported during a recent survey of the species (N. Otway, NSW Fisheries, pers. comm.).

The endangered population of little penguins in Port Jackson is also potentially vulnerable to direct captures by the Estuary Prawn Trawl Fishery. However, there is no evidence of any captures or mortality of little penguins directly attributable to commercial fishing (B. Humphries, NPWS, pers. comm.). The mortality database maintained by NPWS lists numerous other factors, such as gunshot wounds, foxes and dogs that are largely responsible for the 84 deaths recorded since the database was established in 1994. Prawn trawling is banned from the North Harbour Aquatic Reserve, further reducing the risk of direct captures of little penguins by the fishery.

The recovery plan for marine turtles in Australia did not include any commercial fishery within NSW waters in its list of Australian fisheries known or thought to have a potential impact on marine turtles, even though the oceanic prawn trawl fisheries of northern Australia were listed (Environment Australia, 1998). The Estuary Prawn Trawl Fishery probably has a negligible impact on threatened marine turtles. Turtles were not caught during studies of the bycatch from this fishery (Liggins and Kennelly, 1996; Liggins *et al.*, 1996; Gray *et al.*, 1990).

ii) Habitat disturbance or loss

Habitat disturbance or modification, in its various forms and from its varying sources (see sections 1 and 10 of this chapter), is a process threatening the survival or viability of dependent threatened and protected species, populations and communities.

As discussed previously in section 1 of this chapter, there are no quantitative or qualitative data on the direct effects of the Estuary Prawn Trawl Fishery on surrounding estuarine habitats. In a more general context, trawling is known to result in severe physical disturbance of the seafloor through direct net contact (e.g. Collie *et al.,* 1997; Engel and Kvitek, 1998; Schwinghamer *et al.,* 1998; Watling and Norse, 1998). The likely consequences of this activity include: disturbance of seafloor and associated benthic infauna; damage to and/or removal of any epibenthos and associated macroalgae; and damage to seagrass. The degree of these impacts is dependent on the frequency of trawling. In areas that are heavily trawled, long-term habitat damage is likely as the time between trawling events is shorter than that necessary for ecosystem recovery (Watling and Norse, 1998). Such a situation may occur within the trawled estuaries of NSW.

The literature reviewed in section 1 of this chapter show that trawling activity (in general) does have significant impacts on habitat. Therefore, the precautionary principle will be used in this assessment and it will be assumed that otter trawling in NSW estuaries would significantly impact the habitats over which it operates. As discussed in section 1 of this chapter, it is likely that the operations of the Estuary Prawn Trawl Fishery would frequently disturb unvegetated sediments and where trawling has occurred over seagrasses, would damage and remove them. The draft FMS proposes to virtually eliminate seagrass damage from trawling by prohibiting this activity over all known areas of seagrass. Threatened or protected species that could utilise the unvegetated sediment habitat within estuaries include the endangered green sawfish. Trawlers in NSW estuaries generally avoid operating over rocky reefs, consequently reducing their impact on this habitat and the many associated threatened or protected fish species. Trawling requires a minimum depth of 1-2 m, meaning that estuary prawn trawl fishers are likely to leave a buffer area when working adjacent to sandy shorelines, mangroves and saltmarsh. Consequently, the fishery is most likely to impact upon the fauna, including threatened birds, that live in these habitats through disturbance rather than directly. The fishery may also contribute to the erosion of these habitats, however the proposed code of conduct should minimise this. Until research is done, particularly during the formulation of management and recovery plans for threatened species, the extent of impacts on the habitats of threatened species will remain unclear.

Changes in trawling activity, such as the implementation of new gear or seasonal closures, could result in greater fishing effort or change the way trawl nets contact the seabed, having consequent effects on habitat disturbance and/or recovery. Trawling has existed for over 60 years within the four estuaries in question, and it is probable that any relevant major changes in habitat distribution and condition would have taken place early on and that any subsequent changes would have been less visible or dramatic. Furthermore, any such changes may no longer be readily identifiable due to the variety and extent of other factors affecting estuarine habitats, e.g. sand and gravel extraction, dredging, urbanisation and pollution (see sections 1 and 10 of this chapter for more information).

iii) Indirect impacts

Indirect impacts that could affect threatened or protected species include noise, collision with vessels and behavioural modifications arising from fishing activities, although there are no quantitative data about these potential impacts. These impacts could relate to feeding, roosting and/or mating. An example of how commercial fishing activities may disturb the behaviour of threatened species comes from Wollongong, where non-trawling commercial fishing methods were observed to prevent adult little penguins (not part of the threatened population at Manly) from returning to their nests (NPWS, 2000a). Physical obstruction, noise, light and general activity could all have contributed to preventing access. During the breeding season, such denial of access would restrict the ability of adults to feed their young. This example provides some indication of the sensitivity of certain animals to disturbance and provides insight as to what may occur elsewhere, or in relation to other species or populations.

It is important to note that prawn trawl vessels are not the only vessels operating in estuaries. Other boating activity, such as commercial shipping, transport, recreational boating and other commercial fishing activity together account for the vast majority of boating in estuaries. Most estuaries trawled by the fishery are easily accessible by nearby or adjacent urban populations and support large amounts of recreational boat use. Boating activity in the Hunter River and Port Jackson is enhanced by the presence of international shipping ports and, particularly in Port Jackson, busy transport routes. These forms of boating activity could also contribute to any impacts on threatened species from noise and boat strike.

Impacts to threatened species from noise (including disturbance) and boat strike (including disturbance and injury) by the Estuary Prawn Trawl Fishery would be restricted to the operating times of the various prawn trawl fleets (for a summary see Appendix B6), but have not been quantified. When trawling occurs adjacent to rocky reefs, sandy shores, mangroves, saltmarshes and the North Harbour Aquatic Reserve, the fishers would have a greater chance of striking threatened species with their boats or disturbing them with noise, however the proposed code of conduct should minimise this. When operating at night (in Port Jackson and the Hawkesbury River only), fishers are unlikely to be aware of the presence of any fauna beyond the targeted prawn and/or squid catch.

Numerous species have adjusted their behaviour to fishing activities, particularly to the larger trawling and longline operations conducted in oceanic waters. It is not uncommon for many species of dolphins, sharks and birds to aggregate behind vessels associated with such fisheries and scavenge for either discards or bait (e.g. Wassenburg and Hill, 1990; Blaber *et al.*, 1995; Broadhurst, 1998; NPWS species profiles). Broadhurst (1998) noted bottlenose dolphins actively manipulating the codend of an oceanic prawn trawl net to remove and consume its contents. It is unknown whether the threatened species considered in this assessment have become accustomed to feeding from the codends of nets used in the Estuary Prawn Trawl Fishery. Threatened and protected species that may do so include the grey nurse shark, great white shark, Australian bass, estuary perch and threatened species of birds that feed on fish and/or prawns.

Paton *et al.* (2000) examined the effects of disturbance on migratory waders, some of which are threatened, and found that disturbance distances were extremely variable both within and among species. They recommended that key areas used by birds in the Coorong-Murray Mouth estuary should be identified and buffer zones of 150-200 m established around these areas. They did, however, acknowledge that some compromise with respect to the sizes of the buffer zones may be required in areas where current human activity is high, particularly if those activities could not be shifted to other areas of less importance to the birds. The study by Paton *et al.* (2000) was undertaken in wetlands that are likely to receive far less visitation, both recreational and commercial, than the estuaries of this fishery. This relatively high visitation in NSW estuaries complicates the implementation of buffer zones in relation to the Estuary Prawn Trawl Fishery. However, the NSW NPWS is currently considering such temporary zones around the key breeding sites of little terns, which include Botany Bay. When more information is available for other species, it may also be possible to implement permanent or temporary closures for such species in other areas.

Threatened and protected species could also be indirectly affected by changes in trophic structure. Whilst individuals of the little penguin endangered population in North Harbour Aquatic Reserve are unlikely to be captured by the Port Jackson prawn trawlers, they may be indirectly affected through capture of bait species in nearby coastal waters. This would provide direct competition for food resources, particularly during breeding when the penguins are thought to have shorter foraging ranges. Dayton *et al.* (1995) highlighted the ecological effects associated with the capture of aggregated prey, particularly baitfish, and were concerned that these could be a significant but unstudied problem in Australia. A study in Port Phillip Bay, Victoria, suggested that adult little penguins had died from starvation because fishing had depleted stocks of anchovies and pilchards (Harrigan, 1992). A later study reported that weather patterns, particularly in relation to the El Nino-Southern Oscillation phenomenon, had caused dramatic shifts in baitfish recruitment, schooling behaviour, abundances and distributions, such that penguins were probably unable to catch sufficient food, irrespective of fishing practices (Hoedt *et al.*, 1995). There is the potential that, during periods of low abundance, fishers may take a significant proportion of the available fish, thereby severely limiting the resources available to the penguins. The monitoring of catch levels, as detailed in the recovery plan for the endangered population of little penguins at Manly, may not necessarily provide any information about the impact of fishing unless there is also some indication of the stock levels of baitfish and the feeding requirements of the penguins. Chapter E suggests that adequate stock assessments are not yet available, although they will be undertaken under various fishery management strategies. The NSW NPWS is currently researching the feeding requirements and feeding ranges of the little penguin population. A combination of such research may provide some indication of the effects of fishing on the little penguin population at Manly.

c) The Eight Part Test

The various legislatures, under which this assessment is being done, require the determination of whether there is likely to be a significant effect of the Estuary Prawn Trawl Fishery on any threatened species, populations, ecological communities or their habitats (it is not legally required to assess protected species). This requires consideration of the matters listed in s5A of the EP&A Act, generally referred to as the Eight Part Test and itemised in bold below. The following Eight Part Test is considered across all four estuaries proposed to be trawled in the Estuary Prawn Trawl draft FMS - the Clarence, Hunter and Hawkesbury Rivers and Port Jackson. Botany Bay is not considered in this assessment as it has been gazetted to become a recreational fishing area in May 2002, meaning that commercial fishing in the bay will cease before the implementation of the FMS. If the test reveals that a significant impact is likely, a Species Impact Statement will be required. Alternatively, the draft FMS may be modified such that a significant effect is unlikely. Furthermore, a Species Impact Statement would have to be prepared if the strategy incorporated land or water that had been declared critical habitat.

Part 1- Life cycle of threatened species

In the case of a life cycle of threatened species, whether the species is likely to be disrupted such that a viable local population of the species is likely to be placed at risk of extinction.

Green sawfish

In Australia, the green sawfish is most abundant in the tropics from Broome to southern Queensland, with stragglers as far as south as Sydney and a single record from Glenelg, South Australia (Last and Stevens, 1994). Considering that the green sawfish has been recorded in estuaries and feeds on fishes and benthic invertebrates (Allen, 1989), it could be found in the unvegetated sandy habitats of the trawled estuaries, especially the Clarence and Hunter Rivers. It is common inshore at certain times of the year (Last and Stevens, 1994).

In NSW the species is thought to have suffered a serious population decline, with the last documented specimen of green sawfish in the State being taken from the Clarence River heads in

1972. Prior to this, the ten specimens from NSW currently in the Australian Museum collection were taken between 1888 and 1972. In 1940, Whitley described the green sawfish as "…an extralimital species sometimes straying down our eastern coasts in late summer as far south as Sydney" (Whitley, 1940). The last specimen collected from the Sydney area was in 1926. In 1963, Stead described the species as being more prevalent in northern Australia and was frequently found as far south as the mouths of the Clarence and Richmond Rivers (Stead, 1963). In the northern half of the State, four of the specimens in the Australian museum were taken between Smoky Cape and Byron Bay between 1927 and 1957.

In Queensland, the green sawfish has been very rarely recorded in more northern Queensland east coast waters in the last 25 years. In Moreton Bay, there have been no reports of the species since the 1960s (Johnson, 1999).

Considering that trawling occurs over unvegetated sandy sediments, there is potential for the Estuary Prawn Trawl Fishery to capture this species, especially in the Clarence and Hunter Rivers. As green sawfish seem quite rare in the area now, any direct or indirect impact will be significant for the species, especially as the species has a low fecundity and possible late maturity. Bycatch from shallow prawn trawling and habitat degradation are thought to be some of the causes of the apparent decline of this species. To avoid affecting local populations of the species, the Estuary Prawn Trawl FMS will need to consider the possible direct capture of the species, disruption of its habitat and any indirect impacts and seek to reduce any adverse impacts.

It is not known if there is a viable local population of green sawfish in the northern rivers region of NSW, or in the State as a whole for that matter. Despite numerous NSW Fisheries surveys in the shallow water of NSW in the last 25 years by the FRV Kapala research vessel, no sawfishes have been collected (K. Graham, NSW Fisheries, pers. comm., 1999). Nor have any specimens been sent to the Australian Museum in the last 30 years. Also, although not directed at threatened species, no green sawfish were captured in the Clarence River during bycatch studies spanning 1989-1990 (Liggins and Kennelly, 1996). As this species occurs largely in tropical waters and confirmed sightings of the species in NSW have not occurred since 1972, it seems unlikely that trawling activities will place a viable local population of this species at further risk of extinction. However, the FMS should still be precautionary regarding this matter.

The implementation of a code of conduct to ensure fishers release any incidental capture of green sawfish with minimal harm would be a good precautionary measure to minimise mortality following any direct captures. The proposed observer survey should be specifically targeted on the species to record any occurrences or interactions with the fishery and repeated every few years to record any recovery of the species. Similarly, the research proposed to investigate trawling impacts on unvegetated sediments should also investigate any resulting possible effects for the species. These measures should be given immediate attention in the FMS.

In summary, provided the FMS includes precautionary measures regarding the green sawfish, viable local populations of this species should not be significantly affected by estuarine trawling.

Great white and grey nurse sharks

The Estuary Prawn Trawl Fishery nor the otter trawling method have been identified in the list of Australian fisheries known or thought to have a potential impact on great white sharks, as given in the draft recovery plan for this species (Environment Australia, 2000b).

In the draft recovery plan for grey nurse sharks, prawn trawling was identified as one of the methods responsible for the incidental capture of this species, although the degree of this impact is unknown (Environment Australia, 2000a). As grey nurse sharks are marine and occur in inshore waters, they are most likely to be found in the marine portions of the Port Jackson and Hawkesbury River trawled estuaries. Much of these sections are already closed to prawn trawling, reducing the risk of incidental capture. As grey nurse sharks have been reported in these areas (N. Otway, NSW Fisheries, pers. comm.), the Estuary Prawn Trawl Fishery could directly capture this species. However, no grey nurse sharks were recorded during bycatch studies in any of the trawled estuaries (Liggins and Kennelly, 1996; Liggins *et al.*, 1996; Gray *et al.*, 1990) and no captures by the fishery were reported during a recent survey of the shark population (N. Otway, NSW Fisheries, pers. comm.). The draft FMS proposes the measures that are consistent with those required by the recovery plan. The incidental capture of this species by the fishery would be very rare and any affected animals would be easily released. Even though grey nurse shark populations are particularly susceptible to incidental captures in that females only produce two pups every two years, the Estuary Prawn Trawl Fishery alone is unlikely to place this species at risk of extinction, nor is it likely to contribute significantly to such risk.

Black cod

Black cod tend to occupy habitats not generally trawled by the fishery, such as rocky reefs and large underwater structures. The historical decline of this species has probably resulted from recreational fishing and spearfishing pressure (Pogonoski *et al.*, In prep.). Occasional commercial captures of this species have been reported from deeper offshore reefs. The Estuary Prawn Trawl Fishery is unlikely to place viable local populations of this species at risk of extinction.

Threatened birds

The species of threatened birds that may occur in the trawled estuaries include: beach stone-curlew, little tern*, sanderling, great knot, greater sand plover*, lesser sand plover*, pied oystercatcher, comb-crested jacana, Australasian bittern, broad-billed sandpiper*, black-tailed godwit*, Terek sandpiper* and freckled duck, with those species marked with an asterisk having noted populations in trawled estuaries. Most of these birds are migratory, spending spring and summer in our estuaries. However, some species remain over winter and others are permanent residents. There are significant populations of migratory birds in all of the trawled estuaries except the Hawkesbury River (see Table F3). As most of these species inhabit either sand spits, sandy beaches, sand and mud flats or mangroves, hydrological changes and development pressures have been identified as the main threats to their survival. Estuarine prawn trawling activities do occur around noted areas of migratory bird habitat and can potentially affect migratory waders, given that the fishing season coincides with their presence in NSW estuaries. However, as trawling activity is predominantly undertaken in deeper waters, it should not directly affect the nesting and roosting sites of these species. Also, the proposed implementation of a code of conduct for operating adjacent to these populations should reduce any indirect disturbances. The fishery is unlikely to place any local viable populations of threatened bird species, at a State, regional or local level, at risk of extinction.

Threatened plants

Of the threatened plant species, *Wilsonia backhousei*, may occur in saltmarsh and on seacliffs around the Port Jackson and Hawkesbury River area. However, by nature of its habitat, the fishery is unlikely to affect this species. *Zannichellia palustris* (a submerged aquatic plant) is an endangered species found only rarely in fresh to brackish slowly moving waters of the Hunter River region in NSW and the Murray River region in South Australia. Within the Hunter River, it is confined to a couple of brackish creeks that enter the main river's southern arm, in areas where trawling does not occur. As such, the fishery will not affect this species.

Threatened reptiles or mammals

The trawled estuaries of NSW are thought to be only occasionally visited by threatened reptiles or mammals. Species of these groups are predominantly marine and do not usually nest or breed in estuaries. Southern right and humpback whales, found migrating through NSW waters from June to October, have been observed resting in larger embayments such as Port Jackson. The Estuary Prawn Trawl Fishery is closed during this period, except in the Hawkesbury River. Considering that the southern right and humpack whales neither breed or feed in NSW waters and can rest in many deep estuaries along the coast, the Hawkesbury River fishery is unlikely to have a significant impact on these species. Little is known about the occurrence of Indo-Pacific humpbacked dolphins or any of the threatened turtles in NSW waters, although they are known to regularly enter estuaries elsewhere. Their ranges of distribution encompass several north coast estuaries including the Clarence River where prawn trawling occurs. The observer program could help establish any occurrence of these species in the Clarence River, so as to determine if further action, such as Turtle Exclusion Devices is warranted. Given the wide distributions of these species their preference for marine waters, the Estuary Prawn Trawl Fishery would not place any viable local or regional populations at risk of extinction.

Part 2 – Endangered population

In the case of an endangered population, whether the life cycle of the species that constitutes the endangered population is likely to be disrupted such that the viability of the population is likely to be significantly compromised.

The little penguin population at North Harbour in Port Jackson is the only endangered population that could be affected by the fishery. Little penguins are known to travel between 10 and 30 km when foraging for food during nesting and much further during the non-breeding period (review by Gibbs, 1997). Disturbance from commercial fishing, such as preventing adults from bringing food to their fledglings (i.e. similar to the disturbance which has been observed at a colony offshore from Wollongong), has not been reported from the Manly colony (NPWS, 2000a). If such events occurred, the breeding success of the population could be compromised. It will be important for the recovery team, recovery plan and future monitoring programs to consider the potential for such interactions and to record any occurrences and associated outcomes. This will be aided by the observer survey proposed in the draft FMS. The potential for adverse interactions with prawn trawling in Port Jackson exists during weekday evenings between October to Easter. This takes in the period of nesting and chick-rearing, although the extent of any disturbance would depend on the fishing effort and intensity near the colony itself.

Prawn trawling is banned from the North Harbour Aquatic Reserve, thus reducing the likelihood of capturing little penguins or disturbing their nesting or chick-rearing. There have been suggestions that commercial fishing in Sydney Harbour may be having a detrimental impact on food sources utilised by little penguins. An investigation into this claim will be undertaken under the recovery plan for this population. The draft FMS proposes measures that are consistent with this recovery plan. At this stage the fishery does not appear to compromise the viability of the little penguin population.

Part 3 – Regional distribution of habitat

In relation to the regional distribution of the habitat of a threatened species, population or ecological community, whether a significant area of known habitat is to be modified or removed.

Within the four estuaries where prawn trawling would be allowed under the draft FMS, it is restricted to certain areas. Any structural habitat damage caused by trawling would have most likely occurred early in the history of the fishery, and continued trawling has probably prevented any habitat recovery. Thus, any known existing threatened species habitat that has not already been modified by trawling is unlikely to be in the future as the draft FMS proposes to prevent the expansion of trawling activities into new areas.

Of all estuarine habitats, unvegetated sediment is the most likely to be impacted upon by the proposed trawling practices. A current study at Sydney University is examining such impacts in the Clarence River. Of all the threatened species possibly found within trawled estuaries, the green sawfish would be the most likely to be affected by disturbance to unvegetated sediment habitat. It is unlikely that trawling as an activity will remove unvegetated sediment habitat. If trawling modifies this habitat such that it is no longer suitable for the green sawfish and fails to provide an adequate food source for the species, there exists suitable habitat for the species throughout areas closed to the fishery within the trawled estuaries and adjacent estuaries. However, there should be more commitment within the FMS to study such a potential impact on the species so as to implement the proposed closures and gear modifications, if required. The draft FMS proposes closures and gear modifications if trawling is found to have a negative impact upon threatened species habitat.

Black cod tend to occur around rocky reefs where trawling activity generally does not occur. Given the low impact of the fishery on this habitat, it is considered unlikely that the fishery could modify or remove a significant area of rocky reef habitat.

As the draft FMS proposes to prohibit all trawling over seagrass, this habitat should not be significantly modified or removed by the fishery.

As trawling is prohibited in the North Harbour aquatic reserve, the fishery is unlikely to modify or remove habitat used by the little penguin population at Manly.

The fishery would not modify or remove a significant area of habitat for sharks, turtles, whales or dolphins. The habitats of threatened birds, including mangroves, saltmarshes, sandy spits and mud flats, are generally not directly modified or removed by trawling activities.

Part 4 – Isolated habitat

Whether an area of known habitat is likely to become isolated from currently interconnecting or proximate areas of habitat for a threatened species, population or ecological community.

As stated previously, damage to threatened species habitat from trawling activities would have already occurred since the commencement of this fishery. The continuation of prawn trawling proposed in the draft FMS should not further isolate existing threatened species habitat nor fragment such habitat in such a way that it could become progressively isolated. Prawn trawling will not isolate areas of aquatic or terrestrial habitat used by any threatened species of birds. Regarding threatened fish, mammals and reptiles, the connectivity of marine and estuarine systems is such that reproductive isolation as a result of habitat fragmentation is impossible, especially given the techniques used in the fishery.

The penguin population at North Harbour has not become isolated because of commercial fishing, nor is such causing any incremental isolation. Continuing urban development and the existence of a natural geographic formation are largely responsible for the population's isolation. The fishery is also unlikely to prevent any possible further expansion of the area currently occupied by the population.

Part 5 - Critical habitat

Whether critical habitat will be affected.

Critical habitats have not been defined for any of the species considered in this assessment. Irrespective of this, a precautionary approach would suggest that the habitats occupied by the little penguin population are critical to its survival. This suggestion is supported by a recent proposal (from the relevant recovery team) to have parts of North Harbour listed as Critical Habitat. However, as stated above, the fishery is unlikely to modify or remove this habitat, or restrict the distribution of these species. As such, there will be few or no effects on this habitat. Should the above proposal be approved and parts of North Harbour be gazetted as Critical Habitat, activities in the area will be scrutinized under a separate review process, information for which is already being gathered at the time of this report.

Part 6 – Adequate representation in conservation areas

Whether a threatened species, population or ecological community, or their habitats, are adequately represented in conservation reserves (or other similar protected areas) in the region.

Very little is known about the biodiversity of our marine protected areas, and even less of aquatic threatened species, so it is impossible to assess whether the species or their habitats are adequately represented in conservation reserves or the like.

Numerous conservation reserves exist along the coast, including within the regions where estuarine trawling occurs. These incorporate habitat for the threatened species considered in this assessment. The endangered population of little penguins occurs in an Aquatic Reserve and representative habitats of most of the other species occur in National Parks, Nature Reserves, Aquatic Reserves or areas closed to commercial fishing. Black cod is known to occur in Solitary Islands Marine Park, Julian Rocks Aquatic Reserve and Cook Islands Aquatic Reserve. More threatened species that occur in the Solitary Islands Marine Park include the grey nurse and great white sharks, humpack and southern whales, all threatened marine turtles and the little tern.

Further to these conservation reserves, Kooragang Island is listed as internationally important under the Ramsar convention, and is managed accordingly as a nature reserve. Also, major migratory bird sites listed under the JAMBA and CAMBA agreements are found within Port Jackson and the Clarence and Hunter Rivers, particularly at Kooragang Island and Fullerton Cove. While these agreements do not give special conservation status to these areas, they at least ensure that migratory birds are considered when making management decisions affecting these areas. Fullerton Cove is proposed as an aquatic reserve.

Although not a conservation reserve, the area within all the trawled estuaries where trawling is prohibited offers protection from trawling impacts to any threatened species and their habitat found within this area.

The threatened plant species *Zannichellia palustris*, found only in the lower Hunter region in NSW and Murray River estuary in SA, is not formally protected under any conservation reserve nor managed in any way that assists its conservation. However, its location within the tributaries of the Hunter River prevents it from being affected by the fishery.

Part 7 – Threatening processes

Whether the development or activity proposed is of a class of development or activity that is recognised as a threatening process.

The Estuary Prawn Trawl Fishery does not undertake, promote or cause any of the three threatening processes currently listed under the FM Act. In particular, the potential for the fishery to remove woody debris from the riverbed has been removed with the banning of this activity in the draft FMS. Commercial fishing is also not listed as a threatening process under the TSC Act, and the activities proposed under the draft FMS are considered highly unlikely to exacerbate existing threatening processes listed under that Act.

The recovery plan for little penguins at North Harbour does recognise commercial fishing as a threatening process to the colony, and as such this assessment accepts that there is potential for such fishing to constitute a threatening process under the TSC Act in future. At this stage, however, the fishery does not appear to be adversely affecting two or more threatened species, one of the criteria necessary for an activity to be declared a threatening process.

The only threatening processes related to fishing listed under the EPBC Act are the incidental catch of sea turtle during coastal otter-trawling operations within Australian waters north of 28 degrees South, and the incidental catch of seabirds during oceanic longline fishing operations. Neither of these applies to the Estuary Prawn Trawl Fishery; the fishery is confined to estuaries and operates south of 28 degrees latitude.

Part 8 – Limit of known distribution

Whether any threatened species, population or ecological community is at the limit of its known distribution.

The following threatened species reach the limit of their known distribution in Australia along the section of coast where the fishery operates: green sawfish, beach-stone curlew, lesser sand plover, leatherback turtle, green turtle, Indo-pacific humpbacked dolphin and the plants *Zamnichellia palustris* and *Wilsonia backhousei* (see Appendix F4). These distribution limits may be either natural or influenced by human activities. In all but one case, prawn trawling in estuaries does not appear to affect the distributions of these species. An exception may be the green sawfish, for which shallow water trawling was identified as contributing to its decline in NSW.

The endangered population of little penguins at North Harbour must, by definition, be at the limit of its distribution. However, the proposal should not reduce or affect the ability of the population to expand its range.

Conclusion

This assessment has considered the eight factors under Section 5A of the EP&A Act in deciding whether estuary prawn trawling is likely to have a significant impact on threatened species, populations or ecological communities or their habitats. This consideration was based on a review of biological information derived from the various agencies responsible for those species, from published literature and from personal communications. The assessment suggests that the Estuary Prawn Trawl Fishery could significantly impact upon green sawfish, if it were found in the trawled estuaries. The strategy should include such direct measures as a code of conduct for handling captures of the species and the proposed observer and research studies should be focussed on the species, consequently reducing any possible impacts. The fishery alone was not found to have a significant effect on other threatened species, populations or ecological communities or their habitats. The FMS needs to take more direct action, as suggested above, to reduce possible impacts on the green sawfish, and avoid the need for a Species Impact Statement for the proposed activity.

d) Assessment of threatened species management in the draft FMS

i) Management uncertainty

There is a high level of uncertainty in relation to managing possible effects of estuarine prawn trawling on threatened and protected species. This high uncertainty stems from a lack of relevant information on the distribution of threatened species and their habitats within trawled estuaries, the effect of trawling on these habitats, the rate of incidental capture of these species by the fishery and the exact location of trawling activities. Given this high uncertainty, the best management approach for the fishery is precautionary. This approach accepts the possibility that the fishery has had some as yet unknown impact on threatened species.

ii) Proposed management measures

The management measures in the draft FMS that apply to threatened species issues can generally be described as precautionary. While the exact impact of the fishery on threatened species is unknown, there is an increased effort to understand these impacts and minimise them if and where they do occur. The draft measures seek to reduce uncertainty by providing a commitment to record the incidental capture of threatened species (management response 3.1a), the areas of environmental sensitivity and trawling location within estuaries (management response 1.2a), and the effects of trawling on biodiversity (management response 1.3e) and habitat (management response 1.3b). The draft measures should also reduce the effects of incidental captures through the adoption of bycatch reduction devices (management response 1.1b) and better handling procedures for captured organisms (management response 1.1e), preventing the expansion of fishing effort (management response 2.3c) and closures (management response 1.1f). The proposed code of conduct should minimise indirect impacts on threatened species (management response 1.2e) and is a good precautionary measure while the occurrence of threatened species in trawled estuaries is being determined by the observer program (management response 8.1a). The draft measures also provide for more input from the fishery into estuarine habitat management (objective 2.5) and commit to implementing threatened species recovery plans or threat abatement plans (management response 3.1b), both measures being likely to assist in the more integrated and effective management of threatened species issues. The outcomes of these draft measures, whilst not always aimed at directly managing threatened species issues, should help reduce most of the direct and some indirect impacts the fishery may have on threatened species. Table F7 summarises these responses along with the potential impacts they should help manage.

Table F7. The outcomes of management responses in the Estuary Prawn Trawl draft FMS relating to threatened species management, and the potential impacts of the fishery on threatened species these responses should help manage.

Management response	Summary of relevant management response	Predicted outcome of response	Potential impact(s) the response should help manage
1.1a	gear use restrictions	Prevent increased capture rates of threatened species	Direct capture of threatened species; trophic effects
1.1b	introduction of BRD technology developments	Lower capture rates of threatened species	Direct capture of threatened species; trophic effects
1.1e	non invasive handling of non retained animals	Greater survival of captured threatened species	Direct capture of threatened species
1.1f	closures to avoid direct interaction with threatened species	Lower capture rates of threatened species; habitat protection	Direct capture of threatened species; habitat modification; disturbance
1.1g	prohibition on use of firearms, explosive or electrical devices	Lower capture rates of threatened species; habitat protection	Direct capture of threatened species; habitat modification; disturbance
1.2a	define habitat areas, non-trawled areas and environmentally sensitive areas	Reduced uncertainty	Habitat modification; disturbance
1.2b	increases in area available to trawling prohibited	Habitat protection	Habitat modification
1.2c	prohibit wilful damage of marine vegetation	Protection of key habitat	Habitat modification
1.2d	prohibit removal of woody debris from river bed	Habitat protection	Habitat modification
1.2e	code of conduct	Indirect impacts on threatened species minimised	Disturbance
1.3a	incidental catch rate ratios	Prevent increased capture rates of threatened species	Direct capture of threatened species
1.3b	promote research on impacts of fishing on general environment	Reduced uncertainty	Habitat modification; trophic effects
1.3c	increase understanding of ecosystems and individual species	Reduced uncertainty	Direct capture of threatened species; disturbance; trophic effects
1.3d	performance indicator regarding trawling impacts on biodiversity	Effective management of biodiversity	Trophic effects
1.3e	research trawling impacts on biodiversity	Uncertainty reduced	Habitat modification; trophic effects
1.3f	fishery comment on management of marine protected areas	Protection of areas inhabited by threatened species	Direct capture of threatened species; disturbance; trophic effects
2.1a	gear size restrictions	Prevent increased capture rates of threatened species	Direct capture of threatened species; trophic effects
2.3a	separate management rules per zone	Management focus on local issues	Direct capture of threatened species; habitat modification; disturbance; trophic effects
2.5a	restrict impacts of development on threatened species	Integrated management	Habitat modification; disturbance; trophic effects
2.5b	detrimental impacts of external activities brought to management attention	Integrated management	Habitat modification; disturbance; trophic effects
2.5c	fishery input into habitat management policy	Effective integrated management	Habitat modification
2.5d	fishery input into habitat management policy	Effective integrated management	Habitat modification

Table F7 cont.

Management response	Summary of relevant management response	Predicted outcome of response	Potential impact(s) the response should help manage
3.1a	threatened species sightings and capture information on catch return forms	Determination of incidental capture rate and occurrence of threatened species	Direct capture of threatened species
3.1b	implement threatened species recovery plans	Reduced impact on threatened species	Direct capture of threatened species; habitat modification; disturbance; trophic effects
3.1c	prohibit landings of protected fish	Reduced capture of protected fish	Direct capture of threatened species
3.1d	prohibit landings of threatened species	Reduced capture of threatened species	Direct capture of threatened species
4.1a	determine capture rate of threatened species by other sectors	Greater knowledge of threats	Direct capture of threatened species
6.4a	consistently manage fishery with other natural resource management requirements	Effective integrated management	Direct capture of threatened species; habitat modification; disturbance; trophic effects
7.2a	education regarding protection of fish habitat	Greater understanding	Habitat modification
8.1a	scientific observer program	Greater understanding	Direct capture of threatened species; habitat modification; disturbance
8.2b	accuracy of species identification determined	Reduced capture of threatened species	Direct capture of threatened species

As identified earlier, in the Eight Part Test, the FMS should include specific measures to reduce any adverse effects of the fishery on the green sawfish. Any impacts from the direct capture of the species should be minimised by determining the best way to release the species with minimal harm and implementing this procedure across the fishery as a code of conduct. This measure should be incorporated into the FMS. The proposed threatened species management through the observer program, research of trawling impacts and consequent closures and gear modification if required are good measures to reduce impacts on this species. However, considering the direct management required on this species, these programs should be initially targeted on the green sawfish. The observer program should be repeated every few years to record any recovery of the species.

Considering that the fishery could possibly disturb threatened bird species, a precautionary code of conduct is proposed in the draft FMS (management response 1.2e). The code of conduct should incorporate a buffer area for working adjacent to threatened bird habitat to minimise the potential effects of the fishery on these species. When formulating the code of conduct, it is recommended that NSW Fisheries consult with NSW NPWS to confirm important threatened bird sites.

The proposed management measures relate only to the fishery's contribution to the impacts faced by threatened species. These impacts, including habitat modification, disturbance, trophic effects and direct capture, are considered to affect the distribution, behaviour and existence of threatened species. Estuaries, particularly those that are trawled, have a multitude of user groups, each of which may have some known or unknown degree of impact upon threatened species. The prawn trawl fishery is just one estuarine user group. As stated previously, the extent of this fishery's contribution to the impacts on threatened species is generally unknown, although for the most species except the green sawfish, the Eight Part Test and anecdotal evidence suggest that any impacts from the fishery are relatively minor. Thus, the management measures proposed in the draft FMS would only partially manage the total impacts faced by the majority of threatened species in the trawled estuaries. However, there is a commitment for the fishery to have input into habitat management across all government agencies, which should lead to the inclusion of fisheries issues in threatened species management. This also holds for green sawfish, however, as bycatch from prawn trawling activities has been identified as a major threat to this fishery, any attempts by the FMS to reduce such impact on the species should greatly increase its chance of recovery.

iii) Level of confidence in achieving predicted outcomes

The proposed management responses listed in Table F7 work towards minimising or eliminating possible impacts of the fishery on threatened species. Once any impacts from the fishery have been determined, the level of confidence in the draft FMS effectively managing threatened species issues should be high, except for the green sawfish, especially given subsequent measures to implement closures and bycatch reduction programs. Unless direct measures to reduce impacts of the fishery on the green sawfish, especially mortality following direct capture, are implemented the FMS only has a medium confidence level of effectively managing its impacts on this species. The level of confidence in achieving responses that are influenced by external factors and/or organisations is lower, owing to the unpredictable nature of both the external factors and the respective contributions from each user group.

iv) Effectiveness of mitigation measures

The content of each of the responses proposed in the draft FMS should adequately improve fishery issues that pertain to threatened species provided relevant performance indicators and associated triggers are refined and completed. At this stage, a trigger point has not been set for the incidental capture of listed threatened species, populations or ecological communities (see Table C5 in Chapter C). This performance indicator should firstly be refined to also include any sightings of threatened species by professional fishers and the observer program and an appropriate trigger should be set as soon as possible. Given that there are very few threatened species that could actually be captured by the fishery, and that of those, many are highly improbable based on their habitat requirements, this proposed performance indicator appears to be a disproportionate distribution of effort. There should be a commitment within the draft FMS to use the information obtained on the sightings of threatened species. Perhaps observer programs could also be targeted on the risk to particular species or populations, as determined by recovery teams and threatened species units. Threatened species information from fishery independent surveys and bycatch studies could also be incorporated into the associated trigger. It is important that all this information be passed onto other agencies responsible for developing recovery plans (e.g. NSW NPWS) to help determine the distribution of threatened species and any fishery-related effects such as disturbance and habitat modification. This should prevent any duplication of research into threatened species. It is also important that observer programs are repeated every few years to document any potential recovery of threatened species.

e) Assessment of impact on threatened species

Whilst hardly definitive, or based on an abundance of scientific data, the above discussion would suggest that the Estuary Prawn Trawl Fishery in its current form could possibly have a direct and/or adverse impact on the green sawfish. There is, however, a high degree of uncertainty associated with this assessment due to the lack of quantitative data and reliance upon anecdotal or speculative information. The draft FMS proposes numerous management responses to remove this uncertainty and to better estimate what impacts, if any, the fishery is having on threatened species. Along with the proposed data collection and mitigation measures, data will also be collected for the analysis and development of species recovery plans and threat abatement plans. At this stage, there are no recovery plans for any of the relevant marine or estuarine species listed under the FM Act. The NSW NPWS has finalised a recovery plan for the little penguin colony at Manly, and has drafted a recovery plan for the little tern. Environment Australia has drafted a recovery plan for marine turtles, great white sharks, grey nurse sharks and an action plan for cetaceans. The applicability of these recovery plans to the draft FMS is discussed below.

The little penguin population is located within North Harbour Aquatic Reserve, which is administered by NSW Fisheries. Despite being listed in the recovery plan as a threatening process for the little penguin population, some commercial fishing is allowed in the reserve (NPWS, 2000a). The potential impact of this fishing on the population has been assessed under the Estuary General Fishery EIS, but is also considered in this assessment as there is potential for boat-based fishers to indirectly affect the population by competing for bait resources and disturbing penguins during feeding. Part of the overall monitoring program for the population is a threat abatement plan. This includes the establishment of a mortality register by NPWS and the monitoring of fishing effort, baitfish catches, and any incidental catches of little penguins by NSW Fisheries. Since the establishment of the register, there have not been any deaths associated with commercial fishing. At this stage, and until more information is available from the NPWS research, it would appear that the Estuary Prawn Trawl Fishery is not having an adverse impact upon the little penguin population and that the draft FMS will only assist and/or improve the recovery plan.

The draft recovery plan for little terns identifies over-fishing as a possible contributing threat to the tern's food resources. Little terns have been found all along the NSW coast. Of the currently trawled estuaries, recent sightings have only been recorded in Botany Bay. The birds have also been sighted in the Hunter River, but not since 1972/73 (NPWS, 2000b). The possible threat posed by the fishery to the present populations of little terns along the coast will be largely removed once commercial fishing in Botany Bay is phased out with the bay's conversion into a recreational fishing area in May 2002. The little tern populations occurring in Botany Bay, along with those at Harrington, Farquhar Inlet and Lake Wollumboola, were identified as requiring intensive management during the breeding season because they have supported more than 20 breeding pairs for the last few years. Liaison with NSW NPWS to confirm any recent sightings of the species within the trawled estuaries and an annual review of the proposed code of conduct should help reduce any future potential impacts from the fishery.

The recovery plan for marine turtles in Australia did not include any NSW commercial fishery in its list of Australian fisheries known or thought to have a potential impact on marine turtles (Environment Australia, 1998). The plan identified fisheries from Queensland, the Northern Territory, Western Australia and Tasmania, and detailed programs to resolve uncertainties about bycatch and mortality of marine turtles in those fisheries. The draft FMS in proposing to monitor sightings and/or captures of marine reptiles will be consistent with this recovery plan.

The draft recovery plan for grey nurse sharks in Australia identified demersal gillnetting, setlining, droplining and fish and prawn trawling as probably being responsible for incidental catches of this species, but noted that the degree of this impact was unknown (Environment Australia, 2000a). Many of the measures recommended in the plan were consistent with those proposed in the draft FMS and included:

- assessing commercial data to determine current levels of grey nurse bycatch
- modifying fisheries logbooks to record grey nurse catch and biological data
- ensuring that existing fishery observer programs record interactions with grey nurse sharks
- developing appropriate mechanisms to protect key sites.

The draft recovery plan for great white sharks in Australia did not include any NSW commercial fishery, nor the method used in the Estuary Prawn Trawl Fishery, in its list of Australian fisheries known or thought to have a potential impact on white sharks (Environment Australia, 2000b). The plan identified the southern shark fishery, the snapper fisheries in Victoria, the Gulf of St Vincent and the Spencer Gulf, the tuna farming industry and the WA shark fishery as taking or killing significant numbers of great white sharks as bycatch. The plan detailed programs to resolve uncertainties about bycatch and mortality of white sharks in those fisheries.

Overall, the draft FMS is consistent with the limited number of recovery plans that have been implemented or drafted to date. This should minimise any potential impacts on the relevant threatened species or populations and provide data that can be fed into the recovery plans. Assuming that the recovery plans are effective and the numbers of threatened species increase, there will be an associated increased likelihood of occurrence and interaction within the fishery. To make provision for this increase, it will be important that observer surveys are scheduled every few years and not just as a one-off at a time when the likelihood of occurrence or interaction is relatively low.

f) Summary

The proposal has the potential to affect numerous threatened species listed under the FM Act, TSC Act and the EPBC Act. At this stage, there appears to be only some data implicating the fishery in having an adverse impact on the green sawfish, however, this species has not been recorded in NSW over the last 30 years. It will be important for the FMS to include a code of conduct to release any captures of green sawfish with minimal harm, and to target observer and research programs on this species. For the other listed threatened species, there appears to be little or no data implicating the fishery in having an adverse impact on any of these species or their presently known habitats, or in accentuating other circumstances that may be causing an adverse impact upon them. Considering all threatened species, it will also be important for the proposed observer programs to obtain information about effects due to disturbance, and not just direct capture, as this appears to be the more likely form of impact on the majority of threatened species and species of international significance. The four trawled estuaries in NSW have existing closures that probably protect many areas of threatened species habitat. The draft FMS includes several measures to further mitigate any impact, including compatibility with threatened species recovery plans, initiatives to expand the range of marine protected areas, closures and research programs, irrespective of concurrent proposals to create recreational fishing areas. These strategies are considered adequate to mitigate future potential impacts on threatened species from estuarine prawn trawling and should remove a large degree of the uncertainty associated with the existing data.

3. Trophic Structure

Trophic structures depict the relationships between different groups of organisms within a food web and trace energy and nutrient pathways through an environment. These structures are very difficult to describe for estuarine and oceanic environments because they are open systems. In Australia, studies on trophic relationships within estuaries have primarily been done in the tropical regions associated with the northern prawn trawl fishery (Robertson *et al*., 1988; Brewer *et al*., 1995; Lonergan *et al*., 1997; Sainsbury *et al*., 1997). Little work has been done on trophic structures within temperate estuaries except for within Victoria's Western Port Bay. This work focused on relationships between fish and seagrasses (Edgar *et al*., 1995a,b,c). Consequently, this assessment of the trophic impacts of the Estuary Prawn Trawl Fishery will be very limited and based more on inference than direct evidence. This section will discuss the species directly and indirectly affected, possible direct and indirect impacts on trophic structure, and assesses the adequacy of the proposed management measures to address the risk of possible impacts.

a) Species likely to be affected by the fishing activity

Species affected directly by the Estuary Prawn Trawl Fishery are the target, byproduct and bycatch species, lists of which can be found in Tables B1, B17, B20, B23, B26 and B29. These species belong to feeding groups ranging from carnivores to planktivores. The prey of carnivores includes fish (e.g. silver trevally), molluscs and crustaceans. Most of the planktivores (e.g prawns) are preyed upon by fish. Except in a general sense (e.g. predator-prey relationships), interactions among these trophic groups are unknown for NSW estuaries. However it has been found elsewhere that substantial removals of prey species can cause major shifts in trophic relationships through predators switching prey, possibly increasing pressure on the populations of newly targeted species and leading to flow-on effects for other feeding groups (Dayton *et al.*, 1995). Consequently, the potential direct effects of trawling would primarily be associated with the depletion of species preyed upon by predatory fish and the flow-on effects on populations of these fish species.

Species affected indirectly by the Estuary Prawn Trawl Fishery are harder to determine because relationships between those directly affected by trawling and the rest of the environment are unknown. Species indirectly affected potentially include benthic scavengers and omnivores, algae and seagrasses and various sea birds (Jennings and Kaiser, 1998). The extent to which these trophic groups are dependent on each other within the trawled estuaries will determine the magnitude of any impacts on these species and their environment.

b) Impacts of trawling on trophic structure in estuaries

Estuarine communities have a complex array of interspecific relationships, such as competition and predation (Cappo *et al*., 1998; Hall, 1999; Kaiser and de Groot, 2000). Changes to any one component (say through a reduction in the abundance of a particular species or size class) may have a range of consequences for other components, whether they are competitors, predators or prey (Kennelly, 1995a). Trawling potentially has direct and indirect affects on trophic structures within estuaries. Direct affects primarily revolve around the removal of species from food webs. These may include:

- a local decline in the abundance of an apex predator (e.g. tailor, dusky flathead or even seabirds) caused by the selective removal of prawns (Dayton *et al*., 1995; Cappo *et al*., 1998)

- the favouring of opportunistic species (such as polychaete worms and seastars) that are able to regenerate quickly (e.g. Engel and Kvitek, 1998)
- less efficient predator foraging due to the dispersal of prey aggregations, resulting in lower reproductive success and/or reduced populations among predator species (Dayton *et al*., 1995).

Indirect affects are more diverse and include:

- the favouring of mobile opportunists, better able to 'follow' food supplies created by trawling operations, at the expense of less mobile or less aggressive species (Dayton *et al*., 1995)
- decline in the abundance of certain benthic organisms (e.g. molluscs and crustaceans) through greater exposure to predators
- disappearance of certain species (particularly juvenile fish) due to loss of food and shelter arising from removal of epibenthos such as sponges and sea squirts (e.g. Sainsbury *et al*., 1993, 1997)
- the favouring of species that prefer open less complex habitats (Watling and Norse, 1998)
- unknown effects on benthic infauna due to removal of epibenthos (Hutchings, 1990)
- changes to the condition of seagrasses or other marine vegetation through the removal of species (e.g. luderick and leatherjackets) likely to graze on epiphytic growth
- changes to benthic invertebrate communities through the removal of benthic invertebrate eating fish such as sand whiting
- short-term increases in the abundance of scavenger or predator species (fish, crabs or birds) as a result of large numbers of dead or injured fish being made available as food during or after a trawling operation
- longer term increases in the abundances of scavenger or predator species (fish, crabs or birds) as a result of large numbers of trapped, dead or injured animals being made available in regularly fished areas (e.g. Blaber and Wassenberg, 1989; Wassenberg and Hill, 1990).

From these examples it is apparent that food web and community effects are complex and far reaching, and that their prediction in any given case would be very difficult (Cappo *et al*., 1998). Also, consequent cascading effects throughout the food web would also be likely (Kennelly, 1995a). For example, scavengers or predators attracted to a trawl ground may themselves become victims. Furthermore, the availability of trawl discards has caused nesting populations of some seabird species to increase and it may also have (in turn) caused the depletion of other bird species (Cappo *et al*., 1998), possibly through competition for nesting sites (Ross, 1996). It has even been suggested that prawn trawl discards returned to Albatross Bay in the Gulf of Carpentaria fed mainly sharks, which then possibly ate more prawns due to a population expansion (Cappo *et al*., 1998, Blaber *et al*., 1990). On the other hand, significant rates of predation by small fishes on prawns (Salini *et al*., 1990; Brewer *et al*., 1991) may be reduced by the incidental capture and subsequent mortality of these fish as a result of prawn trawling. If such an interaction was sufficiently large, bycatch from prawn trawlers may actually enhance the size of the target stock (Kennelly, 1995a).

It is not known whether increased food supplies associated with trawl grounds actually result in increased populations of the attracted species, or just locally increased abundances. In fact, trawling may result in populations of these species being reduced, due to their concentration in areas where they are more liable to capture (NSW Fisheries, 1999a). The blue swimmer crab, for example, is both readily attracted to trawl discards (Wassenberg and Hill, 1990) and a popular target of commercial and recreational fishers. Nevertheless, Wassenberg and Hill (1987, 1990) conclude that discards from the Moreton Bay prawn trawl fishery have contributed to the success of the local blue swimmer crab fishery, and are probably important in maintaining populations of the major scavengers present.

The nature of the food web and community effects associated with trawling would also depend on whether the discards floated or sank upon return to the water (Harris and Poiner, 1990; Hill and Wassenberg, 1990; Wassenberg and Hill, 1990). Floating discards would be readily available to birds, whilst sinking animals could be taken in mid-water by fish or squid, or by fish and a variety of invertebrates (particularly crabs) on the seafloor.

In the context of the NSW Estuary Prawn Trawl Fishery, the major beneficiaries of discard provisioning are likely to be pelicans, seagulls and crabs such as blue-swimmers. Marine mammals and reptiles are relatively rare within most of the State's estuaries, as are fairy penguins. Pelicans would possibly benefit the most: they can eat larger discards than other species are able to, and their normal feeding behaviour restricts them to the shallow margins of estuaries and small prey items. Large gatherings of pelicans around commercial fishers are a common sight.

In some instances, trawling may cause long term community shifts that persist even after the trawling ceases. These shifts may result from habitat modification or the selective removal of a particular group of species, and be maintained through on-going predation by the 'replacement' specie(s) on the juveniles of the original specie(s), such that the latter are prevented from re-establishing. Cappo *et al*. (1998) reviews an example of such interactions from the North West Shelf trawl fishery. In this case, emperors and snappers were replaced by smaller less valuable species such as lizard fish and butterfly breams after several years of heavy trawling and associated habitat modification (Sainsbury *et al*., 1993, 1997). This situation may persist indefinitely because of continuing heavy predation by lizard fish on juvenile emperors and snappers (Thresher *et al*., 1986). Long term community shifts may also result from differing abilities to survive the rigours of being trawled, sorted and discarded. For example, Greenstreet and Hall (1996) found that dogfish and skates, being relatively hardy, have replaced gadoid finfish on the Georges bank trawl ground in the North Atlantic.

c) Risk and uncertainty of the fishery disrupting tropic structure and the necessary management measures to address this risk

There remains a great deal of uncertainty in relation to trophic impacts associated with fishing (Cappo *et al*., 1998; Jennings and Kaiser, 1998; Hall, 1999). Despite specific evidence in a few cases (e.g. on temperate rocky reefs), Jennings and Kaiser (1998) argue that it is wrong to assume that most predator-prey relationships are so tightly coupled that the removal or proliferation of one species would result in detectable changes in ecological processes. They state that "simplistic models of predator-prey interactions often take no account of prey switching, ontogenic shifts in diet, cannibalism or the diversity of species in marine ecosystems and thus often fail to provide valid predictions of changes in abundance".

Due to the high level of uncertainty about trophic relationships within estuaries, there is also a high risk that trawling could substantially alter these relationships to the detriment of maintaining biodiversity and stock sustainability. Before any management measures can be undertaken to address this risk, the following information is required:

(a) a sound knowledge of the current trophic structure within each of the trawled estuaries and the extent to which the associated relationships are tight or flexible

(b) a knowledge of the historical changes in trophic relationships within these estuaries

(c) an understanding of the extent of inter-dependency between estuaries and coastal waters with respect to trophic relationships

(d) a historical and current analysis of trophic groups within catches of all estuarine fishing sectors, i.e. Estuary Prawn Trawl Fishery, Estuary General Fishery, Indigenous and recreational

(e) based on (a) - (d)above, an assessment of the magnitude and extent of potential impacts on estuarine trophic structures within each of the trawled estuaries.

None of the proposed management responses address these aspects of understanding trophic structure in estuaries. Implementing threatened species recovery and abatement plans (management response 3.1b) will partly help in preserving some trophic relationships. However, because these plans usually focus on single species, they cannot effectively mitigate against the risks of seriously disrupting trophic structures within complex food webs involving many species. The management responses that promote biodiversity in estuaries (See management responses under all objectives of Goal 1 in Chapter C) are the most likely to assist in mitigating against the effects of the Estuary Prawn Trawl Fishery on trophic structure. For example, management response 1.2a will identify sensitive habitats within estuaries. By controlling trawling in areas where these habitats occur, refuges could be provided that allow, over time, the re-building of estuarine communities and their trophic relationships, provided such refuges are sufficiently large (Pauly *et al*., 1998). It is the composition of biodiversity that is the most crucial factor in maintaining or restoring trophic relationships within any estuary. It is possible to have a diverse array of organisms, but if the appropriate trophic levels are not well represented, a fisheries collapse could still occur (Pauly *et al*., 1998).

Therefore, the management responses necessary to address the risks of disrupting trophic relationships are very poorly developed for the Estuary Prawn Trawl Fishery. However, it should be noted that such risks cannot be effectively addressed through a single fishery such as estuary prawn trawl. Given that several fishing sectors operate within estuaries (recreation, Estuary Prawn Trawl Fishery, Estuary General Fishery and Indigenous), they could all potentially be having an affect to varying degrees (not to mention other human induced disturbances such as stormwater run-off). Trophic relationships (as with other aspects of estuarine ecology) could therefore be suffering from effects of cumulative impacts (Dayton, 1996) rather than just those of a single fishery. If so, then a holistic approach to mitigating these affects is needed across all fisheries and government agencies rather than fragmented management by individual fishing sectors or agencies. This will be discussed in more detail in section 11 of this chapter.

4. Translocation of Organisms and Stock Enhancement

Translocation of an aquatic organism can be generally defined as "the movement of live aquatic material (including any stages of the organisms' lifecycle and any derived, viable genetic material) beyond its accepted distribution, or to areas which contain genetically distinct populations, or to areas with superior disease or parasite status." (MCFFA, 1999).

The introduction of exotic species into new environments can pose a major threat to the integrity of natural communities, the existence of rare and endangered species, the viability of living resource-based industries and even human health. Marine pests can be as damaging as pollution events but their effects are usually much more persistent (CRIMP, 2000a).

The risks associated with the translocation of any organism include the potential for the establishment of feral populations, environmental impacts and genetic shifts in wild populations. There is a wide range of species that have been introduced into Australia (Pollard and Hutchings, 1990a,b). Some of the more notable marine translocations which have occurred in Australia include Northern Pacific seastars (*Asterias* sp.) and the Japanese seaweed (*Undaria* sp.).

Translocated species, if introduced to a new water body under the right conditions, may grow or breed prolifically and adversely affect other species or habitats; for example an introduced marine snail may compete with local snails, whilst a macroalgae (such as *Caulerpa taxifolia*) may smother seagrasses.

a) Possible mechanisms of translocation

Live aquatic organisms may be transported either deliberately through the live product trade or by use as live bait, or inadvertently through the movement of water (ballast water and/or bilge waters), vessels (hull fouling) or gear. Some invertebrates and macroalgae readily survive transport if lodged amongst damp equipment, and in some cases only a small fragment of macroalgae is necessary for propagation.

i) Deliberate translocation

Currently there is no trade in live organisms derived from this fishery. Given the species concerned, it is considered unlikely that such trade will develop in the future unless there is a significant increase in market value or demand for live products.

ii) Inadvertent translocation

Movement of water

There is a risk that some vessels will retain water in their bilges, which could therefore be transferred between locations.

Should live product trade or live bait practices be introduced on a significant scale, the fate of the transport medium would be of some concern as undesirable organisms may be transported with it. This would especially be the case if the product/bait is being sourced from an area where pests, red tides, algal blooms or disease outbreaks are current and/or common, and if there is a possibility of subsequent release into waterbodies currently without these problems.

The risk may be minimised through appropriate treatment and disposal of the transport medium, including the appropriate treatment (cleaning etc.) of equipment. The risk can be further minimised through obtaining catches from areas where there have been no associated pest species or disease outbreaks.

Movement of fishing vessels

Only a small number of fishers in the Estuary Prawn Trawl Fishery have endorsements for more than one estuary. The risk of translocating a pest species between estuaries is therefore minimal. However, some Estuary Prawn Trawl fishers also hold endorsements for the Estuary General Fishery, and it is not uncommon for fishers to use the same vessel for both fisheries. There are currently no regulations in the draft FMS that govern the cleaning of vessels used in more than one fishery. Consequently, there is some risk of translocating organisms through the fouling of hulls or via their internal water supply systems.

Movement of fishing equipment

The movement of trawl nets between fishing grounds is a significant vector for the movement of some hardy species, particularly if the net is not thoroughly cleaned after each fishing operation, and it is rolled or bundled so that it remains damp until the next operation. A number of species, including some algae and molluscs, can remain alive in damp conditions for several days and could be routinely and effectively translocated by this means. However, given that there are few fishers who trawl in more than one estuary, the risk of translocating organisms between fishing grounds is small for the Estuary Prawn Trawl Fishery.

b) Species likely to be translocated by fishing equipment

For an organism to be successfully translocated through fishing activities, it will need to survive collection, transportation and release. Species that are most likely to be translocated by fishing equipment are those that are vulnerable to capture by, or attachment to, the gears used, and not susceptible to mortality as a consequence of the collection, transport or release. These will include species that are found on the fishing grounds in association with target species or their habitat, are hardy, and can survive out of water for reasonable periods.

Organisms subject to translocation can include: species native to NSW that are moved between existing populations; native species that are moved to new locations (range extensions); or exotic species which having been established in one location (in NSW or possibly another State) could be spread further via fishing equipment or vessels.

The primary threat of translocation comes from species able to adapt, survive and form viable populations in the new environment. These species can cause direct impacts such as predation and competition. While some translocated organisms do not establish feral populations, they can still have indirect impacts by carrying diseases or parasites from their original environment.

The species most likely to be successfully translocated by the NSW Estuary Prawn Trawl Fishery include any number of native plants and animals, but particularly molluscs, echinoderms and algae.

In addition, there is an increasing number of introduced species that are presently found in NSW or neighbouring States, or which could become established in NSW waters, and which may be subject to translocation by fishing activities in the future. These include the following species that have been listed as ‘trigger’ species for national emergency response procedures:

Caulerpa taxifolia* (Vahl.) C. Agardh (1822)

An invasive strain of this macroalgae has become established in a number of locations in NSW including Port Hacking, Lake Conjola, Careel Bay (Pittwater), Lake Macquarie, Botany Bay, Burrill Lake and Narrawallee Inlet. In the northern hemisphere, this species is known to compete with seagrass populations and colonise a wide range of habitats, reducing biodiversity and possibly fisheries productivity. It is very difficult to eradicate and can be spread readily through fishing gear, anchor chains and boating activities (CRIMP, 2000b; Grey, 2001). Fishing gear has been identified as a possible vector for the movement of the species.

Mytilopsis sallei

This species (known as the Black Striped Mussel) is similar to the Zebra mussel which has invaded the Great Lakes in North America and resulted in annual control costs of over US$30 million. It forms massive monocultures of up to 24000/sq.m., out-competing native species and threatening maritime industries through fouling. Although it was eradicated following a $2million emergency response program, the introduction of this species into Darwin in 1999 threatened the pearl culture industry and could have resulted in an ultimate spread to northern Australian coastal waters between Sydney and Perth. (CRIMP, 2001a)

***Undaria pinnatifida* (Harvey) Suringer**

This Japanese seaweed is extensively cultivated as a food plant in Japan, and was probably introduced to New Zealand and Australia as a result of hull fouling or ballast water. The species is highly invasive, grows rapidly and has the potential to overgrow and exclude native marine vegetation. It also has the potential to create major fouling problem for marine farmers. (CRIMP, 2000c). This species is present in Tasmania and Victoria.

***Maoricolpus roseus* (Quoy and Gaimard, 1834)**

Although native to the south island of New Zealand, the NZ Screw Shell has been reported from NSW waters since having spread from populations established as the result of translocations into Victoria and Tasmania. The species is known to establish extremely dense populations and compete with native molluscs. Its extremely high abundance on some fishing grounds is likely to result in economic losses and the high possibility of further translocations. This species is present in NSW waters.

***Asterias amurensis* (Lutken, 1871)**

The northern Pacific seastar is arguably the most serious marine pest established in Australian waters. In 1998, some 50 juveniles were found in Port Phillip Bay (www.brs.gov.au, 2000) but by June 2001 that population had grown to an estimated 130 million (R. Gowans, CRIMP, pers.comm.). This species is a significant predator and a threat to both native marine communities and commercial shellfish farming operations. Although it is most likely to be translocated as larvae in ballast water, an individual has been found in the water intakes of a coastal vessel, and the movement of adults via fishing gear is possible (CRIMP, 2000d). This species is present in Tasmania and Victoria.

***Codium fragile tomentosoides* (Sur.) Hariot subsp.(Van Goor) Silva**

This species is regarded as a pest because of its invasive capabilities and reported impacts on shellfish farms in the United States of America. It is also reported to settle on native algae and to foul commercial fishing nets. Its habitats include intertidal and subtidal hard substrata within both estuarine and oceanis areas. (CRIMP, 2001b). This species is present in NSW waters.

c) Risks and implications of translocations

The translocation of aquatic organisms raises many issues relating to the maintenance of local biodiversity, including genetic shift in wild populations, the establishment of feral populations, environmental impacts from the release of the species, and the translocation of associated species (MCFFA, 1999). The social and economic impacts of established feral populations caused by previous translocations can be very significant, as evidenced by the financial and amenity costs associated with managing introduced zebra mussel in the Great Lakes of North America.

The introduction of parasites and diseases as a consequence of translocations can also have implications for both biodiversity and social and economic values.

i) Genetic shift in wild populations

Genetic diversity is widely recognised as one of the three levels of biodiversity, and should therefore be preserved to ensure the conservation of biological diversity. Genetic shift is a change in the genetic composition of a population. Such a change may result in a loss of genetic diversity through, for example, certain traits becoming less common than before. Genetic shift may be caused by translocated individuals interbreeding with genetically distinct resident populations of the same species, as such interbreeding would introduce foreign genetic material to the resident population.

Although there is evidence that translocations have caused genetic shifts in native populations (Sheridan, 1995), there are little data available on the genetic composition of populations of aquatic organisms in NSW and no evidence of any such shifts within NSW to date.

ii) Establishment of feral populations

Feral populations are defined as populations that successfully establish as a result of the escape or release of organisms. Translocated organisms may establish feral populations, which can then have a range of negative environmental effects including competition, predation and environmental modification.

There are a number of feral populations of marine organisms already established in coastal waters of NSW, including fish, sea squirts, bryozoans, gastropod and bivalve molluscs, isopods, crabs, barnacles and annelids (Furlani, 1996).

iii) Environmental impacts from escaped organisms

Regardless of their ability to establish self sustaining populations in receiving waters, translocated organisms may have other impacts if they are able to survive long enough in natural waterways. These impacts may include competition, displacement, predation and habitat alteration.

Translocated organisms may compete with and displace local species, potentially causing long-term changes in community structure. Additionally, translocated organisms may eat endemic species. In many cases, endemic species will be at greater risk from the translocated predator than from local predators because there would have been no opportunity for predator-prey co-evolution with respect to the new predator. This may be particularly devastating if the local species are not normally eaten, and consequently have not developed defence mechanisms or appropriate defensive behaviours.

Translocated organisms may alter aquatic habitats, as is believed to occur with the marine alga *Caulerpa taxifolia.* This species has become established in numerous estuaries of NSW, often out-competing and replacing seagrasses. Such a species shift in itself might not always be significant, however *Caulerpa taxifolia* is thought to provide an unsuitable environment for epiphytic organisms, which are important in the food chain of estuaries and adjacent environments.

iv) Implications for aquaculture

Some introduced species, such as the Northern Pacific Seastar, could prey on aquaculture species such as mussels and oysters. Other species such as marine algae could overgrow equipment and sites causing reduced yields and consequent economic losses. Control measures, such as obligatory cleaning of mussel ropes and the washing or sterilisation of gear could impose additional operational and financial burdens on farmers.

As a result of the establishment of *Caulerpa taxifolia* in Lake Conjola, the oyster farmer who holds leases in the area has been obliged (under the conditions of his permit) to ensure that his dinghy and gear are clean, and inspected, before he moves them between the lake and other sites. Furthermore, the depuration water used to treat Lake Conjola oysters must not be released into waterways.

v) Implications for other water users

Introduced species can have a direct impact not only on aquatic biodiversity and fisheries production, but also on other water users. Feral populations of pest fouling organisms such as mussels and algae can result in loss of amenity and additional costs to all water users, and to tourism and the community in general. For example, the introduction of the invasive zebra mussel into the Great Lakes has resulted in the fouling of fishing vessels, pleasure craft, stormwater outlets, marinas and moorings, boat ramps and beach amenities, at significant cost to many sectors of the community.

vi) Implications for the environment

The establishment of introduced species breaks down the isolation of communities containing co-evolving species of plants and animals. Such isolation is essential for the evolution and maintenance of biodiversity. Disturbance of this isolation by alien species can interfere with the dynamics of natural systems and cause shifts in predator/prey relationships, and ultimately, the premature extinction of affected species (www.iucn.org, 1995, see Sheridan (1995) for a review).

vii) Diseases and parasites

Translocations may result in the introduction of an exotic disease or parasite (bacteria, virus, protozoan or other organisms e.g. polychaetes, nematodes) into natural water bodies and the subsequent infection of fish stocks or aquatic vegetation. The translocation of endemic diseases and parasites to new areas is also a major concern.

Parasites and disease are an integral part of any natural system. However, the introduction of disease or parasites (not necessarily exotic) into a natural water body could change the existing parasite and disease status of that waterbody. Such an introduction may perpetuate or aggravate existing diseases by increasing their incidence, virulence, potency and frequency. This impact may apply to parasites such as ecto-parasites on fish, fungal flora and stomach parasites.

d) Assessment of management responses proposed in the draft FMS

As translocation requires the movement of an organism from one water body to another where it is not normally found, the more mobile the fishery and the greater the degree of flexibility for operators to move around the State, the greater is the risk of translocation regardless of the means. In the case of the Estuary Prawn Trawl Fishery, fishing activities are now restricted to specific estuaries and only fishers who hold endorsements for more than one estuary can move between these estuaries. At present, only a few estuary prawn trawl fishing businesses operate in more than one estuary. Furthermore, the risk of the fishery translocating organisms into new areas is small, especially as the geographic range between each estuary is limited (the maximum is less than 200 km of coastline).

An area of concern for the fishery is the possible establishment of *Caulerpa taxifolia* within the trawled estuaries. If this were to occur the fishery could facilitate its spread within an estuary, and restrictions on the use and movement of fishing equipment would be required. Management response 1.4a (the implementation of measures in accordance with any marine pests or disease management plans) accounts for such an outbreak.

i) Management of marine pests in NSW

There are currently no formal processes in place for the management of introduced marine pests in NSW, although the State is committed to the development of such processes in the short term. The NSW Government has endorsed the recommendations of the National Taskforce on the Prevention and Management of Marine Pest Incursions. These recommendations include the requirement for all States and Territories to provide resources in the interim and/or long term for:

- effective and timely implementation of interim arrangements for managing marine pest incursions pending the development of a National System for the Prevention and Management of Marine Pests
- the development and implementation of a NSW Emergency Marine Pest Management Plan (EMPMP)
- data collection and dissemination on pests and response processes
- a review of legislative powers to act in the event of an emergency
- communication and information programs
- the development of the National System for the Prevention and Management of Introduced Marine Pests
- plans for the mitigation of impacts from established marine pests
- the inclusion of marine pests provisions in port environment management plans
- investigating the issue of liabilities for persons involved in dealing with emergency responses

- agreement to contribute to interim national cost sharing arrangements for emergency responses comprising a 50:50 share between the States and the Commonwealth, with the States' contribution calculated on a simple per capita basis
- agreement to contribute to a national funding base for the support of the National System in the long term including port baseline surveys, community preparedness, education and training, research and development and monitoring (AFFA, 2000).

The NSW EMPMP will include details of the mitigation methods proposed, and these will be in accordance with the guidelines laid down in the Taskforce Report (AFFA, 2000). These guidelines will include general protocols for the transport and handling of equipment being moved between estuaries in the event of an outbreak of marine pests in any region.

e) Contingency plan for pest species management in NSW

In the event of an outbreak of marine pests in the intervening period, NSW will adopt the draft Australian Emergency Marine Pest Plan as detailed in the report of the Taskforce on the Prevention and Management of Marine Pest Incursions.

Education programs are required to make boat operators and owners aware of the potential for their vessels to transport exotic fouling organisms and the steps they should take to minimise the risk of this occurring.

Codes of practice are required to ensure that fishing operations do not facilitate the spread of exotic organisms through the movement of equipment between areas. This will involve industry awareness programs and the development of treatment (‘sterilisation’) protocols for gear and equipment. In Victoria for example, research is currently underway to develop ways of treating mussel grow-out lines to kill exotic species before lines are moved between coastal waters (CRIMP, 2000a). Similar protocols are imposed in NSW for the management of *Caulerpa taxifolia*.

i) Current situation: *Caulerpa taxifolia*

Following the identification of invasive populations of the marine algae *Caulerpa taxifolia* in NSW, the Minister for Fisheries announced a series of restrictions, including prohibition on the removal of equipment from already affected estuaries, area specific fishing nets and boats, and the closure of certain waterways to netting activities. These actions have been backed by an intensive public education and awareness campaign on the nature and impact of the species, and by the declaration of the species as Noxious Marine Vegetation.

ii) Small ports project

NSW Fisheries is working in association with the Victorian Department of Natural Resources and Environment, local port managers, the Centre for Research on Introduced Marine Pests and other agencies to develop practical ways to assist fishers, vessel operators and port managers in reducing the risk of spreading marine pests. The key focus is on ways to reduce the spread of marine pests through gear and hull fouling and the results will be in the form of a series of guidelines (DNRE, 2000).

iii) Diseases and parasites

The *Fisheries Management Act 1994* contains provisions for responding to diseases of fish or marine vegetation. These provisions include powers to declare a disease, establish quarantine areas, prohibit the sale or movement of diseased fish or marine vegetation and control the release or transmission of the disease. In addition, plant diseases can also be declared and subsequently managed in a similar manner under the provisions of the *NSW Plant Diseases Act 1924*.

Following its endorsement by the Commonwealth Ministerial Council on Forestry, Fisheries and Aquaculture, NSW (along with all States and Territories) is committed to the management of aquatic animal health through AQUAPLAN. This plan is a broad comprehensive strategy that outlines objectives and projects for developing a national approach to emergency preparedness and responses in the overall management of aquatic animal health in Australia (AFFA, 1999). Within AQUAPLAN there are a series of programs, including Quarantine, Surveillance, Monitoring and Reporting, Preparedness and Response, and Awareness, that will address aquatic disease management issues.

As with marine pests, it will be important to ensure that fishing operations do not facilitate the spread of disease through the movement of equipment between areas. Depending on the nature of the disease, such actions may include industry awareness programs and/or the development of treatment ('sterilisation') protocols for gear and equipment. Alternatively, the closure of areas to fishing can be ordered by the Minister under the provisions of Section 8 of the *Fisheries Management Act 1994.* These aspects are addressed in the draft FMS.

f) Stock enhancement

There are currently no proposals for the artificial enhancement of populations of species targeted by the fishery.

All such proposals would be subject to separate environmental impact assessment processes in accordance with the provisions of the EP&A Act 1979.

5. Fish Health and Disease

a) Impacts of gear types and fishing methods

It is considered that the gear used in the Estuary Prawn Trawl Fishery is unlikely to have a significant impact on the health of target or non-target organisms. While some individuals will be physically injured or damaged by the direct effect of fishing gears (see section 2 of Chapter E), there is no evidence to suggest that fishing activities are having any impact on the health of individuals in the ecosystem, or are promoting increased risks of disease. There is no information available on the levels of stress, injury or susceptibility to disease that might be imposed as a consequence of activities associated with the fishery.

b) Use of bait

The Estuary Prawn Trawl Fishery does not use bait, and therefore does not pose any risk of disease transmission from imported bait products.

c) Stock enhancement

The deliberate translocation of any target species as part of a stock enhancement programme would present a risk of disease and parasites, although this can be mitigated by the use of fingerlings/fry that have been raised in accordance with appropriate health protocols. However, as previously noted, there are currently no proposals for the artificial enhancement of populations of any species targeted by the fishery and none are anticipated in the immediate future. All such proposals would be subject to separate environmental impact assessments.

6. Water Quality Issues

a) Potential sources of pollutants related to the proposal

Potential sources of pollutants from the Estuary Prawn Trawl Fishery operations likely to affect the water quality of trawled estuaries are: antifouling agents; discharge of chemicals; fuel or bilge water; discharge/dumping of debris; and discharge/dumping of on-board processing waste.

i) Antifouling agents

Antifouling agents are painted on boat hulls to reduce marine growth and the consequent loss of performance. In recent years, much concern was raised about the environmental effects of tributyl-tin based compounds, especially regarding their bioaccumulation in sessile organisms. However, these compounds have now been banned on all vessels less than 25 metres in length, and are no longer allowed to be used on boats in the Estuary Prawn Trawl Fishery. Substitute treatments are far less damaging to the environment. Also, many vessels used in the Estuary Prawn Trawl Fishery are regularly moved between brackish and high salinity areas, reducing the need for regular antifouling. Consequently, the frequency of antifouling treatments by the fishery and its environmental effects are minimal (Table F8).

ii) Discharge of chemicals, fuel or bilge water

Accidental or (very rarely) deliberate discharges of chemicals, fuel or bilge water are likely to occur in relation to vessels used in the Estuary Prawn Trawl Fishery. However, serious discharges would be very rare. Modern engines and fuel systems are compact and easily managed, meaning that individual spills of fuel and/or oil are likely to be extremely minor. Some oil and fuel discharge could occur during engine maintenance and re-fuelling. Bilge water is also discharged from estuary prawn trawl vessels. However, the volume of discharge from vessels averaging 7.6 m in length is small. Within the Sydney region, there are numerous bilge water and effluent pump out facilities, but very few outside the Sydney area. Bilge water is likely to consist predominantly of water, along with small amounts of fish waste, fuel and oil. Such discharge would be only mildly toxic and unlikely to have any major effects considering the volumes involved (Table F8).

iii) Dumping of debris

A variety of debris may potentially be dumped or lost from fishing vessels. Examples include plastic, paper and pieces of fishing gear. Such materials are mostly non-toxic, but may injure or interfere with marine life. Such interference or injury would be rare, simply because with estuary trawling the gear is retrieved and rarely lost, and most debris would not be of a shape and/or material likely to trap or ensnare birds and other animals. Also, species likely to ingest items such as plastic bags (e.g. turtles) are relatively uncommon in NSW estuaries. Members of the public are now very conscious of gross litter (Zann, 1995) and commercial fishers in particular are becoming increasingly conscious of any obvious pollution within their working environment. It is therefore likely that any incidents of discharge or dumping of debris by the fishery would be very minor (Table F8).

iv) Discharge/dumping of on-board processing waste

On board processing waste is likely to consist of liquid ‘slurry’ containing body juices, scales etc. For food safety reasons, the Estuary Prawn Trawl Fishery are required to cook their prawns on the water, the discards from which are then thrown overboard. All such waste would be readily decomposed or eaten, although not without possible trophic effects (see section 3 of this chapter) and/or impacts associated with nutrient enhancement (see section 10 of this chapter). While the Estuary Prawn Trawl Fishery cook their prawns on the water, any processing of fish is most likely to occur at shore-based facilities as on-board processing or mutilation of fish is prohibited on or adjacent to the water (management response 5.4b). The discharge of waste associated with the cooking of prawns is considered to be a moderate source of pollution from the Estuary Prawn Trawl Fishery (Table F8). This issue should be addressed within the draft FMS.

Table F8. Characteristics, likely magnitude and probable frequency of pollution sources derived from operations associated with the Estuary Prawn Trawl Fishery.

Source	Characteristics/ issue	Magnitude	Frequency
Antifouling treatments	Toxic chemicals leached into water, more toxic forms particularly harmful to sessile invertebrates	**Low** - less harmful compounds now in use; slow rate of release into environment	**Low** - possibly one treatment per vessel per year
Chemicals, fuels etc.	Toxic chemicals discharged into water; variable effects depending on compound	**Low** to **Moderate** - depending on actual incident	Fuels and chemicals: **Low** except for extremely minor incidents; Bilge water: **Moderate**
Debris	Solid mterial, generally non-toxic; but may injure or interfere with marine life	**Low** - minor accidental dumping only likely; most fishers increasingly conscious of gross pollution	**Low**
On-board processing waste	Organic material likely to be consumed by marine life; can have undesirable trophic effects, and is a source of (usually undesirable) nutrients	**Low** to **Moderate** - vessels used in fishery prohibited from on-board processing of waste; discards from cooking prawns thrown overboard	**Moderate** in relation to waste from cooking prawns; **Low** otherwise

Magnitudes and frequencies are given in relative terms, bearing in mind the size of vessels used in the fishery, other boating activity in the trawled estuaries and their catchment landuses. In terms of magnitude, “Low” means no measurable effect likely from an individual incident; “Moderate” means localised and/or short term effects likely; and “High” means widespread and/or long term effects likely.

b) Associated risks to water quality

Each estuary prawn trawl fleet represents only part of the total boating population in each of the trawled estuaries. Other boating activity, such as transport, recreational boating and other commercial fishing activity, is also common in these estuaries. Most of the trawled estuaries are near or adjacent to large urban populations and consequently support large amounts of recreational boating. In the Hunter River and Port Jackson, boating activity is further boosted by the presence of major international shipping ports and, especially in Port Jackson, busy transport routes. Thus, any water pollution originating from the Estuary Prawn Trawl Fishery represents only a very small proportion of that from the total boating activity in these estuaries. This is especially so when one considers that in all trawled estuaries, except the Hawkesbury River, the prawn trawl fleet is restricted to operating during seven months of the year and at certain times of the day.

As discussed previously, the Estuary Prawn Trawl Fishery is not a major polluting activity as any associated sources of water pollution are likely to be of low magnitude and low to moderate frequency (Table F8). Considering that the catchments of these estuaries are largely developed (see section 10 of this chapter) and that their waterways are busy with a variety of other users, water pollution problems are far more likely to originate from sources other than the fishery. However, trawling activity can contribute to spreading contaminants around estuaries (see section on 'suspended sediments' below).

There is some potential for the fishery to cause localised water pollution problems near areas where on-shore facilities (such as co-operatives and slipways) and mooring facilities are provided. Whilst any effects related to vessel maintenance and bilge water are likely to be insignificant given the number and sizes of other vessels using trawled estuaries, significant (though highly localised) effects from on-shore processing facilities and areas where prawns are cooked are possible. Discharges from such facilities would primarily consist of non-toxic organic waste derived from cleaning fish and cooking prawns. This would be expected to have some localised trophic effects (e.g. attract scavengers) and would contribute nutrients to receiving waters. However, in the context of the plethora of major land-based nutrient sources (section 10 of this chapter), the effects of any such nutrient contrbutions are likely to be minor.

The trawled estuaries are relatively large, deep and have wide permanently open entrances. Their assimilation capacities should be able to handle any pollution events related to the fishery. Even under abnormal conditions, such as stratification after heavy rainfall or lowered dissolved oxygen levels, pollution associated with fishing operations is unlikely to have any significant effects in the context of other vessels using these estuaries, and the wide range of land-based sources of pollution.

Suspended sediments

Sediment resuspension caused by trawling can increase turbidity in the area of the trawl. The extent, duration and magnitude of such resuspension will depend on the composition of the particles, speed and frequency of trawl, sediment penetration, water depth and prevailing water currents (Churchill, 1989). Resuspension of sediments can decrease water quality by releasing heavy metals into the water column, creating anoxic conditions and decreasing visibility. To what extent these conditions occur and if they persist long enough to have any lasting effect is unknown in NSW estuaries. Studies elsewhere suggest that sediment resuspension from trawling can lead to shifts in benthic flora and fauna and community composition (Churchill, 1989).

Conclusion

On the basis of the above, the risk to water quality associated with fishing operations in the Estuary Prawn Trawl Fishery is assessed as being low-medium, and requires only some further management given existing controls as administered by the Waterways Authority and the Environment Protection Authority. The resuspension of sediment from trawling activity and subsequent possible increase in turbidity and spread of contaminants should be given some attention in the draft FMS. The proposed code of conduct (management response 1.2e) is a precautionary measure that should ensure that fishers remain conscious of the pollution they are causing and minimise such events from occurring. However, the code of conduct should be more focussed on the discharge of water from cooking prawns.

c) Baseline studies in areas of significant impact

There are unlikely to be any areas of significant impact on water quality arising from the Estuary Prawn Trawl Fishery, and no baseline studies are therefore necessary. Existing controls (administered by the Environment Protection Authority) on shore-based activities liable to cause pollution are sufficient to effectively manage activities such as on-shore processing and vessel maintenance.

7. Noise and Light Impact Assessment

The following summary is based on the detailed Consultants report prepared by Snowy Mountains Engineering Corporation, presented in Appendix CF1.

a) Noise impact on residents adjoining estuaries

Noise from the Estuary Prawn Trawl Fishery may adversely affect residents where houses are close enough to the estuary for the fishing activity to cause disturbance. There is, however, a diverse range of land uses around the trawled estuaries. Urban development, in particular, dominates the shorelines of Port Jackson and parts of the other estuaries. Against this background of noise sources and given the likely low sound power levels associated with the proposed activity, it is probable that there is only a potential for disturbance during night-time operations. Furthermore complaints related to fishing activity are minimal. The potential for disturbance of a particular household would be determined by a number of factors, namely the:

- size of the boat motor and whether it is an outboard or in-board motor
- duration of prawn trawling and prawn cooking (on the vessel) activity
- number of other trawlers operating in the same area
- position of the house, both its distance from the activity and intervening topography
- land-based activity such as prawn cooking on a wharf in the vicinity of the house.

It should also be noted that a house in a coastal town urban area or close to a wharf could be expected to experience higher background noise levels than an isolated farm property.

b) Noise impact on wildlife

Noise from estuary prawn trawl fishing activities would only affect wildlife when:

- trawling is undertaken in areas where noise-sensitive wildlife are present
- noise from trawling activities disturbs wildlife either due to the volume or type of noise generated.

Noise impacts could result from fisherman's voices, the sound of equipment contacting boats, engines, winches operating, prawn cooking and the splashing of water. There are no data on the level of noise generated by winches and other machinery used in the fishery, nor on the associated likelihood of impacts on wildlife. Wildlife that could be affected may include birds, terrestrial mammals, aquatic mammals and non-target fish. Any such wildlife that is disturbed may:

- remain in the area but become inactive (i.e. hide)
- temporarily move away from the area but return when the disturbance has ceased
- permanently move away from the area (this is more likely if the disturbance is prolonged or frequent).

The significance of such disturbance would vary depending on the species and the timing of the disturbance. The greatest impacts could be expected during nesting or breeding. At these times, any disturbance could affect reproductive success and may endanger the viability of local populations (see section 2 of this chapter). This would particularly be the case if the disturbance was frequent, regular or on-going.

Species most likely to be impacted by prawn trawling during the nesting or breeding season would include birds that nest in aquatic or riparian vegetation. Non-target fish could similarly be impacted if trawling is undertaken near shallow water nursery or breeding habitat such as mangroves or seagrass.

c) Noise mitigation measures

A potential for adverse noise-related impacts from estuary prawn trawl operations on people and wildlife has been identified. This potential is not new, as prawn trawling has taken place in NSW estuaries for 75 years. However, the fishery is governed by a number of existing controls relating to areas and times of operation. These controls were instigated for a number of reasons, including wildlife conservation and the prevention of disturbance to people living near estuaries. They are summarised in Chapter B and include:

- Location controls, referring to restrictions on areas within an estuary where trawling can be done
- Time controls, referring to daily time restrictions on when trawling may be done
- Weekend/public holiday/school holiday closures, referring to total closures or closures to estuary prawn trawl activity during the specified times
- Seasonal controls, referring to restrictions on the periods of the year during which trawling may be done.

Complaints concerning noise levels from the Estuary Prawn Trawl Fishery are currently monitored. Two authorities receive complaints, local councils (who tend to refer them to NSW Fisheries) and regional offices of NSW Fisheries. The number and type of complaints should be used as input into the review the existing controls. The proposed code of conduct should help minimise any noise-related impacts from the fishery.

d) Light impact on residents

The only potential for adverse effects from lights used in the fishery would be from spotlights. Navigation lights or deck lighting would not cause significant adverse effects. Spotlights would only cause problems where they were shone into houses adjoining the estuary. Given that the activities of the Estuary Prawn Trawl Fishery do not normally require intensive use of spotlights nor high strength lights, significant adverse impacts are not anticipated.

e) Light impact on wildlife

Impacts from light upon wildlife are unlikely to be significant unless beams of light repeatedly or continuously affect the same individuals. The severity of such impacts would increase with the intensity of the light. The most susceptible wildlife would be that occurring in the water, on aquatic vegetation or near the water edge. Animals potentially affected would include aquatic mammals, non-target fish, arboreal and terrestrial mammals and birds. Nocturnal species would be the most likely to suffer impacts. However, diurnal species disturbed from their sleep could also be impacted.

f) Light mitigation measures

The mitigation measures outlined above for noise impacts are generally applicable for reducing adverse effects from lighting. In summary, these measures were:

- existing controls to limit the location and hours of estuary prawn trawling
- monitoring of complaints
- code of conduct.

8. Air Quality

The following summary is based on the detailed Consultants report prepared by Snowy Mountains Engineering Corporation, presented in Appendix CF1.

The two identified sources of air emissions from the Estuary Prawn Trawl Fishery boat engines and prawn cookers. Emissions from these sources do not have the potential to significantly affect air quality as they:

- do not represent a concentrated source of inputs, in that the fishery operates in a dispersed manner along the NSW coast
- vary according to both season and time of day
- are from relatively small engines and heat sources.

Mitigation measures to reduce air quality emissions are the same as those proposed to reduce energy and greenhouse inputs. These are discussed in the following section.

9. Energy and Greenhouse Issues

The following summary is based on the detailed Consultants report prepared by Snowy Mountains Engineering Corporation, presented in Appendix CF1.

a) Description of fishing fleet

Boats used in the Estuary Prawn Trawl Fishery are medium sized vessels. They are generally of wood and/or fibreglass construction and normally use diesel marine engines.

Table F9 summarises certain characteristics of the Estuary Prawn Trawl fishing fleet. The median figure represents the size above or below which 50% of the fleet lies. The 80% range indicates the size range within which 80% of the fleet lies, while the range indicates the smallest and largest vessel sizes in the fleet. Most engines are powered by diesel (97%) with smaller numbers using petrol (2%).

Prawns are generally cooked aboard the vessels. Bottled LPG is used as fuel to boil the water in the prawn cookers.

No data are available on the typical operating hours of boats in the fleet. These would vary according to the prawn trawling business, the estuary of operation, and the time of year.

Table F9. Fishing fleet characteristics

Characteristic	Number Registered	Median	80% Range	Range
Engine (kW)	176	67	53.7 to 94.8	6.3 to 263.8
Boat Length (m)	176	7.6	7.0 to 8.8	4.5 to 11.6

Source: Data supplied to SMEC by NSW Fisheries

Petrol and diesel fuels have similar CO_2 emission factors, as shown in Table F10. On that basis, these fuels are similar in their potential greenhouse impact, although actual impacts would depend on other factors such as comparative efficiency between diesel and petrol motors and motor size availability.

Consumption of LPG for prawn cooking results in CO_2 emissions as indicated in Table F10. LPG is a relatively efficient fuel and there are currently no viable opportunities for fuel substitution.

Table F10. CO_2 emission factors

Fuel	CO_2 Emission Factor (kg CO_2/GJ)
Diesel	69
Petrol	65.3
LPG	58.8

Source: *Factors and Methodologies* (Greenhouse Challenge, AGO, 2001)

b) Energy and greenhouse assessment

Energy and greenhouse effects are considered together as the only potential for greenhouse gas inputs is from the energy consumed by boat engines and the LPG used for prawn cookers. Overall, the number and size of the boats, along with the small engines and gas cookers used, means that the overall consumption of energy resources and subsequent greenhouse gas emissions are not significant. The Estuary Prawn Trawl Fishery consists of many small businesses operating in a low technology environment. Potential measures to reduce energy use and/or greenhouse emissions may not be practicable for many of these ventures due to high initial costs.

Renewable energy sources for fishing vessel operation could include solar and wind energy. However, utilisation of these energy alternatives is not currently considered economically viable for vessels used in the fishery

Potential measures to maximise energy efficiency and hence minimise the emission of greenhouse gases for commercial fishing vessels involved in estuarine prawn trawl fishing have not been investigated in any detail within Australia. These measures fall into two main areas, material and technology selection, and operational practice. Specific measures applicable to each of these aspects of commercial fisheries are outlined below.

i) Material and technology selection

Material and technology selection may significantly affect energy use and greenhouse gas emissions. Opportunities for the reduction of greenhouse impacts and improvement in energy efficiency include:

- improved performance marine engines. The US EPA and the State of California EPA's Air Resources Board (ARB) introduced parallel regulations commencing in 2001 that require manufacturers to market improved performance marine engines. According to the ARB the regulations were introduced due to concerns that many conventional two-stroke marine engines burn fuel inefficiently and "discharge up to 30% unburnt fuel into the environment"; the ARB therefore recommend switching from a two-stroke to a more efficient four-stroke marine engine. ARB analysis shows that advanced technology marine engines burn up to 30% less fuel and oil.
- high strength lightweight polyethylene trawler nets. Fuel savings of 10-20% per vessel, reduction of 40% in drag and very short term paybacks in fuel cost savings can be achieved with the use of strong high performance polyethylene smaller diameter fibre in trawl nets
- improvements in bycatch reduction devices, resulting in fuel savings
- selection of equipment with low embodied energy content
- matching equipment size and machinery to catch and journey requirements to minimise energy use
- use of energy efficient lighting systems and controls
- potential application of the Australian appliance energy rating system to assist commercial fishers in selecting energy efficient marine engines and vessels. California's ARB has also introduced a marine engine and watercraft labelling system to indicate to purchasers which vessels 'meet', 'exceed' or 'greatly exceed' their new regulatory requirements.

ii) Operational practice

A number of decisions made during actual operations can have significant impacts on energy efficiency and greenhouse gas emissions. Relevant facets of operational practice include:

- development of systematic and cyclic maintenance programs
- implementation of energy and greenhouse management programs, such as:
  a) ongoing education for the Estuary Prawn Trawl Fishery in energy and greenhouse mitigation strategies through the distribution of information via industry associations and the boat and fishing licence registration system
  b) energy and greenhouse audits
- ongoing consideration of new technologies as they become available and economically viable.

10. External Impacts on the Fishery

External impacts on the Estuary Prawn Trawl Fishery arise both – land based and water based activities. These impacts can affect the sustainability of this fishery and other fishing sectors in a variety of ways. Below is a summary of these impacts and their affects on the fishery.

a) Land based activities likely to affect the environment on which the fishery relies

There are three kinds of land based activities affecting the estuarine environment: foreshore development; stormwater and sewage outfalls; and pollution from point and diffuse sources. All of these occur in or adjacent to the estuaries of the Estuary Prawn Trawl Fishery, although some areas are more affected than others (e.g. foreshore development in Port Jackson is greater than in the Clarence River). Furthermore, research into the impacts of these activities has been patchy and has not covered all the estuaries where the fishery operates. What follows therefore is a summary of studies from a variety of estuaries. Where necessary, inferences are drawn for the Estuary Prawn Trawl Fishery.

i) Foreshore development

Foreshore development includes the construction of marinas, the clearing of foreshore vegetation, drainage of wetlands and reclamation. These developments primarily affect estuaries by destroying habitats for marine organisms (NSW Fisheries, 1999a). These effects are outlined below.

Marinas, jetties and similar structures (NSW Fisheries, 1999a; Hannan, In prep.) may cause direct damage to sensitive habitats during construction. For example, seagrasses may be destroyed by piles, and mangroves may be cut to make way for walkways or ramps. These structures may also cause overshadowing of marine vegetation, with seagrasses (especially strapweed, *Posidonia australis*) being particularly sensitive (Fitzpatrick and Kirkman, 1995; Glasby, 1999; Glasby, 2000; Shafer and Lundin, 1999). Also, localised scouring of the seabed may result from the physical bulk of the underwater portion of a structure causing interference with waves and/or currents. Although the loss of habitat associated with any individual structure may be small, cumulative impacts and fragmentation (especially with respect to sensitive habitat such as seagrass) may be significant along highly developed shorelines (Shafer and Lundin, 1999).

The clearing of foreshore vegetation, say to make way for buildings or recreational facilities, can also have a range of detrimental effects on fish habitats (Hannan, 1997; NSW Fisheries 1999a). Intertidal vegetation such as mangroves or reeds may form habitat corridors for species such as Australian bass and bully mullet, whose juveniles migrate from estuaries to freshwater at a young age. Breaks in habitat corridors may hinder such migration by making the juveniles more prone to predation, by reducing food availability, and/or by altering their behaviour. Foreshore vegetation can also help to absorb and slow runoff, thereby trapping sediments and nutrients before they reach the waterway. Loss of foreshore (riparian) vegetation exacerbates the pollution related problems associated with land clearing and urban development.

Wetlands include mangrove forests, saltmarshes and brackish/freshwater swamps. They provide habitat for a wide variety of fish and invertebrates. They also tend to trap/absorb in-flowing pollutants and therefore contribute to better downstream water quality. Major wetland loss within a particular catchment is likely to impact on fish communities and exacerbate problems relating to nutrient or sediment inputs. For example, a perceived decline in fish populations within the lower

Clarence River over recent decades has been blamed on the widespread drainage of associated swamps, these having provided important nursery and feeding habitats for local estuarine fishes (Pollard and Hannan, 1994). A lack of wetlands (whether natural or artificial) within most urban areas contributes to problems associated with storm water runoff. Furthermore, the drainage and/or excavation of wetlands is also a common cause of acid runoff, which may result in massive fish kills under certain conditions.

Reclamation is often the most damaging type of activity associated with foreshore development, as it usually causes the total destruction (as opposed to modification) of aquatic habitat. Reclamation can also interfere with water circulation, and possibly result in a range of indirect effects beyond the actual works area. These may include increased siltation, reduced water quality and habitat (e.g. seagrass) loss. Major reclamation works, such as those for the runways and port works in Botany Bay (Sydney) can result in the loss of large areas of seagrass and other shallow habitat. Apart from reducing the area available to fishing, such works may have major impacts on an estuary's productivity. In the case of Botany Bay, it is known that reclamation for the third runway resulted in the loss of a particularly productive juvenile habitat, where consistently outstanding recruitment of juvenile tarwhine, luderick and yellowfin leatherjacket had been previously noted by McNeill *et al.* (1992).

ii) Stormwater and sewage outfalls

Stormwater and sewage decrease water quality in estuaries as it carries a wide range of pollutants, the most notable being pathogens, nutrients and sediment. Excessive pathogen concentrations, whilst of primary concern to swimmers, are also likely to affect fish and other aquatic life. Many types of pathogens (particularly bacteria) are not host-specific, and are capable of infecting aquatic animals, particularly when such animals have already been injured in some way. Fish that have suffered damage to their skin or gills are particularly susceptible. Also, many types of mollusc (including oysters and mussels) are filter-feeders and tend to concentrate pathogens in their gut, thereby posing a risk to human consumers. In regularly affected areas, the resultant marketing problems (discussed below) tend to include all types of seafood (including finfish).

High nutrient concentrations can, under the right conditions, promote excessive growths of microscopic algae (such as cyanobacteria and dinoflagellates) in the water. Such 'algal blooms' can become toxic, to the point that other aquatic life are harmed. Also, humans can become ill from consuming affected seafood (especially filter feeding molluscs), leading to marketing problems.

Suspended sediments can clog fish gills and block the filter-feeding systems of invertebrates. In reducing underwater visibility, they can also reduce the feeding ability of sight based predators, including many types of carnivorous fish.

Impacts on habitat

Seagrass habitats are particularly vulnerable to the effects of pollution. Urban runoff (stormwater), sewage overflows and septic seepage threaten seagrass habitat through the continuing addition of suspended sediments and nutrients. These inputs cause greater than natural turbidity, both directly and from excessive phytoplankton growth. Such turbidity is most evident where flushing is poor and inputs are great. Increased turbidity reduces the light available to seagrass, with the deeper parts of a bed being particularly vulnerable to consequent damage (Shepherd *et al.,* 1989; Fitzpatrick and Kirkman 1995). Whilst extra nutrients can actually enhance seagrass growth, very high levels are likely to cause heavy epiphytic growth that can smother and shade seagrass, and eventually lead to its decline (Shepherd *et al.,* 1989). Nutrient enrichment may also promote the competitive replacement of seagrass by *Caulerpa* sp., which are green macroalgae morphologically similar to seagrass.

Also, sedimentation gradually makes areas too shallow for seagrass, particularly in bays receiving urban stormwater runoff. Heavy loads of fine sediment washed down after heavy rain can coat seagrass leaves, reducing photosynthetic efficiency and therefore vigour (Poiner and Peterken, 1995). Seagrass is especially vulnerable to being thus coated in sheltered bays where waves and currents are slight. Where sediment inputs are particularly great, seagrasses can be completely buried. Sedimentation also alters the nature (particularly with respect to parent material and grain size composition) of substrata supporting seagrass which can cause both changes in the seagrass itself, and in the invertebrate community associated with the substrata.

Other habitats can also be seriously effected by sediment-laden runoff. Macroalgae (an important component of rocky reefs) are liable to be affected in the same ways as seagrasses. Macroalgal assemblages on rocky reefs are complex (Kennelly and Underwood, 1992; Kennelly, 1995b) and their recovery after smothering could take years because some species of algae will recolonise faster (such as green turfing algae) than other species (such as kelp). In fact Kennelly (1987) found that early colonising turf algae can inhibit later colonisation by kelp species. Sessile invertebrates (another major component of rocky reef habitat; section 1 of this chapter) are also vulnerable to suspended sediments, which can interfere with their feeding and respiration. Rocky reef itself is vulnerable to being buried by sediment derived from new urban developments and rural erosion; for example, within many of the sheltered bays and inlets in and around Sydney, deposits of sand or mud are slowly encroaching on adjacent rock habitat.

Impacts on seafood marketability

Filter feeding bivalve molluscs (such as oysters, mussels and pipis) are very efficient at concentrating within their guts any bacteria, viruses or toxic algae that might be present in seawater. Whilst these organisms might not harm the mollusc, they can cause serious illness in human consumers, particularly when the mollusc is eaten raw. The risk of human illness is greatly increased when the water from which the mollusc is harvested has been recently contaminated with sewage effluent, stormwater or an algal bloom. Such contamination has the potential to cause many cases of illness, as illustrated in the recent cases of hepatitis attributed to Wallis Lake oysters. These cases were believed to have resulted from poorly treated sewage effluent.

Areas that have been associated with multiple cases of seafood-borne illnesses are likely to acquire a reputation of being 'polluted' and treated with extra caution by members of the public, leading to on-going marketing problems. Furthermore, any negative perceptions (whether based on reality or not) are likely to extend to other types of seafood, such as finfish.

iii) Disturbance / drainage of acid sulphate soils

Excavation or dredging associated with the installation of floodgates or other foreshore works can expose acid sulfate soils to air.

Impacts of acid water

The effects of acid sulphate soil drainage on aquatic biota can be described at the ecosystem, population and species level. In general the effects can be categorized as mortality of fish and invertebrates, increased susceptibility to disease especially epiozotic ulcerative syndrome (EUS), physiological effects (related to reduced growth, visual and olfactory impairment, bone disorders), and avoidance responses (Sammut *et al.,* 1993; Sammut *et al.,* 1995). The cause of the observed effects is not fully understood; however, the interrelation between pH and both the chemistry of iron and aluminum and their respective toxicity are the key contributors to the impacts on biota.

The physiological effects of low pH and its association with aluminum and iron are well studied for northern hemisphere freshwater fish and other aquatic organisms (Erichsen Jones, 1969; Lloyd, 1992; Howells, 1994). However, data for Australia are limited to the work by Wilson and Hyne (1997) and Hyne and Wilson (1997) on Sydney rock oyster embryos and larvae of Australian Bass plus the Richmond River study on estuarine fish and benthic communities (Roach, 1997).

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

Hydrology and rainfall within the catchments govern acid production in a sequence of events that have the following major features and impacts (adapted from the reviews of Alabaster and Lloyd, 1980; Howells, 1994; Cappo *et al.,* 1998; and the research of Sammut *et al.,* 1993, 1995, 1996; Willet *et al.,* 1993). After rainfall events and a rise in the water table, aluminium, iron, manganese and other ions are stripped out of the soil by sulphuric acid originating from the oxidation of pyritic sediments. The significant quantities of aluminium and iron are derived from the aluminosilicate clays commonly associated with coastal estuaries. The lower the pH, the greater the amount of aluminium and other ions that are mobilised. In addition, low dissolved oxygen in water bodies has also been linked to the suspension of iron monosulfides in drains.

Floods and other high flow events drain large "slugs" of this low pH water through floodgates to meet higher pH bicarbonate rich estuarine water. This can produce aluminium hydroxide and iron hydroxide flocs in massive amounts. About 1 tonne of iron floc is produced for every tonne of pyrite oxidised. The Al and Fe flocs disperse through the estuary producing a bluey-green stain. The flocs then bind to clay particles and settle out to produce clear estuarine waters. Smothering of the substratum with flocs of iron hydroxide (up to 1 metre deep) can result in the death of most gilled, benthic life. During this time, fish and invertebrate kills occur for a variety of reasons that depend on the prevailing pH:

- acid kills most fish and invertebrates at approximately pH 3 - 3.5
- aluminium hydroxide flocs bind to clays, attach to skin and block gills at higher pH
- above pH 4, iron oxyhydroxides are precipitated and may cause suffocation
- inorganic monomeric aluminium [$AlOH_2^{++}$] toxicity kills most fish at pH 5
- lack of dissolved oxygen can occur when iron oxidises from the ferrous iron to ferrihydrate.

Fish with epithelial defenses weakened by metal flocs and acid suffer from *Aphanomyces* fungal infections. These infections produce extensive ulcers on fish ("red-spot", "EUS", "Bundaberg Disease"). These are often so deep that the caudal rays or neural spines of the backbone are visible. Survivors of these attacks invest so much energy in healing that there is no reproduction until condition is regained in subsequent years.

Fish with ulcers or healed ulcer scars are unmarketable and have, at times, comprised up to 30% of some catches of whiting, bream, mullet and flathead. Lower growth rates of prawns in pond aquaculture occurs because less bicarbonate is available to them in the low pH water and they will not molt. In the Tweed and Hastings Rivers, the role of acid drainage in oyster mass mortality, disease, shell erosion and low growth performance has also been apparent.

Impacts of floods

Major flooding due to climatic events can adversely affect fish resources and result in significant fish kills. The February/March 2001 floods and resultant fish kills in the Richmond and Macleay Rivers are examples. The floods initially resulted in minor fish kills, but within a week these had escalated to become unprecedented relative to available records. Surveys revealed tonnes of dead and dying fish and invertebrates, from juveniles to adults, throughout the river.

These were sudden floods, the water level peaked quickly and dropped very fast with large volumes of water inundating the floodplain. Then, as the weather cleared, high daytime temperatures followed. Much of the decaying organic material on the floodplain drained into the river over a few days, dramatically reducing oxygen levels. Although water sampling on the floodplain and in the rivers showed acceptable acidity, the dissolved oxygen levels were below one part per million.

The relationship between the floodplain and the fishery is not fully understood and more investigation is needed to identify specific problem areas. However, the changed nature, management and use of the floodplain has altered natural drainage patterns. Flood waters once took 100 days or more to drain back into the river, but now take about five to seven days – resulting in significant impacts on water quality.

iv) Pollution from point and diffuse sources

Unpolluted water is the most critical component of fish habitat, with few fish species being able to survive in badly polluted water. Pollutants affect fish and other aquatic animals in a variety of ways, including direct toxicity, interference with feeding and respiration, altered behaviour, increased susceptibility to disease and reduced reproductive success. Even if pollution does not directly kill affected animals, a variety of chronic or sub-lethal effects can occur.

A wide variety of pollutants enter estuaries and associated rivers and streams. Common pollutants include pathogens, nutrients, sediments and a wide range of toxic chemicals such as heavy metals, oil and pesticides (Table F11).

Table F11. Types and sources of pollutants affecting estuaries.

Type of pollutant	Specific examples	Main sources
Pathogens	Bacteria and viruses	discharges from sewage treatment works; sewerage overflows; stormwater runoff from urban areas
Nutrients	nitrogen and phosphorus	discharges from sewage treatment plants; sewerage overflows; stormwater runoff from urban areas; agricultural runoff from fertilised areas
Sediment	silt, mud, sand; coal wash and clay	land clearing; erosion; building sites; dredging; mining; stormwater runoff
Heavy metals	copper, mercury and zinc	current and former industrial sites; refuelling and boating facilities; airborne dust; sewage overflows; waste dumps; stormwater runoff from urban areas
Oil	crude oil, diesel and petrol	accidental spillage during transport (e.g. ship or road tanker); refineries and associated berthing facilities
Pesticides	various organo-chlorine compounds; dieldrin, heptachlor	agricultural runoff; aerial spraying
Acid	sulphuric acid, hydrochloric acid	runoff from acid sulfate soils that have been exposed to air; accidental spillage/discharge during transport or industrial process
Other toxic chemicals	dioxin, alkalis,	current and former industrial sites; accidental spillage/discharge during transport or industrial process
Thermal	excessively hot or cold water	power stations (hot water); discharges from large reservoirs (cold water)

Further information provided in Birch *et al.* (1996), NSW Fisheries (2000a,b,c), and Irvine and Birch (in press). Those pollutants strongly associated with stormwater and sewage outfalls (pathogens, nutrients and sediment) have been discussed above under section (ii); the remainder are discussed in the following paragraphs.

The sources of pollution as listed in Table F11 fall into two categories: point sources and diffuse sources. Point source pollution originates from a specific identifiable site, such as a discharge point from a sewage treatment plant or industrial site, an accidental spillage or a particular activity (such as dredging or mining). Diffuse source pollution arises from a large area and/or a collection of unidentifiable sites, such as is the case with urban or agricultural runoff. Following is a discussion of the nature and impact of the main types of point source and diffuse source pollutants not already dealt with under section (ii) “Stormwater and sewage outfalls”.

Heavy metals and organo-chlorine compounds, if present in unnaturally high concentrations, tend to accumulate within fish tissue in a process termed bio-accumulation (e.g. Scanes and Scanes, 1995; Birch *et al.,* in press), in some cases leading to ‘biomagnification’, whereby top predators may have very large concentrations of contaminants even without being exposed to the original source (Scanes and Scanes, 1995). Biomagnification occurs because such metals are not easily excreted and because, at each level in the food chain, a particular fish (or other animal) must consume, in the course of its life, many times its own weight in prey (whether that prey be another smaller animal or plant matter). Consequently, tissue concentrations of such substances progressively increase as one goes up the food chain, resulting in particularly high concentrations in long-lived, top predators. Such concentrations, whilst unlikely to kill these predators outright, are likely to have a range of (unknown) chronic effects on growth and reproduction. Affected seafood may, in severe cases, pose risks to human consumers; and associated marketing problems are likely in relation to areas perceived to be polluted by heavy metals or organo-chlorines. Sediments subjected to runoff from urban/industrial areas progressively accumulate heavy metals and other toxic chemicals (Shotter *et al.,* 1995; Birch 1996; Birch *et al.,* 1996,1997; Irvine and Birch, in press). Of particular concern is the fact that previously contaminated sediments continue to affect associated biota (particularly benthos, but also benthos-eating fish), even though waste disposal practises have since improved (Scanes and Scanes, 1995).

Oil and related products can harm fish and other aquatic organisms in several ways. Not only do oil spills release toxins, they can also cover intertidal invertebrates, resulting in suffocation and disruption of feeding mechanisms. In severe cases whole intertidal communities can be affected, denying dependent fish species an important food resource. The short-term effects of an oil spill depend greatly on weather and sea conditions, as well as the clean up method(s) used. Ultimate recovery depends on the recruitment of organisms from other unaffected areas. Mangroves and saltmarsh are most vulnerable to water pollution during high tides, at which time they can be affected by events such as oil spills (Allen *et al.,* 1992a,b), acid soil leachate or toxic spills.

Most aquatic organisms can only tolerate a relatively narrow range of pH values; for example most estuarine fish prefer pH values between 6.5 and 8.5 (Howells, 1994). Values outside of this range (whether caused by acid or alkali) cause irritation and injury to skin, gills and other membranes. This damage subsequently leaves fish more vulnerable to disease. For example, acidic water derived from the disturbance of acid sulfate soils has been shown to cause 'red-spot disease' in fish (NSW Fisheries 2000a,b,c). Extreme pH values, such as might be caused by concentrated runoff or spillage in a confined area, quickly kill fish and other aquatic organisms. Furthermore, the activity of other chemicals present in a water body is strongly influenced by the prevailing pH: for example the bio-availability of nutrients, heavy metals and organo-chlorines may be increased under low pH conditions.

Thermal pollution, whether caused by unnaturally hot or cold water, will kill or repel less tolerant aquatic organisms from the affected area (Hannan, 1985, 1989). Those species remaining will often experience altered growth, feeding and/or reproduction. Within NSW estuaries, the main cause of thermal pollution is the discharge of heated cooling water from facilities such as power stations and refineries. In the case of the power stations on the central coast (in Lake Macquarie and Tuggerah Lakes), discharge temperatures may exceed 35 °C in summer and are commonly around 20-22 °C in winter. The associated plumes may cover many hectares and have been shown to have a range of effects on local fish and invertebrate communities (Friedlander 1980; Virgona 1983; King 1986; Hannan, 1989). These effects include:

- year-round reduction in the abundance of certain species, particularly those closely associated with seagrass (e.g. leatherjackets and pipefishes)
- increased abundances of many species during winter, including most commercially important species
- reduced abundances of most species during summer (but through emigration to other areas rather than through mortality)
- presumed possible increases in overall growth rates
- a range of possible effects relating to increased predation and/or exploitation of fish concentrated as a result of warm waters during winter
- locally altered benthic communities, including the occurrence of tropical species not normally found in central NSW
- habitat alteration, particularly in relation to seagrasses.

Whilst the central coast power stations may be providing a net benefit to fisheries production within the affected estuaries, it is difficult to determine whether the warm water is actually causing an overall improvement, or whether it is merely concentrating fish from other areas and at the same time making them more vulnerable to exploitation (Hair and Bell, 1992).

A database of fish kills in NSW is maintained by NSW Fisheries. Of the more than 400 kills reported from estuarine areas since the early 1970s (A. Lugg, NSW Fisheries, pers. comm.), approximately 53% were attributable to a particular cause (Figure F1). ‘Pollution’ in the simplest sense (i.e. toxic chemicals, pesticides and sewage) was blamed for nearly 18% of the reported kills, while runoff from acid sulfate soils is considered to have caused nearly 16%. Whilst nearly half of the kills able to be attributed to a particular cause were linked to potentially natural processes such as de-oxygenation or algal growth, many of these processes would have been the result of human-related factors such as nutrient enrichment and/or the alteration of natural water circulation.

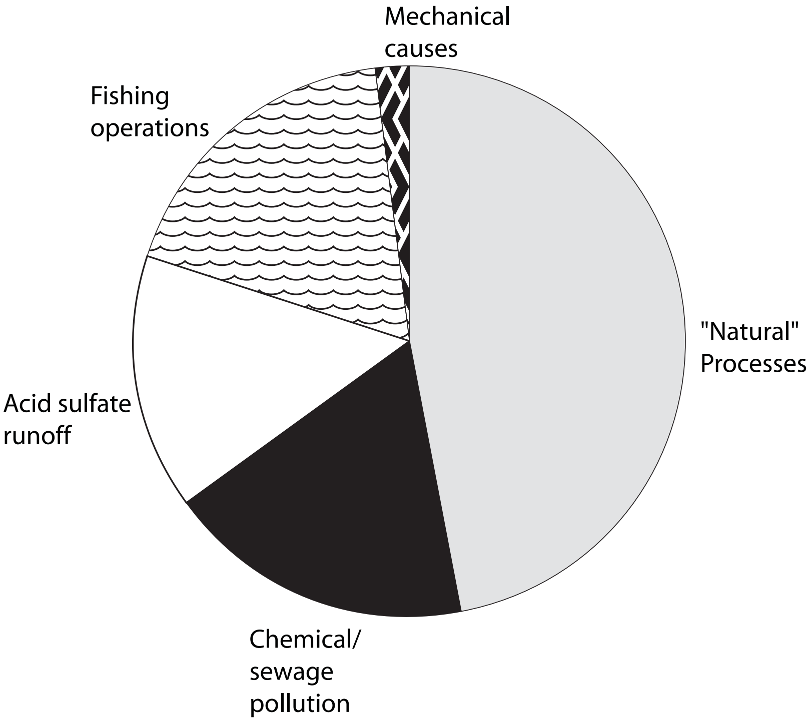

Figure F1. Breakdown of all fish kills in NSW estuaries attributable to a particular cause (data from 1970 to 2000 inclusive).

‘Natural’ processes include events such as water column de-oxygenation and algal blooms; chemical and sewage pollution includes toxic spills, pesticide contamination and sewage discharge; acid sulfate runoff refers to the low pH waters generated from the exposure of acid sulfate soils; fishing operations relate mainly to the discard of unwanted commercial catches; and mechanical causes include underwater explosions and impingement on intake screens. (A. Lugg, NSW Fisheries, pers comm.).

Whilst the number of reported fish kills in NSW estuaries directly attributed to pollution (including industrial chemicals, pesticides, sewage or acid runoff) only averages around 10 to 15 per year (A. Lugg, NSW Fisheries, pers. comm.), many of these kills involve thousands of fish and several species. In severe cases, such as a major spillage into a confined creek, whole fish communities can be killed within the affected area.

With respect to the above-discussed forms of pollution, some estuaries or parts thereof are intrinsically more vulnerable than others. The lower reaches of large ‘drowned valley’ type estuaries such as Sydney Harbour are kept relatively clean by efficient tidal exchange with ocean waters.

However, coastal lagoons which are intermittently open to the sea, and barrier estuaries which have restricted tidal exchange, are particularly susceptible to water pollution. In these cases the reduced tidal flushing means that any pollutants readily accumulate. Even within generally well flushed estuaries, pollutants (including sediment) often accumulate in upper reaches and in tributary bays (Birch, 1996; Irvine and Birch, in press). Also, estuaries with heavily urbanised or intensively farmed catchments suffer far more pollution and/or fish kills than those with unaltered (e.g. forested) catchments. Furthermore, within altered catchments, a greater proportion of incident rainfall ends up as overland runoff, resulting in a more direct and efficient delivery of pollutants to receiving waters.

Overall these pollutants affect the Estuary Prawn Trawl fishery chiefly through reduced water quality and consequent deformities in fish and decreased abundance and diversity of target species. Polluted waters, if known, are generally avoided by commercial fishers who would fish elsewhere. Thus pollutants could temporarily or permanently close an area/estuary to fishing.

b) Water based activities likely to affect the environment on which the fishery relies

i) Vessels

A variety of vessel activities may affect the Estuary Prawn Trawl Fishery, including commercial shipping, vessels from other commercial fisheries and recreational boating. The associated effects are outlined in the following paragraphs.

Commercial shipping is concentrated in a small number of deepwater ports, particularly Newcastle Harbour, Port Jackson, Botany Bay and Port Kembla. Large scale shipping operations are generally incompatible with commercial fishing, especially where hauling or meshing are concerned. However, the affected areas represent only a very small fraction of the potentially available fishing area within the State's estuaries, and are usually characterised by very deep water and a lack of productive shallow water habitats. Commercial shipping does bring with it the risk of a major pollution incident such as an oil spill. Whilst such incidents can cause significant damage to shallow water and intertidal habitats (e.g. mangroves and rocky shores), major events are very rare, and are unlikely to have major long term effects. Chronic or repeated pollution, as from some land-based activities, is likely to be far more serious in this regard (Skilleter, 1995). Commercial shipping may also result in introductions of exotic pest or disease organisms with potentially serious ecological consequences (section 4 of this chapter).

Berthing facilities for large ships typically include large 'finger wharves' and/or smooth vertical walls plunging into deep water. Whilst the wharves have some value as artificial habitat for certain species, their shear size means that extensive dark areas are created. Such areas have been shown to affect significantly fish behaviour, particularly in relation to feeding. For example, (Glasby, 1999) found that species were less abundant under large wharves than in either open areas or unshaded areas with pylons. Also, the smooth vertical walls typical of berthing facilities provide few opportunities for small fish to hide, and are likely to be far less attractive as habitat than natural rocky reef or structures made of broken rock (Coleman and Connell, 2001).

The only commercial fishery other than the estuary prawn trawl that operates within estuaries to any significant extent is the Estuary General Fishery, although lobsters are occasionally trapped over rocky reefs near the entrances of larger (drowned valley) estuaries such as Sydney Harbour. Estuary general fishers operate in many estuaries along the coast of NSW including those of the

Estuary Prawn Trawl Fishery. Estuary general fishers capture (either as bycatch or as target species) several of the target species taken in the Estuary Prawn Trawl Fishery. The associated mortality, along with trophic effects related to discards, and possible habitat damage relating to the various fishing methods used by estuary general fishers, may affect the Estuary Prawn Trawl Fishery (Alverson *et al.,* 1994; Kaiser and de Groot, 2000). However, until specific information about the magnitude of some of these interactions is obtained, the extent of these effects cannot be determined.

Unlike commercial shipping, and vessel activity associated with other commercial fishers, recreational boating significantly affects most estuaries within the State. On many of the more popular waterways, weekend closures affecting estuary prawn trawl operations have been established to minimise conflicts between estuary prawn trawl fishers and recreational users. Cumulatively, these closures affect a large portion of the State's estuaries. Recreational boating is also associated with competition for fish stocks from recreational fishers (West and Gordon, 1994) and possible damage to habitats such as seagrasses (Hannan and Simpson, 1999). Whilst the ultimate effect of these interactions is difficult to quantify, it is clear that recreational boating and its associated activities have had a major influence on the development and operation of the Estuary Prawn Trawl Fishery.

ii) Dredging

Dredging refers to the removal of substrata (e.g. sand, mud or rock) from aquatic or intertidal areas. Apart from the direct loss or modification of habitats in the immediate works area, dredging is likely to cause increased turbidity and/or sedimentation over a much wider area, depending on the nature of the sediments involved and the prevailing waves and currents (NSW Fisheries, 1999a). Habitats such as seagrass and rocky reef may therefore be degraded well outside of the actual area dredged. Dredging may also create stagnant deep holes, alter currents, cause seabed or river bed erosion and liberate pollutants previously trapped in sediments (Scanes and Scanes, 1995; NSW Fisheries, 1999a). Dredging can, however, be used to rehabilitate fish habitats: in some situations appropriate dredging can improve water circulation and quality and promote habitat diversity (NSW Fisheries, 1999a).

The long term effects of dredging on fish habitats can be far reaching. Quigley and Hall (1999) found that a control site 500 m away from a dredged site had been affected and that both areas had not recovered six months after dredging ceased. Also, *Posidonia* (strapweed) seagrass, if removed, will take many decades to recover, if recovery occurs at all (King, 1981a; Keough and Jenkins, 1995). Even with more vigorous seagrasses such as *Zostera* (eelgrass), recovery may be prevented by instability of the remaining sediment, particularly in areas subject to strong waves or currents (Hannan, in prep).

Whilst most dredging projects involve small-scale works and only localised effects, large scale works for projects such as port development or entrance maintenance can have estuary-wide effects involving to altered tidal and/or wave regimes. Possibly the best example of such effects can be found in Botany Bay, where configuration dredging was done in the early 1970s. This dredging altered the path of incoming swells, substantially increasing wave heights on the southern shores, including those at Towra Point. Seagrasses were damaged, and many sections of shoreline began eroding at accelerated rates. Consequently, protective works such as rocky groynes and concrete seawalls have had to be installed and the availability of shorelines for commercial fishing operations has been compromised. The rocky groynes have not only interfered with some fishing operations but they have also modified the habitat. Seagrasses and benthos have been directly lost, although the effects of this on associated fish communities is unknown. However, habitat diversity has been increased (by the addition of rocky substrata) and anecdotal information suggests that certain species such as luderick have benefited.

iii) Structural engineering works

These include barriers to river flow (such as dams and weirs), groynes and training walls. These works can potentially impact on the fishery, either with respect to operations, or through effects on fish communities and/or their habitats.

Groynes are normally constructed out of large rocks and are used to prevent shoreline erosion. They work by intercepting longshore drift and the associated sand movement: sand becomes trapped on the up-drift side, thereby stabilising the shoreline in this area. Unfortunately, this process deprives the beach on the down-drift side of sand, thereby worsening any erosion in that area. So, consequently, several groynes are often needed to stabilise a substantial length of shoreline. Groynes have both negative and positive effects on fish habitats. Whilst their construction is often at the expense of seagrass, they provide good substitutes for natural rocky reef habitats (SPCC, 1981a; Burchmore *et al.,* 1985; Lincoln Smith *et al.,* 1992). Large numbers of groynes have been placed within Sydney's Botany Bay (see also under 'dredging' above), but in general they are rare or non-existent in most estuaries.

Training walls are used to stabilise estuary entrances. They are constructed with the same material as groynes and have similar implications for fish habitat. Training walls normally ensure that an estuary entrance remains open either permanently, or at least more consistently than would otherwise be the case. They can therefore have far-reaching effects on an estuary's ecology: essentially they promote greater tidal exchange, which in turn leads to higher salinities and better overall water quality. Larval distributions, patterns of juvenile recruitment, and overall community structure among fish and invertebrates are also likely to be affected due to reduced effective distances from the ocean (Bell *et al.,* 1988; Hannan and Williams, 1998) and by altered salinity regimes and habitat condition. Furthermore, productivity may be reduced due to increased flushing by ocean waters that may lower nutrient concentrations and therefore reduce phytoplankton densities. This possibility is partly supported by the findings of Gibbs (1997) who, in an analysis of south coast commercial catch data, found that intermittently open estuaries are frequently more productive (in terms of reported values and weight of finfish and prawn catches) than are permanently open estuaries. Although the above-mentioned effects are potentially very significant, and training walls are present at the entrances of many of the State's estuaries, there is no clear evidence of any overall negative impact on the Estuary Prawn Trawl Fishery.

There are more than 2500 barriers to river flow, including dams, weirs and floodgates within the major coastal catchments of NSW (Thorncraft and Harris, 2000). These structures serve various purposes including the supply of drinking and irrigation water, flood mitigation and the improvement of in-stream aesthetics. Dams are the largest of these structures, many being more than 50 metres high. Weirs are essentially low dams and are typically between 0.5 and 5 metres high. Floodgates (also known as 'tidal barriers') are specialised structures designed to exclude tides and backed-up floodwaters whilst allowing local runoff to escape. Major barriers such as dams, weirs and floodgates are most numerous in the north of the State (Williams and Watford, 1996; Thorncraft and Harris, 2000). Among the major coastal river systems, the Tweed, Richmond, Clarence, Bellinger, Macleay, Hasting, Hunter, Hawkesbury and Shoalhaven rivers all have at least 100 barriers of one kind or another (Thorncraft and Harris, 2000). Other in-stream structures that result in at least a partial barrier include road crossings and culverts (Williams and Watford, 1996; NSW Fisheries 1999b). These structures are quite numerous, particularly in urban and well populated rural areas.

These various barriers can have a range of environmental impacts, the most notable relating to fish passage, environmental flows and thermal (cold water) pollution. These are discussed in the following paragraphs.

Fish passage

Fish passage is the process by which fish move around within their environment (NSW Fisheries, 2000a). These movements can be for a variety of reasons including reproduction, feeding and habitat selection. Fish populations subject to restricted passage are likely to suffer reductions in overall distribution, reduced juvenile recruitment, increased predation and/or disease at sites of enforced overcrowding and/or reduced genetic diversity. Even the best possible habitat is of no value to fish if they cannot reach it.

Structures such as dams, weirs, floodgates, culverts and road crossings present a physical barrier that completely or partially blocks fish passage, by creating either a complete break in the aquatic medium, a tight constriction or an impassable current. Partial blockage occurs where a weir or road crossing is low enough for fish to negotiate under high flows, where a culvert admits water at high tide or where a floodgate leaks.

Complete barriers such as dams and high weirs have the most dramatic effects on fish passage. For example, nine species are now locally extinct upstream of Tallowa Dam on the Shoalhaven river (NSW Fisheries, 2000a). Within the coastal rivers of NSW, species such as sea mullet, freshwater (pink eye) mullet, Australian bass and Australian grayling have become extinct upstream of major barriers (NSW Fisheries, 2000a). Each of these species have life cycles that involve juveniles migrating upstream from estuarine waters (McDowall, 1996), making them particularly vulnerable to such barriers. Whilst the adults may be able to descend some major barriers under certain conditions, they (like the juveniles) cannot return upstream. In fact, only specialised species such as eels and galaxiids are likely to be able to ascend these barriers.

Partial barriers, such as most weirs, can still have dramatic effects on fish populations. Such barriers are generally only passable by upstream-migrating fish when the structure is ‘drowned out’ by floods. Under these (relatively rare) conditions, fish are able to swim around the structure by keeping close to the waters edge where currents remain weak. The problem is that, within the coastal river systems of NSW, most of the species affected by in-stream barriers have specific seasons for upstream migration, particularly as juveniles (McDowall, 1996). For any given species, correspondence between the timing of a suitable flood and juvenile migration would be rare: in the case of a particular community of species, it would probably never happen. Furthermore, the suppression of flows by river regulation (as discussed below) has compounded the effects of barriers such as weirs by making them less likely to ‘drown out’, and by denying many species the environmental cues needed for spawning and migration.

Even relatively modest structures can seriously affect fish passage. Bridges, road crossings, culverts, floodgates and causeways can impede or prevent fish passage because of factors such as excessive water velocity or turbulence, dark passages, sudden drops in water level across the structure, loss of tidal exchange and poor maintenance (Pollard and Hannan, 1994; NSW Fisheries, 1999b; Williams *et al.,* unpublished data). Small juveniles that recruit to shallow habitats can thus be denied access to creeks, drainage channels, saltmarsh and shallow lagoons. This problem is often compounded by habitat modifications above the barrier. For example, a lack of tidal flushing can result in poor quality water and the loss of mangroves upstream of a structure. Furthermore, if the barrier stops all saline water intrusion, the area above will become freshwater wetland.

The species regularly taken in the Estuary Prawn Trawl Fishery do not travel into freshwater where they would most likely encounter physical barriers. However, commercially important species, including silverbiddy, yellowfin bream, tarwhine, luderick, flat-tail mullet and yellowfin leatherjacket might just be seriously affected by the amount of habitat lost from physical barriers, judging by the results of Pollard and Hannan (1994) and Williams *et al.,* (unpublished data).

Environmental flows

Dams not only block fish passage, they alter natural river flow patterns. In most cases, overall flows are reduced as a consequence of water being removed from the system for drinking supply and/or irrigation. In highly regulated rivers, such as the Hawkesbury-Nepean west of Sydney, only the largest floods are likely to wash down through the whole length of the system. More specifically, dams affect downstream flows in the following ways (NSW Fisheries, 1999a):

- suppression of moderate flows and minor floods, as they are normally taken up by spare capacity in the reservoir rather than allowed to pass downstream
- changes in the seasonal pattern of flows
- reduction in the variability of flows
- increased rates of change in flow volumes due to the sudden 'switching' on or off of spillways etc. as reservoir levels change.

Water abstraction also reduces overall stream flows, and consequently the amount of fish habitat available in a stream. 'Water abstraction' refers to the manipulation and/or diversion of river flows to supply needs such as irrigation, urban and industrial use, and hydro-electric power generation (NSW Fisheries 1999a). In eastern NSW, the greatest amount of abstraction is likely to occur in those catchments where dams and weirs are most numerous. According to Thorncraft and Harris (2000), these catchments are those of the Richmond, Clarence, Bellinger, Macleay, Hastings, Hunter, Hawkesbury, Shoalhaven and Bega rivers.

Secondary effects of reduced flows (whether caused by abstraction or dams) may include increased summer water temperatures, alteration of habitat from a running water to a still water environment, and reduction in water quality (NSW Fisheries, 1999a).

Alteration to natural flow regimes are most noted for their effects on freshwater fish communities (Pollard and Growns, 1993; NSW Fisheries, 1999a). However, such changes also affect some estuarine fish and invertebrates. Species that migrate upstream into freshwaters (such as sea mullet and eels) are likely to be affected by a loss of habitat wherever suppressed flows reduce either the area of suitable habitat, or access to such habitat. Sea mullet, in particular, are also more likely to become trapped in freshwater areas (e.g. lagoons and billabongs) under a regulated flow regime, and whilst affected individuals may grow to large sizes, they are prevented from spawning (at sea) and therefore from recruiting to populations. Some species, however, are unable to tolerate low salinities, and may be flushed out of upper estuarine areas during natural flood events. Under such conditions, these species may be rendered more vulnerable to capture by commercial fishers. This is the likely reason behind the association between high catches of school prawns and increases in river discharge (NSW Fisheries, 2000a). It follows that any suppression of major discharge events (say as a result of river regulation) may adversely affect estuarine prawn fisheries. Also, the distributions and abundances of a wide range of organisms may be altered because of changed salinities associated with altered flow regimes (Pollard and Growns, 1993). For example, some estuarine species may extend further upstream than before the flow regimes were altered. Such changes may have far-reaching food web and community effects, and may therefore also affect commercial fishing.

Unnaturally rapid recession of flood waters, as a result of river regulation (particularly due to large dams), can result in bank slumping (Pollard and Growns, 1993). Sudden drops in water level leave banks saturated with water, but without the support of surrounding floodwaters. The resultant bank collapses release sediment that may then cover fish habitats such as macrophyte beds and snags. Also, banks affected by slumping are left vulnerable to on-going erosion of the exposed sediment. River systems badly affected by sedimentation are likely to provide fewer suitable fish habitats for species such as sea mullet, yellowfin bream, Australian bass and estuary perch.

Thermal Pollution

Water released from the deeper layers of large reservoirs (such as Lake Burragorang on the Nepean River) can be up to 15 degrees cooler than surface waters (Pollard and Growns, 1993; NSW Fisheries, 1999a). Such cold waters have been shown to have profound effects on the distribution and abundance of native fish in coastal and inland river systems, and effects have been noted up to 400 km downstream (Pollard and Growns, 1993; NSW Fisheries, 1999a; Astles *et al.,* 2000). Within estuaries, the possible effects of upstream releases include reductions in juvenile abundance and growth (particularly for species that spend significant amounts of time in upper estuaries, such as sea mullet, eels and school prawns), reductions in abundance of prey, and shifts in community composition (NSW Fisheries, 1999a). Such changes could easily have flow-on effects on commercial fishing, particularly in upper estuarine areas.

iv) Other issues

Sea level rise

Sea level is predicted to rise over the next 40 years (Eliot *et al.,* 1999). For estuarine areas this poses a potentially serious threat as it could result in the loss of fish habitat and numerous fishing areas. The effects of sea-level rise will vary depending upon the type of estuary (drowned river valley to barrier estuary) and whether it is located in a temperate or tropical environment (Dame *et al*., 2000). A study on South African estuaries concluded that sea level rise will increase the occurrence of extreme flood and erosional events (Hughes and Brundrit, 1995). Similar events are likely to occur in NSW estuaries. It is clear from a number of studies that the impacts of sea level rise and its accompanying climatic changes will vary from place to place. In NSW, the best predictor of change is an analysis of structure and function of existing estuaries compared with the size and distribution their respective habitats in the postglacial marine transgression (Roy *et al.,* 2001). The comparison indicates that drowned river valleys may have less shallow habitats while barrier estuaries will have more. Therefore, it is impossible to predict precisely what impact sea level rise will have in NSW. However, the vulnerability of the Estuary Prawn Trawl Fishery to impacts from sea-level will need to be assessed in more detail for each estuary.

Recreational Fishing

Recreational fishing is an increasingly popular past time. The activities of recreational fishers impact estuarine environments in a number of ways including bait collection (Cryer *et al.,* 1987; Underwood and Kennelly, 1990), trampling (Keough and Quinn, 1998), physical damage to habitats, lost or discarded fishing gear, hook and handling damage to fish, and landings of commercial fish species (West and Gordon, 1994). The large numbers of people engaged in this type of fishing suggests that the collective impact of these activities could be quite large.

A management strategy is to be developed for the recreational fishing sector as required under the *Fisheries Management Act, 1994.* As part of this, an environmental impact assessment is to be done on all aspects of how this fishery may impact the environment and other fishing sectors. Therefore, whilst it is acknowledged that recreational fishing is potentially having a substantial impact on the Estuary Prawn Trawl Fishery, a comprehensive assessment of these impacts will be given in the environmental impact study of the recreational fishery management strategy. The strategy is due to be developed before June 2003.

Aquaculture

Aquaculture in NSW estuaries largely consists of oyster farming and, more recently, the rearing of fish in cages (McGhie *et al.,* 2000). Mather (1993) reviews the environmental impacts of all types of aquaculture in Australia. For estuaries, these impacts include introduced species, alterations to trophic structures, sediment degradation and hydrological modifications (Mather, 1993). Oyster leases can also impact upon the fishery by obstructing trawling activity. Such is the extent and growth of aquaculture in NSW that NSW Fisheries has developed the NSW North Coast Sustainable Aquaculture Strategy (2000). This strategy covers all issues relating to the environmental impacts of aquaculture and includes management responses to mitigate these impacts. Further strategies are being developed for other parts of coastal NSW (D. Ogburn, NSW fisheries, pers comm.).

c) Dredging works necessary to maintain access necessary for the fishery activities proposed under the strategy

Dredging specifically to maintain or provide access for vessels used in the Estuary Prawn Trawl is not likely to be required: the vessels are relatively small and general navigation dredging (as administered by NSW Waterways, Department of Land and Water Conservation and/or NSW Fisheries) is likely to be sufficient. This dredging is carefully managed, with a range of safeguards to minimise environmental harm (NSW Fisheries, 1999a). Under these present circumstances, there is minimal risk to boats or fisher access with respect to the Estuary Prawn Trawl Fishery.

d) Management measures necessary to limit impacts of external factors

i) Landuse planning and development controls

A wide range of landuse planning and development controls, including controls on infrastructure design and operation, are necessary to minimise the various impacts of factors external to the Estuary Prawn Trawl Fishery. These controls need to focus on habitat protection, and must operate within a TCM (Total Catchment Management) Framework. The new Catchment Management

Boards will be instrumental in the development and on-ground application of these controls. The necessary controls are discussed under the following subheadings.

Urban landuse

Much of the pollution entering the State's estuaries originates from diffuse urban-related sources, and is transported via stormwater. To effectively tackle the serious issue of stormwater runoff from urban areas, a catchment-focused approach is required. In terms of landuse planning and development controls, the following measures are likely to be needed to protect nearby estuaries and their biota:

- provision of sufficient space for stormwater treatment devices (including artificial wetlands)
- preservation or restoration of all natural creek lines, including adequate provisions for protecting/ restoring aquatic habitats and fish passage
- provision of vegetated buffer zones along all creeks (including intermittent) and around all wetlands
- maximum possible use of on-site retention and porous surfaces
- stringent environmental safeguards in relation to all construction and associated works.

The preservation or restoration of natural creeks not only provides fish habitat, it helps in the treatment of runoff. Natural creeks (and properly restored ones) have aquatic vegetation, gravel and detritus to help filter and treat polluted runoff before it reaches an estuary or river. Concrete-lined drains, with their greatly reduced quantity of biologically active surfaces and their uninterrupted flows, are much less effective in this way. Riparian vegetation and porous surfaces also help to retard and filter stormwater flows.

Whilst these measures are likely to be very expensive, particularly in existing urban areas, they raise the broader planning issue of how and where people wish to live. Society must recognise the respective environmental costs of increased urban density and of urban expansion, and decide on the best trade-off between these in terms of environmental, social and economic needs. Recognising the pressures for development, particularly along the NSW coast, society must decide to what extent the State's estuaries can support further development in their catchments, and at what cost.

Treatment

Major point sources of pollution (such as an industrial discharge or major sewer overflows) can be addressed by upgraded treatment standards and/or engineering works at specific sites. This has been done successfully in many instances. For example, upgrades to sewage treatment plants along the Hawkesbury-Nepean River since the early 1980s resulted in improved water quality (in particular phosphorus levels) chlorophyll-a concentrations and turbidity (Williams *et al.,* 1993; Kerr 1994). Also, the recently completed Northside Storage Tunnel and associated works are expected to dramatically reduce sewer overflows into the northern parts of Sydney Harbour. In terms of adequately protecting receiving waters, existing Environment Protection Authority requirements are likely to be sufficient for most point sources.

However, diffuse source pollution is far more difficult to isolate and treat, particularly in urban areas. In rural areas, individual farmers can at least be encouraged to follow best practice with respect to erosion prevention and the use of chemicals such as pesticides and fertilisers. In urban areas, however, there are so many sources and individuals involved that it is extremely difficult to rely on education/encouragement alone. Stormwater runoff, in particular, requires a range of prevention and treatment measures to protect nearby estuaries and their biota. These measures are likely to include:

- appropriate land use and planning controls as outlined above
- on-going community education, with an emphasis on source control
- use of large numbers of relatively small stormwater treatment devices located high in the catchment, rather than a few large devices close to receiving waters or major streams
- provision of artificial wetland(s) so that total area of wetlands (available to retain and treat stormwater) represents at least 3 to 5% of the urban area within the catchment
- adequate provision for the on-going maintenance of all treatment devices.

Whilst past efforts at stormwater treatment have often been focused on the protection of the ultimate receiving waters, councils are increasingly recognising the need to not only protect the main river, lake or estuary, but to also protect the major tributary creeks. However, given the ecological links between even small intermittent creeks and downstream waters (in terms of energy flows and fish passage), even minor creeks should be protected by placing devices higher in the catchment or offline wherever possible.

A fundamental problem is that urban areas, with their high proportion of hard surfaces and plethora of potential pollution sources, represent a highly artificial environment. Furthermore, the volume and rate of surface runoff is greatly enhanced with respect to that from more natural environments, thereby ensuring the rapid and efficient delivery of pollutants to receiving waters. The challenge is therefore to slow the passage of the runoff and its pollutants, so that natural and artificial treatment processes have an opportunity to work. However, to do this effectively is a complex and expensive exercise. An urban area is likely to need large expenditures to establish artificial wetlands and other stormwater treatment devices.

In most cases the required suite of measures, along with the necessary land acquisitions and changes to urban design, are likely to be very expensive. For established urban areas, the above planning and treatment measures could most realistically be considered as a long-term goal. However, for new or expanding areas, much money can be saved by making provisions for these measures in advance. Also, the 'polluter-pays' principle need to be implemented where feasible (NSW Fisheries, 1999a), possibly in the form of the environmental levies that have already been used by some local councils.

Sediments contaminated as a result of past industrial practices pose their own special problems, because they do not normally comply with guidelines for offshore dumping or 'clean fill' and have to be taken to special waste facilities for treatment and/or disposal. Remediation attempts, such as that recently undertaken in Sydney's Homebush Bay, are therefore difficult and expensive. In most such cases it is likely that removal of the worst contamination, in conjunction with the capping of the remainder with clean sediment, would be the most feasible option.

Foreshore works, dredging and reclamation

Existing fisheries legislation and policy (particularly the *Fisheries Management Act 1994,* the *Policy and Guidelines: Aquatic Habitat Management and Fish Conservation 1999*, and Habitat Protection Plan No. 2: Seagrasses) provide effective means to ensure that current and future works do not unduly affect fish or fish habitats (as discussed above under sections (a)(i) and (b)(ii)). Specific information on how foreshore structures can be designed in a way that minimises damage to sensitive habitats such as seagrass is now available (Shafer and Lundin, 1999; Hannan, in prep.). Essentially, jetties and similar structures should be designed to take into account prevailing conditions (such as waves or currents) and, ideally not built where highly sensitive habitats are present.

However, past works (particularly those done before the late 1980s) were not subject to the same degree of control. Some of these earlier works have consequently caused impacts that might not have been accepted today. Also, many works (including some of those undertaken in recent years) have been related to major projects of state or national interest (e.g. the 'Third Runway' in Botany Bay). In these cases, possible habitat protection measures were often constrained by overwhelming social and/or economic considerations, and outright refusals or major modifications based solely on fishery or habitat grounds would have been unrealistic.

Other measures are available to help mitigate the impacts of future works. Of fundamental importance is prior consultation with commercial fishers. Such consultation allows fishers concerns' to be taken into account at an early stage of a project, at which time any suggested changes are more likely to be accommodated. Project planning would also be greatly assisted by an updated documentation of all 'Recognised Fishing Grounds' within NSW estuaries. More specifically, structures such as seawalls and berthing facilities can be designed to provide the best possible fish habitat consistent with their function and reasonable costs. For example, instead of a smooth vertical wall, one with indentations could be used to provide a greater surface area for sessile invertebrates and better opportunities for juvenile fish to hide (Chapman and Blockley, 1999).

Fish passage

Under the *Fisheries Management Act 1994*, NSW Fisheries may order that a fishway be installed on new weirs and dams, or on any that are being repaired or refurbished. NSW Fisheries policy also requires that all proposals for the construction/modification of dams, weirs, floodgates or any other such structure on a waterway be referred to the department for assessment (NSW Fisheries, 1999a). NSW Fisheries has also developed specific policies for addressing fish passage (and other environmental issues) associated with road crossings and related works (NSW Fisheries, 1999b).

Under the NSW Weir Policy, the NSW government is attempting to reduce the environmental impacts of weirs. In particular, the construction/enlargement of existing weirs is discouraged, weirs no longer serving any useful purpose are to be removed where possible, and owners are encouraged to alter retained weirs to reduce their environmental impact. The State Weir Review Committee oversees the implementation of the policy. The committee has undertaken a comprehensive review of the State's weirs and has suggested actions for remediating the impacts of these structures.

A number of fishway options suitable for native fish such as mullet and bass have been developed (NSW Fisheries, 1999a, 2000a,b,c). The best choice for a particular barrier depends on factors such as barrier height, flow rates and the species of fish present. For barriers up to 6 metres high, the most suitable option is likely to be the 'vertical slot' fishway. This is essentially a series of covered pools, each slightly higher than the last, through which the fish progressively ascend. The pools are linked by narrow vertical openings, through which currents are sufficiently restricted to allow native fish to pass. For low barriers (up to 1 metre high), a rock ramp fishway with a slope of 1:20 or less may be appropriate. Rock ramp fishways essentially mimic natural riffle zones instead of an impassible single fall, fish are presented with a series of small rocky pools each separated by transverse rock bars and a slight change in water level. Other fishway options, such as Denil fishways, lock systems, trap and transport and by-pass channels may also be suitable in some circumstances. Whilst these other fishway types may be less expensive than vertical slot designs, their use in coastal streams remains experimental, and in need of further evaluation. For high barriers such as dams, trap and transport fishways offer the best potential. A system by which fish are attracted, trapped and then pumped through a pipe and over the barrier, is currently being considered for Tallowa dam on the Shoalhaven River. As an interim measure pending fishway construction, NSW Fisheries supports the periodic release of flows to drown-out weirs and other barriers to enable upstream fish passage (NSW Fisheries, 1999a).

In terms of road-related barriers, NSW Fisheries have developed the *Policy and Guidelines for Bridges, Roads, Causeways, Culverts and Similar Structures 1999* (NSW Fisheries, 1999b), which set minimum preferred solutions depending on the value of fish habitat affected. In general terms, bridge or tunnel crossings are preferred, particularly where major fish habitat is concerned. Where culverts are to be used, large box culverts are preferred to round pipes as the former provide easier fish passage. Also, causeways should be designed so that stream flows and stream widths remain unchanged. In relation to culverts, NSW Fisheries (1999a) provides the following specific guidelines to ensure habitat continuity and therefore assist fish passage:

- the cross-sectional area of the culverts should equal or exceed the cross-sectional area of the stream
- they should be as short as possible, so that dark passages are not created
- they should be as level as possible, so that natural flow velocities are maintained
- their base should be set into (rather than on) the stream bed so that natural sediments can cover the bottom.

The timing of associated works is also important (NSW Fisheries, 1999b). Wet months should be avoided and every effort should be made to avoid predicted rain events. Also, known migratory seasons should be avoided: for example, juvenile sea mullet are known to recruit to estuaries during winter and spring and are likely to be moving up creeks and rivers during this period (SPCC, 1981b; Hannan and Williams, 1998).

NSW Fisheries is currently developing strategies for the opening regimes for floodgates (NSW Fisheries, 2000a). Previous studies (Gibbs *et al.*, 1999) have shown that ‘leaky’ floodgates allow estuarine (rather than freshwater) habitats to be maintained above the gates as well as the recruitment of estuarine fish and invertebrates to these habitats.

Environmental flows

The issue of environmental flows is being addressed as part of the State government’s Water Reform Package. As part of this package, the NSW government, has developed Interim River Flow Objectives for most of the State’s catchments. Particular flow issues being addressed include the need to protect low flows, freshes and natural variability and the importance of factors like floodplain connection, rates of rise and fall in river height, groundwater interactions, impact of weirs, estuarine processes and the quality of storage releases (NSW Fisheries, 1999a). Essentially what is needed is the “formal recognition of the environment as a water user” along with support for “changes which allow more water for the environment in over-allocated systems” (NSW Fisheries, 1999a).

Provision of appropriate environmental flows helps to ensure fish passage, water quality and maximum habitat availability. Also, the maintenance of natural rates of fall in river height helps to prevent bank slumping and associated erosion and sedimentation.

Under the Water Reform Package, the State government can also limit future abstraction from sensitive river systems. The placement of an appropriate 'cap' on abstractions from such systems, backed by strategies to reduce water consumption and increase efficiency of use, can help allow for environmental flows. Measures to reduce consumption could include the use of drought-resistant crops, the on-going education of landholders with respect to current best practice, and the installation of water-efficient irrigation systems. In urban areas, the provision of advisory material to householders can help reduce town water consumption.

Thermal pollution

The release of unnaturally cold water from reservoirs can be avoided by the installation of variable-level offtakes and/or de-stratification by aeration or other mechanical means (NSW Fisheries 1999a). The big challenge is retro-fitting the necessary works on existing dams. To do this cost-effective engineering solutions need to be further developed (Sherman, 2000). NSW Fisheries has recently held discussions with the Department of Land and Water Conservation and State Water on progressing actions to address cold water pollution on State government owned structures.

The discharge of artificially warmed water from power stations into estuaries can cause significant but localised drops in fish species richness and biomass during summer (Scanes, 1988). The outlets off the State's power stations are designed to cause plumes to spread out over the water's surface. This takes most of the heated water away from sensitive benthic habitats and maximises heat loss to the atmosphere.

Acid sulfate soils and flooding

Authorities are now well aware of issues relating to acid sulfate soils, and proponents for developments are invariably required to test for the presence of such soils in areas where they may occur. A series of acid sulfate soil maps has been published by the DLWC. These maps show the risk of acid sulfate soil being present for any particular location in coastal NSW. Protocols such as keeping works shallow and not allowing the ground to dry out have been developed to minimise the likelihood of acid formation in high risk areas. Also, treatment with lime may help to neutralise any acid that forms. Protocols currently being developed for the management of barriers such as floodgates may also play a role in helping to mitigate the impact of chronic acid drainage (NSW Fisheries, 2000a).

Major flooding and drainage from the river floodplains, which can result in significant fish kills, were addressed in section 10(a)(iii) of this chapter. Management measures to limit these impacts include coordination with the floodplain management and estuary management programs presently supported by the DLWC. The Estuary Management Manual currently being revised by DLWC also assists in the future management of these external factors affecting the Estuary Prawn Trawl Fishery.

ii) Management measures in the draft FMS with regard to external activities

Draft management measures for the Estuary Prawn Trawl Fishery aimed at controlling impacts from external activities involve: firstly, ensuring that the industry has input into the decision making of relevant government; and secondly, helping the industry itself to curtail the impact of external factors. The relevant management responses are discussed below.

Those responses which will help industry (directly or via NSW Fisheries) to have input into the decision making of other government agencies include:

- NSW Fisheries continues to review and where necessary place conditions on development applications impacting on the fishery resource (management response 2.5a)
- Management Advisory Committee (MAC) for the Estuary Prawn Trawl Fishery brings detrimental external activities to the attention of NSW Fisheries (management response 2.5b)
- MAC contributes to the reviews of habitat management policies and guidelines and protection plans (management response 2.5c)
- MAC contributes to the development of policies and legislation by other government agencies wherever relevant to fish stocks or fish habitats (management response 2.5d).

These responses will not guarantee that external activities threatening the sustainability of the fishery will be stopped or minimised because of the many other groups and agencies that are involved. However, the responses do show a commitment by industry and NSW Fisheries to participate as far as possible in the relevant decision making. The effectiveness of these management responses will depend on how well the MAC is kept informed of external issues that may impinge on the fishery, and how well NSW Fisheries handles such threats – in terms of both proactive approaches and follow-up responses when dealing with the many decision makers and stakeholders involved.

Those responses which will help the industry itself (directly or via NSW Fisheries) to curtail external impacts include:

- assess the size of the non-commercial and illegal catch and the impact of such harvesting on the resource (management response 4.1a)
- monitor catch levels and management structures in fisheries outside NSW jurisdiction for species where stocks are shared with the Estuary Prawn Trawl Fishery (management response 4.2a)
- monitor catches of prawn and squid species that are also taken in other commercial fisheries (management response 4.2b)
- use the Prawn Resource Forum to discuss management issues across relevant fishers (management response 4.2d)
- participate in development and reviews of the Indigenous Fishing Strategy (management response 4.3a)
- co-operate with Safefood Production NSW in developing and implementation of food safety programmes (management response 5.4a).

These management responses seek to address issues regarding practices within the industry that could threaten resource viability (such as handling of catches before market; management response 5.4a). The effectiveness of these responses will depend on how the information (i.e. management response 4.1a&b) and the issues (management response 4.2b, 4.3a and 5.4a) are used in strengthening the Fishery Management Strategy to minimise impacts on the fishery from external activities.

11. Data Requirements in Relation to Assessment of Impacts on the Biophysical Environment

a) Data and research

Data and information used to assess impacts of the fishery on the biophysical environment were obtained from a variety of sources, but primarily State and Commonwealth government agencies and peer reviewed scientific publications. The government agencies include the National Parks and Wildlife Service Threatened Species Unit, Environment Protection Authority, Environment Australia and Australian Museum. The reliability of this information is variable. From the above agencies it could range from low-medium to high depending upon the quality of the research involved. Peer reviewed scientific publications provide the most robust information for the assessments. It was not, however, possible to make any detailed assessment of the information used. It should also be recognised that for many of the issues relating to impacts on the biophysical environment, information is not available from any source. The uncertainties associated with the data and associated impact assessment are due to the gaps in our knowledge of the effects of fishing, particularly in relation to possible impacts on threatened and protected species and their habitats.

i) Knowledge gaps

There are at least seven areas where we have little or no knowledge regarding the impact of the Estuary Prawn Trawl Fishery on the biophysical environment. These are:

- status of fish stocks
- knowledge of invertebrates and other fauna contributing to the biodiversity of estuaries
- relationship between fish stocks, habitats and biodiversity
- effects of recreational fishing
- effects of trawling on trophic structures in estuaries
- effects of trawling on fish and habitats
- effects of fishing on threatened species.

These knowledge gap areas are discussed below.

Knowledge of fish stocks

Significant gaps exist in our knowledge of the distribution, abundance, mortality and recruitment patterns of the species retained by the Estuary Prawn Trawl Fishery. The most significant amount of information available is on the general ecology of eastern king and school prawns (Pollard, 1991; Vigona *et al.,* 1998; Gray *et al.,* 2000). But as noted in Chapter E, very little is known of the other retained species. Building a knowledge base of the ecology of these species will enable more realistic assessments to be made of their resilience (Underwood, 1989) to fishing pressure.

Knowledge of the ecology of invertebrates and other fauna and flora contributing to biodiversity in estuaries

Invertebrates make up a large proportion of the biodiversity in estuaries. Yet little is known about the ecology of invertebrates in estuarine habitats. Furthermore, we do not have good knowledge of the ecology of small species of fish nor a variety of algae in estuaries. Understanding of the ecology of populations of these species and of the communities of which they are a part will provide a more informative basis on which to investigate the extent and magnitude of potential impacts of trawling and other fishing methods in estuaries.

Relationship between fish stocks, habitats and biodiversity

The relationship between fish stocks, their habitats and biodiversity is an extension of the previous two knowledge gaps. Very little is known about how retained species interact with their habitats, nor even what habitats are important to them. There are also significant knowledge gaps with respect to how retained species contribute to maintaining biodiversity in estuarine environments. Understanding these complex interactions will enable better strategies to be developed for the protection of threatened habitats, enhancement of biodiversity and maintenance of viable retained stocks across all fishing sectors.

Effects of recreational fishing

The Estuary Prawn Trawl Fishery is one of a number of commercial fisheries in NSW that strongly interact with recreational fishing. This is because estuaries are among the most accessible and safest places for amateurs to fish (Henry and Vigona, 1984). The majority of recreational fishing occurs in estuaries and such fishing will often target the same species as those sought by the Estuary Prawn Trawl Fishery (West and Gordon, 1994). Given the large overlap between the two fishing sectors, there is substantial potential for there to be major effects of recreational fishing on commercially retained species in estuaries (Lal *et al.,* 1992). A lack of knowledge concerning the magnitude, frequency and extent of these effects inhibits our ability to develop effective management responses in this area.

Effects on trophic structure of estuaries

Very little is known of the trophic structures existing within estuaries nor of the effects the Estuary Prawn Trawl Fishery might be having on these structures. Given the extent to which fishing occurs within the State's estuaries, trophic structures may be affected at several spatial and temporal scales. However, little is known specifically about these affects. Overseas studies have demonstrated a number of trophic effects attributable to commercial fishing (Dayton, *et al.,* 1995). For example, large-scale removals of schooling prey result in wider dispersal of these species and increased capture difficulty for their predators (Murphy, 1980). Given that prawns are a major prey item of many estuarine predators, the Estuary Prawn Trawl Fishery could be causing substantial trophic shifts in estuaries. A lack of understanding of such possible interactions adds to the uncertainty in the risks associated with the fishery.

Effects of trawling on fish and habitats

There are a few comprehensive studies that specifically test the effects of trawling on fish (Broadhurst *et al.,* 1997,1999; Gray *et al.,* 2000). Trawling can affect the seabed through disturbance of the upper sediment layer, damage or removal of epibenthos and macroalgae, and damage to seagrasses. However, the effects of trawling on habitats within NSW estuaries has received relatively little attention. Poor of knowledge of these effects contributes to the uncertainty surrounding the effectiveness of the management strategy's input controls on trawling gear and usage. Therefore, it will be essential to better understand the magnitude and extent of these effects in order to improve the input controls on the fishery in a way that best ensures the maintenance of biodiversity within the trawled estuaries.

Effects of fishing on threatened species

There is currently little scientific data on possible interactions between the fishery and threatened species. Despite an increasing awareness of related issues on the part of the general public, and the listing of numerous threatened species under several legislative Acts (e.g. *Fisheries Management Act*, *1994*; *Threatened Species Conservation Act*, *1995*), little effort has been directed at understanding the effects of commercial fishing on these species. A lack of knowledge in this area seriously restricts our ability to make reliable predictions about the impacts of the proposed harvest strategy on threatened species or whether the management responses designed to protect threatened species and populations will be effective.

ii) Research assessment

With one exception, all of the knowledge gaps outlined above are addressed by at least one of the six proposed research areas (Table F12). The one exception is the effects of recreational fishing. These effects are not explicitly mentioned in the research proposed under the draft FMS. Their study should be specifically identified as a need within the research programme. The effects of recreational fishing on fish stocks and the broader environment are part of a wider issue covering the interactions between all fishing sectors, and their collective effects on fish stocks and the environment. For example, prawn species, such as school prawns, are fished by three commercial fisheries (Estuary General, Estuary Prawn Trawl and Ocean Prawn Trawl) and also by recreational fishers in large quantities. The resultant interactions could have substantial effects on the estuarine environment as well as on the prawn stocks themselves. There are no proposed research programmes in the draft FMS that deal with these interactions or their effects. Clearly, a coordinated approach across fishing sectors is required to identify specific knowledge gaps and research needs.

Table F12. Summary of knowledge gaps and the proposed research areas that can address them.

	Research Area					
Knowledge Gap	**Stock assessments**	**Reduction of incidental catch**	**Effects of fishing methods on habitats**	**Importance of habitats to shellfish and finfish populations**	**Impact of fishing on trophic interactions and ecosystems**	**Impacts of fishing on threatened species**
Shellish and finfish stocks	✔					
Relationship between shellfish and finfish stocks, habitats & biodiversity			✔	✔		
Effects of recreational fishing	✔		✔		✔	
Effects of trophic structures in estuaries					✔	
Effects of different gear types on fish and habitats			✔			
Effects of fishing on threatened species		✔			✔	✔

When designing projects within each research area, specific knowledge gaps will need to be articulated and addressed. For example, research into stock assessments will need to focus on aspects such as habitat use, juvenile mortality, feeding habits and life cycles, as well as traditional stock assessment information, if it is to fill knowledge gaps concerning the basic ecology of the species concerned. Moreover, the interlinkage between research areas needs to be recognised and built into the research programmes. For example, research into the effects of fishing methods on habitats will need to use the outcomes of research into the effects of habitats on fish populations in order to identify what habitats are important to consider in the former research. In addition, some knowledge gaps could be addressed by more than one research area, depending upon the issue (Table F12). These linkages between research areas will need to be clearly identified and addressed if knowledge gaps on environmental impacts are to be properly dealt with.

As mentioned in section 4 of Chapter E, it is difficult to assess the sufficiency of the research proposed as there are few details on what specific research will be done. Nothing is provided on the spatial and temporal scales of the research, the proposed research bodies or the specific null hypotheses to be tested. However, overall research needs are being discussed and prioritised (see Chapter C) and further details on the research programs will be available after this has process has been completed in 2002.

b) Performance and monitoring

i) Performance indicators and trigger points

Performance indicators concerning impacts of the fishery on the biophysical environment relate specifically to Goals 1 and 3 of the draft FMS. These indicators and their trigger points seem appropriate for gauging whether the associated goals are being met. Further discussion on the performance indicators and trigger points can found in section 4 of Chapter E.

ii) Monitoring and review

The proposed monitoring and review process for the biophysical environment is similar to that for the fishery resource. However, there are two exceptions: monitoring for captures of threatened species and reports of marine pests and disease. These monitoring programs are the responsibility of groups either outside of NSW Fisheries (e.g. NPWS) or in another section of NSW Fisheries, i.e. Office of Conservation. For these monitoring programs and consequent reviews to have the best chance of benefiting the fishery, clear links between all groups concerned will need to be made and maintained. Such a process is suggested in the proposed monitoring programme but not elaborated upon. Clear communication between and within government departments will be essential for the proposed monitoring programmes to be effective.

c) Relationship between research, performance indicators and review

The relationship between research, performance indicators and review has been discussed in section 4(c) of Chapter E. The principles identified in that section are equally important to impacts of the fishery on the biophysical environment.

d) Timetable for developing information

The implementation timetable for research and monitoring is as set out under each management response in section 4 of Chapter C of the draft FMS. However, a precise timeframe cannot be finalised for the research projects until priorities have been agreed to between all stakeholders.