VOLUME 2 TABLE OF CONTENTS

CHAPTER E. IMPACT ON THE FISH RESOURCES E-225
1. Retained Species E-225
a) Species based biological assessment E-225
b) Assessment of retained species management measures in the draft FMS E-234
2. Bycatch (non retained) Species E-248
a) Method based assessment of potential impacts E-248
b) Method based assessment of bycatch reduction strategies E-256
c) Assessment of bycatch management measures in the draft FMS E-259
d) Use of indicator groups to monitor bycatch E-261
3. Bait Resources E-263
4. Data, Monitoring and Research Adequacy E-264
a) Data and research E-264
b) Performance and monitoring E-267
c) Relationship between research, performance indicators and review E-269
d) Timetable for developing information E-270
CHAPTER F. IMPACT ON THE BIOPHYSICAL ENVIRONMENT F-273
1. Biodiversity and Habitat Issues F-273
a) Major habitats of the trawled estuaries F-273
b) Marine protected areas within trawled estuaries F-279
c) Effects of the fishery on estuarine habitats F-282
d) Proposed habitat management in the draft FMS F-287
e) Alternate mitigation measures F-289
2. Threatened and Protected Species F-292
a) Threatened species that may be affected by the Estuary Prawn Trawl Fishery F-292
b) Impact due to direct capture or disturbance F-295
c) The Eight Part Test F-299
d) Assessment of threatened species management in the draft FMS F-306
e) Assessment of impact on threatened species F-309
f) Summary F-311
3. Trophic Structure F-312
a) Species likely to be affected by the fishing activity F-312
b) Impacts of trawling on trophic structure in estuaries F-312
c) Risk and uncertainty of the fishery disrupting tropic structure and the necessary management measures to address this risk F-314
4. Translocation of Organisms and Stock Enhancement F-316
a) Possible mechanisms of translocation F-316
b) Species likely to be translocated by fishing equipment F-317
c) Risks and implications of translocations F-319
d) Assessment of management responses proposed in the draft FMS F-321
e) Contingency plan for pest species management in NSW F-322
f) Stock enhancement F-323
5. Fish Health and Disease F-324
a) Impacts of gear types and fishing methods F-324
b) Use of bait F-324
c) Stock enhancement F-324
6. Water Quality Issues F-325
a) Potential sources of pollutants related to the proposal F-325
b) Associated risks to water quality F-326
c) Baseline studies in areas of significant impact F-327

7. Noise and Light Impact Assessment F-328
a) Noise impact on residents adjoining estuaries F-328
b) Noise impact on wildlife F-328
c) Noise mitigation measures F-329
d) Light impact on residents F-329
e) Light impact on wildlife F-329
f) Light mitigation measures F-330
8. Air Quality F-331
9. Energy and Greenhouse Issues F-332
a) Description of fishing fleet F-332
b) Energy and greenhouse assessment F-333
10. External Impacts on the Fishery F-335
a) Land based activities likely to affect the environment on which the fishery relies F-335
b) Water based activities likely to affect the environment on which the fishery relies F-343
c) Dredging works necessary to maintain access necessary for the fishery activities proposed under the strategy F-349
d) Management measures necessary to limit impacts of external factors F-349
11. Data Requirements in Relation to Assessment of Impacts on the Biophysical Environment F-356
a) Data and research F-356
b) Performance and monitoring F-359
c) Relationship between research, performance indicators and review F-359
d) Timetable for developing information F-360
CHAPTER G. ECONOMIC ISSUES G-361
1. Existing Information G-361
2. Assessment G-364
3. Conclusions G-366
4. Data Requirements in Relation to the Assessment of the Impacts on the Economic Issues G-367
a) Reference to technical data and other information relied upon to assess impacts G-367
b) Important knowledge gaps G-367
c) Timetable for developing the data sets G-368
CHAPTER H. SOCIAL ISSUES H-369
1. Existing Information H-369
2. Assessment H-371
3. Conclusions H-372
4. Health Issues H-373
a) Health risks related to the environment H-373
5. Heritage Issues H-375
a) European heritage H-375
b) Aboriginal Heritage H-375
6. Indigenous Issues H-378
a) Current access of Aboriginal communities to estuary fishing H-378
b) Management of interactions between Indigenous fishing and the Estuary Prawn Trawl Fishery H-378
c) Summary H-380
7. Data Requirements in Relation to the Assessment of the Impacts on the Social Issues H-382
a) Reference to technical data and other information H-382
b) Important knowledge gaps H-382
c) Timetable for developing the data sets H-382
CHAPTER I. JUSTIFICATION FOR THE PROPOSED COMMERCIAL FISHING ACTIVITY I-383
1. The Need for the Estuary Prawn Trawl Fishery I-383

a) Employment I-384
b) Supply of seafood to the community..........I-385
c) Economic benefits..........I-385
2. Sensitivity Analysis..........I-387
a) Sensitivity of major alternative management approaches I-392
3. Justification of Measures in Terms of ESD Principles I-393
a) Precautionary principle I-393
b) Intragenerational equity I-394
c) Intergenerational equity I-395
d) Conservation of biodiversity and ecological integrity I-395
e) Improved valuation, pricing and incentive mechanisms I-396
CHAPTER J. REFERENCES J-397

CHAPTER E. IMPACT ON THE FISH RESOURCES

The purpose of this chapter is to assess the effectiveness of the management measures proposed in the Estuary Prawn Trawl draft FMS in ensuring the sustainability of the fishery resources it harvests, including both the stocks marketed commercially by the fishery and those caught as bycatch. This chapter also assesses the effectiveness of the monitoring and research programs proposed in the draft FMS in providing the information required to adequately determine the sustainability of the fishery.

The scientific names of the fish and invertebrates referred to by their common name in this chapter can be found in Tables C16 and C17 in Chapter C and in bycatch studies by Liggins and Kennelly (1996) and Liggins *et al.* (1996).

1. Retained Species

a) Species based biological assessment

i) Stock status

The current status of each of the species proposed to be retained under the Estuary Prawn Trawl draft FMS (see Tables C16 and C17 in Chapter C) is summarised in Table E1. Information was derived from NSW Fisheries (2001a) and the NSW Fisheries Commercial Catch Database. These 22 species (including groupings of species) represented approximately 99% of the total catch of the Estuary Prawn Trawl Fishery during the 1997/00 period, and will be known throughout this section as the retained species of the fishery.

The current knowledge of stock status for many species proposed to be taken in the Estuary Prawn Trawl Fishery is non-existent or poor. No formal stock assessment has been completed for the 19 species (including groupings of species) retained by the fishery that have an unknown exploitation status (Table E1). The assessments for eastern king prawns (fully fished) and yellowtail (fully fished) can only be used with moderate confidence when making stock status predictions (Table E1). These assessments were completed using both fishery dependent indices of abundance and ancillary information such as age structures or independent surveys, but are not yet in a formal model framework (assessment reliability 3; NSW Fisheries, 2001a). The assessment for school prawns (fully fished) can only be used with low confidence when making stock status predictions (Table E1). This assessment is still under development or is only completed at an elementary level, where questionable underlying data (such as the use of only fishery dependent effort) and overly simple assumptions may have been used (assessment reliability 4; NSW Fisheries, 2001a).

Table E1. Known information on the current stock status, including stock assessment reliabilities and levels of confidence in making predictions regarding stock status, for the retained species proposed to be taken in the Estuary Prawn Trawl Fishery.

Species/group	Exploitation status +	Stock levels (exploitable) +	Stock levels (spawning) +	Five year estuary prawn trawl catch trend	Stock assessment reliability +	Confidence in making predictions regarding stock status
Prawn, school	fully fished	inadequate	uncertain	fluctuating	4	low
Prawn, eastern king	fully fished	inadequate	uncertain	stable	3	moderate
Squid (at least 2 species)	unknown			increasing, drop in last 2 years	no assessment	low
Whiting, trumpeter	unknown			increasing	no assessment	low
Octopus (at least 3 species)	unknown			fluctuating	no assessment	low
Silver biddy	unknown			increasing, drop in last year	no assessment	low
Crab, blue swimmer	unknown			fluctuating	no assessment	low
Flounder (at least 2 species)	unknown			fluctuating	no assessment	low
Yellowtail*	fully fished	uncertain	uncertain	increasing, drop in last year	3	moderate
Prawn, greasyback	unknown			decreasing	no assessment	low
Catfish (at least 3 species)	unknown			increasing	no assessment	low
Trumpeter	unknown			increasing	no assessment	low
Crab, mud	unknown			stable	no assessment	low
Hairtail	unknown			stable	no assessment	low
Whitebait (glass fish) (at least 2 species)	unknown			stable	no assessment	low
Shrimp, mantis (at least 3 species)	unknown			stable	no assessment	low
Prawn, tiger	unknown			decreasing	no assessment	low
Pike, long-finned	unknown			stable	no assessment	low
Dory, john	unknown			stable	no assessment	low
Sole, black	unknown			stable	no assessment	low
Crab, sand	unknown			stable	no assessment	low
Bullseye (at least 2 species)	unknown			stable	no assessment	low

+ The definition of terms is provided in Table B5 and in NSW Fisheries (2001a).

* Information largely derived from fisheries other than the Estuary Prawn Trawl.

Scientific names of species can be obtained from Tables C16 and C17 and from bycatch studies by Liggins & Kennelly (1996) and Liggins *et al.*, (1996).

Available stock assessment information for the retained species in the Estuary Prawn Trawl Fishery is provided in Appendix E1 and NSW Fisheries (2001a), and summaries for all target species plus yellowtail are provided below. Given the reliability of the stock assessments (Table E1), considerable caution would be needed when making conclusions from this data, at least until stock assessments are better developed. Only with increased monitoring and research will the levels of confidence for most species improve over the proposed fishery management strategy.

School prawns (*Metapenaeus macleayi*) and eastern king prawns (*Penaeus plebejus*) are taken from estuaries by both commercial and recreational fishers. Within the Estuary Prawn Trawl and Estuary General Fisheries, school prawns dominate commercial catches with only small percentages of other prawn species being caught. Recreational prawn catches, which are entirely estuarine, are dominated by eastern king prawns and represent 5% of statewide prawn catches. Landings in the Ocean Prawn Trawl Fishery are also dominated by eastern king prawns. Both school and eastern king prawns are caught along the entire NSW coast, although they are taken in greatest quantities in the north. While prawn catches characteristically fluctuate, there is some indication of overall declines in estuary prawn trawl catches of both species since 1985. School and eastern king prawns are taken over a wide size range, although most individuals are taken below the estimated size of maturity. Considering their life cycle, all eastern king prawns caught within estuaries are likely to be immature, with adults taken exclusively in ocean waters. The spawning stock levels of these two prawn species are uncertain, and no data on the distribution or abundance of stocks for school prawns are available. Spawning stocks of eastern king prawns appear to be concentrated in ocean waters off far northern NSW and southern QLD (Montgomery and Reid, 1995). Based on a preliminary assessment of the reported commercial catch and the available size data, prawn stocks of these two species are assumed to be fully fished (Montgomery, 2000; NSW Fisheries, 2001a). Results of modelling by Gordon *et al.* (1995) suggest that both biological and economic benefits may be gained by allowing eastern king prawns in certain areas to move into ocean waters before being caught.

A formal stock status for squid species has not been determined and little is known of the biology of squid. However, current research at the University of Sydney investigating the life history of broad squid (*Photololigo etheridgei*) has found this species to reach sexual maturity when their mantle length reaches 10 cm (K. O'Donnell, Sydney University, pers. comm.). The Estuary Prawn Trawl, Ocean Prawn Trawl and Estuary General Fisheries are the main contributors to statewide commercial squid catches, which consist of four species (*Loliolus noctiluca, Photololigo etheridgei, Photololigo sp.,* and *Notodarus gouldi*). Catches of these species are reported together and the total catch has declined since 1984. Some 99% of the squid caught by the Estuary Prawn Trawl Fishery come from the Hawkesbury River and consists of *Photololigo etheridgei* and *Loliolus noctiluca*. Catches of these species have increased since 1995, the year when the fishery for the species developed.

Yellowtail (*Trachurus novaezelandiae*) are caught by a variety of methods in several different fisheries, with about 80% taken by purse seining in ocean waters. Recent total landings have averaged approximately 370 tonnes, with most being caught off the southern half of the State, particularly near Wollongong. Total commercial landings have increased since the late 1980s. The Estuary Prawn Trawl Fishery contributes only a small proportion of this catch (0.3% during the 1997/98 to 1999/00 period) and the yellowtail catch trends in the fishery are similar to those for the State. Most of the commercial catch consists of fish two or three years old, with ages ranging between 1 and 11 years. The spawning stock level is uncertain. Based on a preliminary assessment of the reported commercial catch and age data, the yellowtail stock is assumed to be fully fished (NSW Fisheries, 2001a).

ii) Species risk assessment

Determining the likelihood of a species being over-fished involves a risk assessment. There are many forms of risk assessment (e.g. Francis and Shotton, 1997) and they can be either quantitative or qualitative (Handmer, 1995; Harding, 1998). The purpose of risk assessment is to use various categories of information about a fishery to determine the likely effects of current and/or alternate management options (Francis and Shotton, 1997). Harding (1998) sets out five logical steps in risk management – risk context, identification, analysis, assessment and treatment. This section of the EIS concentrates on the last three steps, as the draft FMS and Planning NSW (formerly DUAP) guidelines provide the context and identification of the risks. Analysis of the risks (e.g. overfishing) examines the levels of risk involved for a species or habitat (i.e. high, medium or low). Assessment of risk determines whether a risk level is acceptable or unacceptable. The risk treatment examines what options are available to manage the different levels of risk.

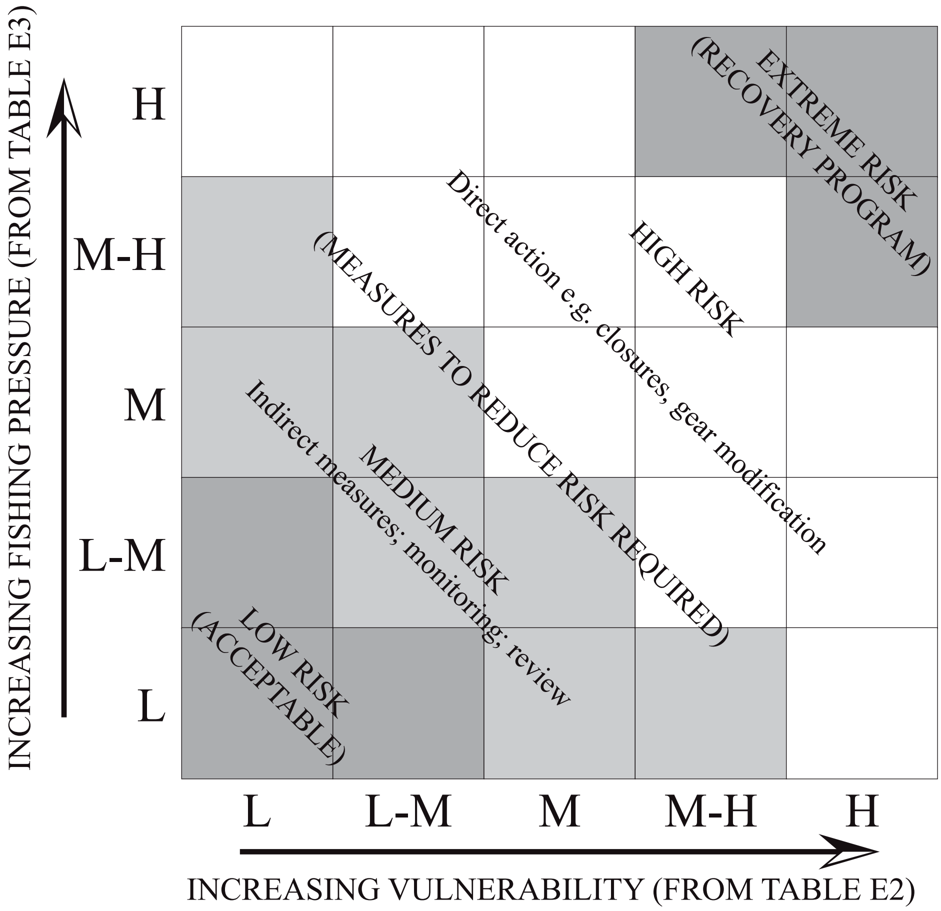

Figure E1. Diagrammatic framework for risk assessment of the retained species in the Estuary Prawn Trawl Fishery.

(Source: adapted from Harding, 1988).

Figure E1 shows the framework for risk analysis and assessment that was used to determine the likelihood of overfishing the retained species in the Estuary Prawn Trawl Fishery. As a precautionary measure, there are more possible combinations that result in a "high risk requiring direct action", as opposed to the alternative of concluding that a species was "medium risk requiring indirect action". A species' vulnerability to overfishing (determined in Table E2) is matched against the fishing pressure exerted by the Estuary Prawn Trawl Fishery (Table E3) to determine the overall risk of overfishing by the fishery (Table E4). As numeric data are not available to estimate likelihood, a qualitative risk analysis was undertaken. This risk assessment assumes equal weighting of the vulnerability and fishing pressure axes in Figure E1.

For the Estuary Prawn Trawl Fishery, the vulnerability of the species to fishing pressure based on species' biological and habitat attributes was assessed using the species information and references in Appendix B1, with additional expert opinion from fisheries scientists (Table E2).

The vulnerability of each species depends on the factors listed below. Categories within each of these vulnerability factors, as used in Table E2, are also described below.

Reproductive strategy

Broadcast marine spawners with high fecundities and long pelagic larval stages have been classed as "low". Species or groups believed to spawn exclusively within estuaries have been classed as "medium". None of the retained species in the Estuary Prawn Trawl Fishery have such limited reproductive capacities as to warrant a classification of "high" (an example of "high" would be those sharks which produce one or two pups every second year).

Tendency to aggregate

Species that often form large dense schools, whether for spawning, migration, or any other reason, have been classed as "high". Species that usually form loose aggregations have been classed as "medium", whilst those that do not normally school or aggregate have been classed as "low".

Size (age) when fished

Species mostly retained near or before their size (age) of first maturity are classified as "high". Those species mostly taken well above their size (age) of first maturity are classified as "low", and those typically taken at a wide range of sizes (ages) with respect to first maturity are classified as medium. Classifications with respect to this factor are based on available size and age-based catch data and information on life histories (SPCC, 1981b; NSW Fisheries, 2001a; Scandol and Forrest, 2001; Appendix B1; Appendix E1).

Position in food web

Species that primarily consume detritus, algae, sessile invertebrates and/or very small (typically planktonic) animals are classed as "low". Those species mainly eating fish and/or large invertebrates (i.e. 'predatory' species) are classed as "high", whilst those species with broad diets, or which prey on small invertebrates such as worms and molluscs, are classed as "medium".

Sensitivity of preferred habitat

Species that usually occur in association with marine vegetation are classed "high", while those found only sometimes in association with marine vegetation are classed "medium". The more pelagic species are classified as "low".

Sensitivity to pollution

There is no readily available literature for the species in the fishery to provide a definitive classification for this subsection. For the purposes of this assessment, species that regularly enter freshwaters, where water quality is often poor in comparison to marine waters, are classed as "low". Whilst it may not necessarily follow that those species normally only found in marine waters are highly sensitive to pollution, as it is only meant as an indicative guide, that scenario is applied in Table E2. Most of the species taken in the Estuary Prawn Trawl Fishery fall between these extremes and are therefore classed as "medium".

Fish passage issues

Species that regularly enter tributary rivers, streams or channels are classed as "high". Species that only occasionally enter such confined waters are classed as "medium", while those that rarely or never enter such waters are classed as "low".

Proportion of habitat fished

Species that are likely to be sought throughout most of their usual habitat range are classed as "high"- these species tend to remain confined to estuaries and/or are easily accessible to fishers throughout their adult life (e.g. prawns). Those species that often utilise habitats which are inaccessible (e.g. small creeks and swamps) or difficult to fish intensively (e.g. rocky reefs) are classed as "low". Species that fall between these extremes and are classed "medium".

Table E2. Life history and habitat vulnerability of the retained species in the Estuary Prawn Trawl Fishery.

	Vulnerability								
Species/group	**Fishing pressure - life history and behaviour**				**Habitat preference**				**Overall vulnerability**
Specific aspect of vulnerability	reproductive strategy	tendency to aggregate	size (age) when fished	position in food web	sensitivity of preferred habitat	sensitivity to pollution	fish passage issues	proportion of habitat fished	
Prawn, school	l	h	h	l	m	m	h	h	M-H
Prawn, eastern king	l	m	h	l	m	m	m	h	M
Squid (at least 2 species)	m	m	m	m	m	h	l	m	M
Whiting, trumpeter	l	l	l	m	l	m	m	m	L-M
Octopus (at least 3 species)	m	l	m	m	m	h	l	l	M
Silver biddy	l	m	m	l	m	m	m	m	L-M
Crab, blue swimmer	l	l	m	m	m	m	l	m	L-M
Flounder (at least 2 species)	l	l	m	m	l	m	l	m	L-M
Yellowtail	l	h	l	l	m	m	l	l	L-M
Prawn, greasyback	l	m	l	l	m	m	m	h	M
Catfish (at least 3 species)	m	m	m	l	l	l	m	m	L-M
Trumpeter	l	m	m	m	h	m	m	h	M
Crab, mud	m	l	m	m	m	m	h	h	M
Hairtail	m	h	m	h	l	h	l	m	M
Whitebait (glass fish) (at least 2 species)	m	h	m	l	l	m	m	h	M
Shrimp, mantis (at least 3 species)	m	l	l	h	m	m	m	h	M
Prawn, tiger	l	m	h	l	m	m	m	h	M
Pike, long-finned	l	m	m	h	m	h	l	l	M
Dory, john	m?	m	h	h	l	h	l	m	M
Sole, black	l	l	m	m	l	m	l	m	L-M
Crab, sand	l	m	h	l	m	m	l	h	M
Bullseye (at least 2 species)	l	m	m	m	m	h	l	l	M

Explanations of ratings within each of the specific aspects are given in the previous text.

To maintain consistent terminology between tables E3 and E1, a codified stock status was used in Table E3 based on the status described in Table E1. The equivalent phrase from Table E1 for "m" in Table E3 is moderately or fully-fished; "h" is fully to overfished; and "u" is unknown or uncertain. As a precautionary measure, wherever the stock status of a species is unknown, this assessment has determined that the overall fishing pressure by the Estuary Prawn Trawl Fishery must be high, irrespective of the harvest level by the fishery. For example, the fishery only accounts for 0.002% of the total mud crab harvest for the State, but as there is no information about the stock, fishing pressure is considered to be high and in need of direct action within the FMS.

The fishing pressure on the species and the relative contribution of the Estuary Prawn Trawl Fishery (Table E3) are based on the commercial fish catch database harvest tonnage averaged for the years 1997/98, 1998/99 and 1999/00. The estimated total harvest by all sectors is derived from the commercial fish catch database harvest tonnage averaged for the years 1997/98, 1998/99 and 1999/00, preliminary data from the National Survey of Recreational and Indigenous Fishers (G. Henry, NSW Fisheries, pers. comm.) and from Anon (1981), Henry (1984, 1987), Henry and Virgona (1980), Henry *et al.* (1987), Steffe *et al*. (1996a, b), Steffe and Chapman (in review), West and Gordon (1994) and Williams *et al.* (1993). The preliminary recreational harvest data from the National Survey of Recreational and Indigenous Fishers are the estimates of the total number of kept fish by species, unweighted for the statistical divisions of the State's population. These estimates were converted to weights using data on the median length or weight of retained fish for individual fish species from the above referenced recreational fishing surveys. Where necessary, the fish and invertebrate lengths were converted to weight using the length/weight conversion keys in Steffe *et al.* (1996a).

Table E3. Overall assessment of the pressure associated with each of the retained species in the Estuary Prawn Trawl Fishery.

Species/group	Fishing Pressure					
	Average estuary prawn trawl harvest (tonnes)*	Estimated average total harvest in NSW (commercial + recreational) (tonnes)*	Estuary prawn trawl harvest as a percent of total harvest	Level of bycatch taken in the Estuary Prawn Trawl Fishery ^	Codified stock status (from Table E1)	Overall fishing pressure by the Estuary Prawn Trawl Fishery
Prawn, school	401	836	48	h	m	M-H
Prawn, eastern king	230	903	25.5	h	m	M-H
Squid (at least 2 species)	42	136	31	m	u	H
Whiting, trumpeter	18.7	92	20	m	u	H
Octopus (at least 3 species)	12.1	470	2.6	m	u	H
Silver biddy	5.9	150	4	m	u	H
Crab, blue swimmer	4.7	321	1.5	h	u	H
Flounder (at least 2 species)	1.6	39	4.1	m	u	H
Yellowtail	1.4	495	0.3	l	m	L-M
Prawn, greasyback	0.9	570	0.15	m	u	H
Catfish (at least 3 species)	1	85	1.2	m-h	u	H
Trumpeter	0.5	8.4	6	m	u	H
Crab, mud	0.4	200	0.002	l	u	H
Hairtail	0.3	16.7	1.8	l	u	H
Whitebait (glass fish) (at least 2 species)	0.3	24.5**	1.2	l	u	H
Shrimp, mantis (at least 3 species)	0.3	0.3**	100	m	u	H
Prawn, tiger	0.2	13**	1.5	l	u	H
Pike, long-finned	0.08	6.7	1.2	l	u	H
Dory, john	0.048	32.5	0.1	l	u	H
Sole, black	0.04	4**	1	l	u	H
Crab, sand	0.009	20**	0.05	l	u	H
Bullseye (at least 2 species)	0.004	0.4**	1	l	u	H

* see text for explanation of data sources.
** no recreational values available (but likely to be very low).
^ excluding prawns, values were adapted from bycatch studies in the Estuary Prawn Trawl Fishery (see Liggins and Kennelly, 1996; Liggins *et al.*, 1996.

The overall stock status of target species within the Estuary Prawn Trawl Fishery (Table E1) is based on information derived from the Estuary Prawn Trawl Fishery and from other commercial sectors. The vulnerability of each species (Table E2) was determined independently of the Estuary Prawn Trawl Fishery. The fishing pressure associated with each species (Table E3) was determined based on the impact of the Estuary Prawn Trawl Fishery relative to all other harvest sectors (commercial and recreational). The information in Table E1, E2 and E3 are the basis for the risk assessment presented in Table E4.

Table E4. Risk assessment for each of the retained species in the Estuary Prawn Trawl Fishery.

"Overall risk" is based on the intersection of vulnerability and fishing pressure as per Figure E1 above. "Direct action" refers to management approaches such as fishing closures, gear modifications and size limits. "Indirect measures" refers to approaches such as monitoring and review.

Species/group	Vulnerability (from Table E2)	Fishing pressure (from Table E3)	Overall risk associated with species (Figure E1)	Required management (Figure E1)	Draft FMS match to required mgmt	Draft key FMS objectives
Prawn, school	M-H	M-H	High	Direct action	Yes	1.1; 2.1; 2.2; 2.3; 4.2; 5.1
Prawn, eastern king	M	M-H	High	Direct action	Yes	1.1; 2.1; 2.2; 2.3; 4.2; 5.1
Squid (at least 2 species)	M	H	High	Direct action	Yes	1.1; 2.1; 2.2; 2.3; 4.2; 5.1
Whiting, trumpeter	L-M	H	High	Direct action	Yes	1.1; 2.1; 2.3; 4.2
Octopus (at least 3 species)	M	H	High	Direct action	Yes	1.1; 2.1; 2.3; 4.2
Silver biddy	L-M	H	High	Direct action	Yes	1.1; 2.1; 2.3; 4.2
Crab, blue swimmer	L-M	H	High	Direct action	Yes	1.1; 2.1; 2.3; 4.2
Flounder (at least 2 species)	L-M	H	High	Direct action	Yes	1.1; 2.1; 2.3; 4.2
Yellowtail	L-M	L-M	Medium	Indirect action	Yes	1.1; 2.1; 2.3; 4.2
Prawn, greasyback	M	H	High	Direct action	Yes	1.1; 2.1; 2.3; 4.2
Catfish (at least 3 species)	L-M	H	High	Direct action	Yes	1.1; 2.1; 2.3; 4.2
Trumpeter	M	H	High	Direct action	Yes	1.1; 2.1; 2.3; 4.2
Crab, mud	M	H	High	Direct action	Yes	1.1; 2.1; 2.3; 4.2
Hairtail	M	H	High	Direct action	Yes	1.1; 2.1; 2.3; 4.2
Whitebait (glass fish) (at least 2 species)	M	H	High	Direct action	Yes	1.1; 2.1; 2.3; 4.2
Shrimp, mantis (at least 3 species)	M	H	High	Direct action	Yes	1.1; 2.1; 2.3; 4.2
Prawn, tiger	M	H	High	Direct action	Yes	1.1; 2.1; 2.3; 4.2
Pike, long-finned	M	H	High	Direct action	Yes	1.1; 2.1; 2.3; 4.2
Dory, john	M	H	High	Direct action	Yes	1.1; 2.1; 2.3; 4.2
Sole, black	L-M	H	High	Direct action	Yes	1.1; 2.1; 2.3; 4.2
Crab, sand	M	H	High	Direct action	Yes	1.1; 2.1; 2.3; 4.2
Bullseye (at least 2 species)	M	H	High	Direct action	Yes	1.1; 2.1; 2.3; 4.2

The risk assessment (Table E4) shows that the Estuary Prawn Trawl Fishery should not place any of the proposed retained species in an extreme risk of being overfished. Nearly all of the retained species in the fishery are at a high risk of being overfished without immediate direct management measures. Only one species in the fishery, yellowtail, is at a medium risk of being overfished and only requires indirect management measures.

Of the 21 species considered a high risk in this assessment, 17 were calculated as such due to the precautionary approach adopted, i.e. by considering all species with an unknown stock status to be under high fishing pressure by the Estuary Prawn Trawl Fishery. Table E4 a suggests that the draft FMS proposes appropriate management responses for all retained species within the fishery, and the degree of that adequacy is discussed in part b of this section.

b) Assessment of retained species management measures in the draft FMS

i) Adequacy of the draft FMS for the different categories of stock exploitation

External factors likely to affect stock status

Before discussing the various categories of stock exploitation within the fishery, it is important to highlight that the stock assessments are at various levels of development. Furthermore, whilst the draft FMS may improve upon the assessments, there are external factors affecting stocks, which are generally beyond the control of the FMS. They include stock resilience and external environmental influences, both human-related and natural (see section 10 of Chapter F). Whilst such factors are beyond the direct control of the fishery, they do need to be considered within the draft FMS, both in terms of allowing for any potential negative influences on stock status, and in terms of their indirect control (as, for example, through Catchment Management Boards).

The resilience of a stock refers to that stock's ability to recover after having been affected by previous fishing pressure (Underwood, 1989; Skilleter, 1995). For the species taken in the Estuary Prawn Trawl Fishery, there is no specific information on resilience. The aspects of vulnerability presented in Table E2, however, would provide some indication of resilience for each retained species, as recovery potential is likely to be strongly tied to these aspects and especially to reproductive strategy. On the basis of the limited information available (Table E2), it is likely that most of the retained species are fairly resilient to fishing pressure. Most of these are broadcast marine spawners, with high fecundity and a long pelagic larval stage, features that would assist any recovery, particularly in the case of localised and/or short term depletion (Skilleter, 1995).

Apart from trawling, each of the trawled estuaries is subject to varying degrees of impacts as a consequence of human population and development pressures. These pressures include: (i) land clearing; (ii) contaminants from agriculture, industry, effluent and runoff; and (iii) reduced stream flows. Such pressures impact upon the environment by reducing habitat and water quality. Species taken in the Estuary Prawn Trawl Fishery use sensitive estuarine habitats (such as seagrass) for at least part of their life cycle (particularly as juveniles) and are potentially more vulnerable such external influences. The threat is two-fold for not only can stock numbers be directly affected in the event of major habitat loss, but so can the recovery ability (i.e. resilience) of dependant species. Even if a depleted species can still produce large numbers of widely dispersed larvae, its harvestable population would be unlikely to recover if there was insufficient suitable habitat available to support the settlement of larvae and growth of juveniles.

Other external factors that affect stock status and resilience are weather, oceanographic conditions, pollution from commercial and recreational uses of waters. These factors, particularly weather and oceanographic conditions, can significantly affect the distribution, abundance, behaviour and recruitment of fish. These factors, whilst external to the fishery, need to be considered during the formulation and analysis of stock assessments, as they can account for significant variations in fish catch beyond effort or technology associated with the fishery. The role that these factors have in affecting the fishery as a whole is discussed in section 10 of Chapter F.

The relative contributions of external factors to mortality and habitat condition are currently unknown, meaning that related predictions given in Tables E5 and E6 are indicative only. Whilst the relevant responses in the draft FMS can be expected to (for example) reduce mortality or improve habitat condition, there is no way of predicting the extent to which such benefits will offset adverse influences from the many external factors affecting the fishery.

Categories of stock status in the Estuary Prawn Trawl Fishery

The retained species within the Estuary Prawn Trawl Fishery have been identified as having either a fully fished or unknown exploitation status (Table E1). As no stock assessments have been completed for most of the species retained by the Estuary Prawn Trawl Fishery, it is not known if the unknown species are moderately fished or over fished/depleted.

It should be noted that over fished species can be either 'growth overfished' and/or 'recruitment overfished' (NSW Fisheries, 2001a). Growth overfishing refers to the excessive harvesting of relatively young individuals of a stock, such that biomass yield is reduced. Recruitment overfishing refers to a situation in which fishing pressure has caused a significant reduction in a stock's reproductive success, such that the recruitment of young fish into the fishery is reduced.

Fully fished

Among the retained species listed in Table E1, at least three species taken by the Estuary Prawn Trawl Fishery are classified as being fully fished according to the latest stock assessments (NSW Fisheries, 2001a). These species are school prawns, eastern king prawns and yellowtail. Eastern king prawns and yellowtail have a moderate confidence level associated with their stock assessments (Table E1), while the confidence associated with the stock assessment of school prawns is low (Table E1). For fully fished species, current catches are thought to be sustainable and close to optimal levels, although any significant increase in fishing effort may lead to overfishing and stock depletion (NSW Fisheries, 2001a).

Maintaining sustainable stocks of target species in the Estuary Prawn Trawl Fishery is important for the fishery's long-term viability. Consequently, with respect to the fully fished species, the draft FMS takes a more active approach in understanding and maintaining the stocks of school and eastern king prawns than it does for yellowtail stocks. This approach can also be justified as the fishery accounts for only a small proportion of the total commercial catch of yellowtail (0.3% of total commercial landings over the 1997-2000 period) and a stock assessment of this species will be completed under the Ocean Hauling FMS. Also, the risk assessment (Table E4) indicates that the fishery in isolation has a medium risk of over-exploiting yellowtail species and only indirect management measures are required. The draft FMS satisfies this requirement by taking direct management action on yellowtail stocks (see Table E4 for relevant management objectives).

With respect to the species currently assessed as fully fished, the relevant management measures in the Estuary Prawn Trawl draft FMS (see Table E5) are expected to result in:

- more reliable stock assessment information for the targeted school and eastern king prawns, and a subsequent reduction in uncertainty when managing these stocks
- more effective monitoring of fully fished species
- reduced mortality of juveniles from improved fishing practices and handling procedures
- the identification and subsequent protection of environmentally sensitive areas, especially seagrasses used by juvenile prawns
- a reduction in active and latent fishing effort

- more sustainable fishing of the targeted fully fished species (school and eastern king prawns)
- a reduced likelihood of the Estuary Prawn Trawl Fishery causing the overfishing of the byproduct fully fished species (yellowtail)
- more holistic management of target species across all fishing sectors and external factors.

On the next review of the status of fisheries resources in NSW, both school and eastern king prawn stocks would probably be classified as being growth overfished. Objective 2.6 in the draft FMS proposes to manage such a change in stock exploitation status by implementing a recovery plan for the species involved. The draft FMS proposes measures that would control problems in a growth overfished fishery, such as controlling the size of prawns taken in each estuary through management responses 2.1e, 2.1f, 5.1a and 5.1b, and is precautionary in this respect.

The draft FMS should ensure the sustainability of all fully fished species mostly through reducing fishing effort. It will achieve this through improved gear configurations (management response 2.1a) and bycatch reduction devices (management response 1.1c), the introduction of limits on the catches of target (management responses 2.1e and 5.1b) and byproduct species (management responses 1.3a and 4.2c), and prevention of active and latent effort expansion (objectives 2.3 and 2.4). Once the strategy is implemented, if problems concerning the sustainability of fully fished species are identified, the overall fishing effort on these species can be decreased through closures (management response 1.1f), gear modifications (management response 2.1a) and other measures pending the result of a subsequent review.

With respect to the targeted fully fished species, the proposed measures within the draft FMS also focus on improving the knowledge of stocks and include fishery-independent surveys of these species (management response 8.1b). Improvements in the stock assessments of both school and eastern king prawns will be critical to the long-term sustainability of these species and the long-term viability of this fishery as a whole. The ability to predict the effectiveness of management responses will improve significantly once robust and reliable stock assessments are complete. The improved stock assessments will be complemented by the implementation of a scientific observer program, which will improve the knowledge of active effort and help quantify the extent and composition of bycatch within the fishery.

The draft FMS places a strong emphasis on a more holistic management approach when managing stocks of the targeted school and eastern king prawns. It seeks to sustainably share the prawn resources across all relevant sectors, especially considering these species' exploitation status, life cycle and migration requirements. The strategy should result in the maintenance of sustainable populations of these species by: establishing catch limits across all sectors (management responses 2.1h, 2.2a, 4.2d); increasing the reliability of their stock assessments (management responses 2.1d and 2.1i); limiting the total effort across all sectors (management response 2.3b); and discussing relevant management issues within a forum group (management response 4.2d). The current harvesting of school prawns by the Hawkesbury River fishery in winter does not seem to consider life cycle requirements of this species. It is important for this matter to be investigated further, perhaps by the Prawn Resource Forum. For further information on this matter refer to section 1(e) of Chapter F.

Table E5. Direct actions within the Estuary Prawn Trawl draft Fishery Management Strategy most relevant to species with a fully fished stock status in the fishery.

draft FMS Measures (Chapter C)			**Summary of purpose/ action**	**Factor(s) likely to be positively affected by implementation of responses**
Goals	**Objectives**	**Responses**		
1			Conserve biological diversity	
	1.1		Minimise impact on non-retained fish	
		1.1a	restrictions on use and type of fishing gear	Fishing effort (constrained)
		1.1c	develop and introduce alternate fishing gears	Juvenile mortality (reduced)
		1.1d	ban cooked prawn riddling, investigate ban on riddling green prawns	Overfishing risk (reduced) Juvenile mortality (reduced)
		1.1e	better handling of non retained animals	Juvenile mortality (reduced)
		1.1f	avoid places or times of high juvenile abundance; protection of seagrass and other areas of environmental significance	Juvenile mortality (reduced), stock preservation, habitat condition
		1.1g	prohibit use of firearms, explosive or electrical devices	Habitat condition, mortality (reduced)
	1.2		Minimise impact on habitats	
		1.2a	areas of environmental sensitivity and non-trawled areas within the current trawled areas defined	Habitat condition, uncertainty (reduced)
		1.2b	expansion of trawling area prevented	Habitat condition
		1.2c	prohibition of wilful habitat damage	Habitat condition
	1.3		Protect ecosystem integrity	
		1.3c	research ecosystem function	Understanding (improved)
	1.4		Prevent marine pests and diseases	
		1.4a	implement NSW Marine Pest Management Plans	Habitat condition, mortality (reduced)
2			Maintain fish populations at sustainable levels	
	2.1		Avoid overfishing	
		2.1a	limit size and dimensions of gear	Overfishing risk & morality (reduced)
		2.1b	monitor commercial landings from each estuary	Monitoring of catch trends (improved)
		2.1d	promote prawn stock assessment research	Uncertainty regarding stock size and fluctuations (reduced)
		2.1e	implement maximum counts on prawns	Overfishing risk (reduced)
		2.1f	review maximum counts on prawns based on new research	Overfishing risk (reduced)
		2.1h	complementary counts of prawns in other fisheries	Overfishing risk (reduced), resource allocation (improved)
		2.1i	stock assessments of prawns	Uncertainty and overfishing risk (reduced)
	2.2		Achieve spawner biomass levels that will reduce risk of recruitment overfishing	
		2.2a	appropriate fishing effort on spawning stocks of prawns	Overfishing risk (reduced)

Table E5 cont.

draft FMS Measures (Chapter C)			Summary of purpose/ action	Factor(s) likely to be positively affected by implementation of responses
Goals	Objectives	Responses		
	2.3		Manage active effort	
		2.3b	level of total allowable effort on target species determined	Overfishing risk (reduced)
		2.3c	set minimum shareholdings, or limit number of fishing days per business	Future effort (better controlled)
		2.3d	continue licensing arrangements	Future effort (better controlled)
		2.3e	restrict engine power of Port Jackson trawling vessels	Future effort (better controlled)
	2.4		Prevent activation of latent effort	
		2.4a	implement owner-operator rule	Future effort (better controlled)
		2.4b	set minimum entry requirements	Future effort (better controlled)
	2.5		Minimise impacts of external activities	
		2.5b	detrimental impacts of external activities considered	Holistic management
4			Appropriately share the resource	
	4.1		Proper allocation of fisheries resources between fishing groups	
		4.1a	assess size and impact of non-commercial and illegal catch	Holistic management
	4.2		Fair and equitable sharing of fisheries resources among commercial fisheries	
		4.2a	monitor associated fisheries outside NSW jurisdiction	Overfishing risk (reduced), resource allocation (improved)
		4.2b	monitor catches of prawn species by other commercial fisheries	Overfishing risk (reduced), resource allocation (improved)
		4.2c	limit landings of byproduct species	Overfishing risk (reduced)
		4.2d	discuss management issues relevant to more than one fishery	Holistic management, resource allocation (improved)
5			Promote a viable commercial fishery	
	5.1		Optimise biological yield so economic return is maximised	
		5.1a	controls to ensure catches are larger than minimum sizes	Risk of fishery collapse (prevented)
		5.1b	implement maximum counts on prawns	Overfishing risk (reduced)

Table E5 cont.

draft FMS Measures			Summary of purpose/ action	Factor(s) likely to be positively affected by implementation of responses
Goals	**Objectives**	**Responses**		
6			Efficient management and compliance	
	6.1		Maximise compliance with strategy	
		6.1a	compliance audit scheme, operational plans and voluntary compliance	Adherence to rules
		6.1b	demerit points system	Adherence to rules
		6.1c	publish successful prosecution results	Adherence to rules
8			Improve knowledge of species	
	8.1		Promote appropriate scientific research and monitoring	
		8.1a	scientific observer program	Monitoring of catch trends (improved)
		8.1b	Fishery independent survey of prawn stocks	Uncertainty and overfishing risk (reduced)
	8.2		Improve catch and effort information	
		8.2a	review and alter catch return forms as needed	Accuracy of catch data

Factors listed in the right column are specifically in relation to the fully fished species. It should be noted that positive effects given in the right column are indicative only, and that currently available data do not allow absolute or relative (as a proportion of total) estimates of factors such as juvenile mortality or habitat condition to be made.

Unknown

No stock assessment information has been gathered for most of the species listed in Table E1, and the stock status of 19 species taken by the Estuary Prawn Trawl Fishery is unknown. These species are trumpeter whiting, silver biddy, blue swimmer crab, greasyback prawn, trumpeter, mud crab, hairtail, tiger prawn, long-finned pike, john dory, black sole, sand crab and groupings of squid, octopus, flounder, catfish, whitebait, mantis shrimp and bullseye species (Table E1).

With respect to the species currently assessed as ‘unknown’, the relevant management measures in the Estuary Prawn Trawl draft FMS (see Table E6) are expected to result in:

- an improved knowledge of squid populations and a detailed knowledge of their catches across all sectors
- limits on the landings of all ‘unknown’ species in the fishery and more effective monitoring of them
- reduced uncertainty when managing squid populations, with the determination of an exploitation stock assessment category for squid species targeted by the fishery and subsequent management
- sustainability of squid stocks with: the establishment of a minimum legal length (if required) of squid across all fisheries; preservation of squid spawning stocks; and gear, effort and landing restrictions
- for unknown species other than squid, a reduced risk of being overfished by the Estuary Prawn Trawl Fishery via gear, effort and landing restrictions

- reduced mortality of all species through reductions in bycatch and improved fishing/ handling practices
- a reduction in active and latent fishing effort
- the identification and subsequent protection of environmentally sensitive areas, especially seagrasses used by blue swimmer crabs and juvenile trumpeter whiting, silver biddy, trumpeter and tiger prawn
- an improved understanding of ecosystem function.

With respect to increasing our knowledge about these 'unknown' species, the Estuary Prawn Trawl draft FMS is largely focused on determining a reliable exploitation stock status for squid, being a target species of the fishery in the Hawkesbury River (management responses 2.1c, 2.1d and 2.1i). Part of this direct action involves an investigation into the Statewide decline in reported commercial landings of squid. The draft FMS proposes adequate precautionary measures to ensure the sustainability of squid, even considering the currently unknown exploitation status of squid. These measures include ascertaining the need for a minimum legal length of squid and implementing as required (management response 2.1g), effort controls (objectives 2.3 and 2.4) and the monitoring of squid catches in other fisheries (management response 4.2b).

There is little commitment in the draft FMS to increase our knowledge of the stock status for the other 'unknown' species caught by the fishery, only a commitment to improve and monitor catch information. This approach can be justified as the permitted landings of byproduct species in the fishery represent only a low proportion of the total State harvest of these species, except trumpeter whiting and mantis shrimp species (see Table E3). Determining the stock status of some of the byproduct species would need to be a priority in other commercial fisheries where these species are targeted, and the Estuary Prawn Trawl Fishery can contribute the relevant landings information to these assessments. Stock assessments for mud crab and yellowtail will be completed under the management strategies for the Estuary General and Ocean Haul Fisheries respectively. For trumpeter whiting, the fishery caught 20% of the total State harvest during 1997-00. Perhaps there is a need to understand more about this species, although patterns in annual landings or CPUE (see Appendix B5) show no need for concern. For mantis shrimp, while the fishery caught approximately 100% of the total State harvest during the 1997-00 period, very few of these species are landed, and consequently there is less need to understand the stocks of these species.

Although the draft FMS makes no attempt to improve on the knowledge of byproduct species, it still proposes management responses that should directly ensure the sustainability of these species. Currently fishers can land any species of marketable quality that do not have a size limit. Under the draft FMS, it is proposed to restrict the fishery to certain byproduct species only and to implement landing limits on these species (management response 4.2c). This approach should maintain landings of byproduct species by the fishery at conservative levels, with appropriate monitoring programs preventing an expansion in fishing effort. These limits vary between estuaries (Table C2) and are based on historical catch records for the fishery which generally represent a low proportion of the total State harvest of these species. The fishery should not considerably affect the sustainability of byproduct species in the Hunter and Clarence rivers and the upper and middle zones of the Hawkesbury River as byproduct species are a negligible part of the landings allowed in these areas (Table C2). In Port Jackson and Broken Bay, byproduct species represent a considerable proportion of the allowed landings (Table C2). The allowed landings of some byproduct species in these more marine areas appears to be quite high (Table C2), however, a yearly review of the landing limits based on up to date information from the observer program and catch records should result in a reduction of these limits. Also, a reduction on byproduct limits in Broken Bay is also expected if an effective byctach reduction device is designed for the Hawkesbury River squid component.

The draft FMS also proposes to manage byproduct species by controlling active effort (objective 2.3), reducing the capture of juveniles (management response 1.1c), implementing gear restrictions (management response 2.1a) and monitoring large scale changes in annual landings of the prominent byproduct species (see Table C11b). These measures along with limiting the landings of byproduct species should adequately provide the direct action required from the species risk assessment (Table E4) for the sustainable management of the 'unknown' byproduct species.

In the draft FMS byproduct species are described as those that have traditionally significantly contributed to the marketed catch of the fishery. For some species identified as byproduct this does not appear to be the case. Bullseyes and pike have not traditionally contributed to the landings of the fishery (refer to Figure AE10 in Appendix E1). Also, some byproduct species, namely sand crab and sole, appear not to significantly contribute to the value of the fishery as only small quantities are allowed to be landed in one estuary (Table C2). The composition of the byproduct species list should be reassessed based on the definition of byproduct species.

Many of the byproduct 'species' listed in Table E1 are actually groupings of a few species. These species should benefit through a commitment to improve the quality of collected catch and effort information (objective 8.2) including where possible their recording as separate species.

Table E6. Indirect measures and direct actions within the Estuary Prawn Trawl draft FMS specifically relevant to species with an 'unknown' stock status in the fishery.

draft FMS Measures (Chapter C)			Summary of purpose/ action	Factor(s) likely to be positively affected by implementation of responses
Goals	**Objectives**	**Responses**		
1			Conserve biological diversity	
	1.1		Minimise impact on non-retained fish	
		1.1a	restrictions on use and type of fishing	Effort (constrained)
		1.1c	develop and introduce alternate fishing gears	Juvenile and adult mortality (reduced)
		1.1e	better handling of non retained animals	Juvenile and adult mortality (reduced)
		1.1f	avoid places or times of high juvenile abundance; protection of seagrass and other areas of environmental significance	Juvenile mortality (reduced), overfishing risk (reduced), habitat condition
		1.1g	prohibition on firearms, explosive or electrical devices	Habitat condition, mortality (reduced)
	1.2		Minimise impact on habitats	
		1.2b	prevent the expansion of trawling area	Habitat condition
		1.2c	prohibition of wilful habitat damage	Habitat condition
	1.3		Protect ecosystem integrity	
		1.3a	implement incidental catch ratios	Juvenile mortality (reduced)
		1.3e	research ecosystem function	Understanding (improved)
2			Maintain fish populations at sustainable levels	
	2.1		Avoid overfishing	
		2.1a	limit size and dimensions of gear	Overfishing risk & mortality (reduced)
		2.1b	monitor commercial landings of squid by zone	Knowledge of catch trends (improved)
		2.1c	review exploitation of squid resources	Uncertainty (reduced)
		2.1d	promote squid research	Knowledge
		2.1g	minimum legal length for squid	Knowledge, overfishing risk (reduced)
		2.1h	mimimum legal length for squid in other fisheries	Overfishing risk (reduced), resource allocation
		2.1i	stock assessment of squid	Uncertainty & overfishing risk (reduced)
	2.2		Achieve spawner biomass levels that will reduce risk of recruitment overfishing	
		2.2a	appropriate fishing effort on spawning stocks of squid	Overfishing risk (reduced)
	2.3		Manage active effort	
		2.3a	separate management rules for each	Management (improved)
		2.3c	set minimum shareholdings, or limit number of fishing days per business	Overfishing risk (reduced)
		2.3d	continue licensing arrangements	Effort (controlled)
		2.3e	restrict engine power in Port Jackson	Effort (restricted)
	2.4		Prevent activation of latent effort	
		2.4a	implement owner-operator rule	Effort (restricted)
		2.4b	minimum entry requirements	Effort (restricted)

Table E6 cont.

draft FMS Measures (Chapter			Summary of purpose/ action	Factor(s) likely to be positively affected by implementation of
Goals	Objectives	Responses		
4			Appropriately share the resource	
	4.1		Proper allocation of fisheries resources between fishing groups	
		4.1a	assess size and impact of non-commercial and illegal catch	Understanding of total landings
	4.2		Fair and equitable sharing of fisheries resources among commercial fisheries	
		4.2a	monitor associated fisheries outside NSW jurisdiction	Overfishing risk (reduced), resource allocation (improved)
		4.2b	monitor catches of squid species by other commercial fisheries	Overfishing risk (reduced), resource allocation (improved)
		4.2c	limit landings of byproduct species	Overfishing risk (reduced)
5			Promote a viable commercial fishery	
	5.1		Optimise biological yield so economic return is maximised	
		5.1a	investigate controls to ensure catches are larger than minimum sizes	Risk of fishery collapse (prevented)
		5.1b	implement minimum legal lengths for squid if necessary	Risk of fishery collapse (prevented)
6			Efficient management and compliance	
	6.1		Maximise compliance with strategy	Adherence to rules
8			Improve knowledge of species	
	8.1		Promote appropriate scientific research and monitoring	
		8.1a	scientific observer program	Monitoring of catch trends (improved)
		8.2b	Fishery independent survey of squid stock	Uncertainty & overfishing risk (reduced)
	8.2		Improve catch and effort information	
		8.2a	review and alter catch return forms as needed	Accuracy of catch data

It should be noted that positive effects given in the right column are indicative only, and that currently available data do not allow absolute or relative (as a proportion of total) estimates of factors such as juvenile mortality or habitat condition to be made.

Uncertainty in relation to the management of stocks

The major uncertainty associated with the management of target species is the knowledge of stocks and the accuracy of species assessments. Such uncertainty can only be addressed through the development of more robust and reliable stock assessments and through increased confidence in the accuracy of data collected, whether from within the fishery or from independent sources. The draft FMS details a number of measures to meet these requirements through improved stock assessments, verification of catch data and fishery independent and species-specific research. However, it must be accepted that a level of uncertainty will remain until improvements in our knowledge of the stocks are cross-referenced against the predicted outcomes.

In terms of the management responses themselves, the greatest uncertainty surrounds the management of active effort. The control of active effort in the Estuary Prawn Trawl Fishery is important in determining and limiting the degree of bycatch and habitat disturbance in sensitive estuarine environments and in responding to potential species declines in the future. The existing endorsement system has limited impact on active effort, and provides a poor representation of the actual effort involved in the fishery. The draft FMS proposes three options in management response 2.3a but is indecisive as to how active effort will be managed in the fishery. It is difficult to assess the appropriateness of these options as the draft FMS provides only limited information as to how they will be implemented and how they will affect the historical level of fisher participation. The options include implementing minimum shareholdings over set time periods to limit the number of operators in each estuary, or to either limit the number of fishing days that may be applied in each estuary or the number of fishing days available to each fishing business. A decision as to how active effort will be managed in the fishery should be made before the implementation of the FMS.

It should also be recognised that variability is inherent within ecosystems and species themselves. Species abundance at any point in time at any location is highly dependent on a range of local and global factors. These may include rainfall, temperature, catchment influences, and historical fishing pressure or habitat availability. The draft FMS accounts for this potential variation within and among estuaries through an estuary specific approach to managing the fishery, with the setting of different species limits per estuary and different management rules per estuary. When considering the variation within certain species, the draft FMS caters for this by setting wide trigger points and monitoring short-term temporal trends in catch data.

Uncertainty is also generated through the recording of fishers' catches. There is considerable variation in the accuracy and precision of the data supplied by fishers and the timeliness of processing monthly catch returns. This issue is addressed through quality control mechanisms (objective 8.2). An improvement to data quality is pivotal to the success of the FMS, as any doubts surrounding the data would weaken any stock assessments that are used for future management and would prevent the timely implementation of trigger points, which are the overarching tool of the strategy.

Compliance with the fishery management rules by all sectors (recreational, commercial, Indigenous and non-consumptive) is the other uncertainty in the draft FMS. The consequences of non-compliance can negate the management initiatives introduced to ensure stock sustainability. Goal 6 addresses this issue in the draft FMS. The detailed responses and performance monitoring associated with this goal are the basis for constant review and improvement.

Confidence in achieving the planned outcomes of the draft FMS

Due to the lack of information available for many of the species in the Estuary Prawn Trawl Fishery, it is difficult to accurately assess the level of confidence in relation to the responses that manage the fishery's impact and its associated risks. Prawns are broadcast marine spawners and are short-lived. As a result, these species should be able to respond to management initiatives to control their overfishing, and any adverse effects from excessive harvesting would be relatively short term and reversible. Whilst the overall impact of the Estuary Prawn Trawl Fishery is largely unknown, the draft FMS manages the uncertainty relating to both individual species and the wider environment through a series of appropriate precautionary management responses.

The ultimate success of the draft FMS in achieving its stated goals and objectives is intrinsically linked to the acceptance/implementation of the proposed management rules. The greatest risk to the fishery would be represented by a failure to implement the proposed management responses, particularly the commencement of formal stock assessments for all target species, the implementation of active effort controls, the implementation of codend counts of prawns or the undertaking of an appropriate review if a trigger point is breached. Despite the lack of quantitative data available, it would appear that the management responses and initiatives of the draft FMS would allow an improved confidence in the sustainability of the Estuary Prawn Trawl Fishery.

Overall acceptability of measures proposed in the draft FMS

Given our incomplete understanding of the status of retained stocks and their associated ecological interactions, and the wide range of external environmental influences (both anthropogenic and natural) affecting the fishery, it is impossible to predict the precise effect of the draft strategy's implementation on the resource status of the retained species taken in the Estuary Prawn Trawl Fishery.

The draft FMS contains a series of measures that aim to improve knowledge of stock status, limit active effort, improve participant management and minimise habitat damage. Of these, the measures to improve knowledge of stock status will be important in determining the overall adequacy of the proposed measures in the draft FMS. The confidence in making predictions for most species is low (Table E1), and as a result, improving our knowledge for each of the target species is the major challenge for the future management of this fishery. Despite specific concerns over certain aspects of the draft FMS, the implementation of the aforementioned initiatives and the continuation of current restrictions will increase the likelihood of long-term resource sustainability and the equitable distribution of resources. This is especially so as the draft strategy takes an integrative management approach, considering the relationships between species (especially the targeted prawns), the relevant habitats and cumulative effects of other fisheries or fishing sectors.

The integrated management approach taken in the draft FMS also considers the possible impact of external factors on stock sustainability. While these factors are generally unpredictable, there is commitment in the draft FMS for any observed effects on the fishery to be brought to the attention of relevant managers. There is also a commitment to minimise the impacts of anthropogenic factors where possible, through the review of development applications and contribution to external government policies. Although such measures cannot remove the impacts of external factors on the sustainability of retained species, they should help minimise these impacts where possible.

The principles of ESD are foremost in the philosophy behind how the State's fisheries are managed. The Estuary Prawn Trawl draft FMS is an integrated management tool that, on the basis of information provided within this section, should maintain sustainable populations of the species retained by the fishery. Where uncertainty is highest (especially concerning the byproduct species), the draft FMS proposes conservative parameters for future harvesting with an increased focus on monitoring and research programs. The proposed management measures in the draft FMS are likely to be acceptable in terms of maintaining sustainable stock levels.

ii) ESD assessment

Ecological Sustainable Development refers to the effective integration of economic, social and environmental considerations in society's decision making process. The four principles of ESD are outlined under Section 6 of the *Protection of the Environment Administration Act 1991* and can be summarised under the following headings. An assessment is provided of how the draft FMS addresses each principle of ESD.

The precautionary principle

The precautionary principle states that if there are threats of serious or irreversible environmental damage, a lack of full scientific certainty should not be used as a reason for postponing measures aimed at preventing environmental degradation. For example, poor information should not be used as a reason to delay the implementation of more stringent management controls in relation to a fish species, if there is already reason to suspect that the species concerned may be over exploited.

This principle requires decision makers to carefully evaluate a given proposal to avoid, wherever practicable, serious or irreversible environmental damage. It also calls for an assessment of the risk-weighted consequences of all feasible options associated with a proposal.

Given the data-poor environment in which the Estuary Prawn Trawl Fishery operates, the draft FMS is substantially based on the precautionary principle. Our knowledge of the relevant ecosystems, habitats, threatened species and shellfish and finfish stocks, as well as the interactions between them, is currently limited. Goals 1, 2 and 3 of the draft FMS are therefore largely concerned with the application of the precautionary principle: specific management responses are, for the most part, designed to protect natural values on the basis of educated belief rather than hard scientific evidence. Under this approach, some specific strategies may ultimately prove (in light of further scientific understanding) to have been unnecessarily conservative. However, such an outcome would be far better than a situation under which serious or irreversible environmental damage occurred as a result of not taking action in the first place.

Specific examples of the precautionary principal being adopted in the draft FMS include: the prohibition of trawling over seagrass (management response 1.1f); the implementation of landing limits on byproduct species (management response 4.2c); the development of a maximum count on prawn landings (management response 2.1e); consideration of a minimum legal length for squid (management response 2.1g); and effort limitations (objectives 2.3 and 2.4).

Despite a lack of scientific knowledge in many areas, the draft FMS provides a wide range of measures to address each of the main issues associated with the Estuary Prawn Trawl Fishery: protection of stocks, bycatch reduction, resource allocation, threatened and protected species, protection of key habitat, and latent effort activation and major effort shift. An assessment of whether the proposed measures are the best option is provided in Chapter D, where feasible alternative management strategies for the Estuary Prawn Trawl Fishery are evaluated.

The need for inter-generational equity

Under the principle of inter-generational equity, the present generation needs to ensure that the health, diversity and productivity of the environment are maintained or enhanced for the benefit of future generations. For example, fish stocks need to be preserved so that fishing (whether commercial or recreational) remains viable in the future.

The preservation of inter-generational equity is fundamental to the goals of the draft FMS. The strategy is essentially focused on maintaining and or improving fish stocks, habitats and ecosystems for long-term benefit. The main difficulty is our current lack of knowledge concerning these aspects. However, given this constraint, the draft FMS covers the important issues and adopts the precautionary principle (see above) where knowledge is lacking. Furthermore, the draft FMS contains a range of scientific measures to ensure that our knowledge of the relevant fish stocks and their environment will continue to improve. Such measures include the definition of environmentally sensitive areas within trawled areas (management response 1.2a), an assessment of the impact of trawling on biodiversity (management response 1.3e) and the development of formal stock assessments for the target species (management response 2.1i).

The need for the conservation of biological diversity and ecological integrity

This principle calls for the conservation of all aspects of biological diversity and ecological integrity, including species diversity, genetic variability and community interactions. This principle recognises that the conservation of these aspects should be a fundamental consideration. For example, under this principle the indirect effects of a fishing activity on non-target species need to be considered, even if the affected species are of no direct economic value.

This principle is also fundamental to the goals of the draft FMS, and especially so for goals 1 and 3. These goals relate to "biological diversity" and "threatened species, populations and ecological communities" respectively. Again, the main difficulty is our current limited knowledge concerning interactions between the fishery and both biodiversity and threatened species. However, given this constraint, the draft FMS covers a wide range of important issues relating to these aspects, including bycatch, and adopts the precautionary principle (see above) where knowledge is lacking. Furthermore, the draft FMS contains a range of specific measures to ensure that our knowledge of biodiversity and threatened species, along with that of the associated interactions, will continue to improve. Such measures include the scientific observer program (management response 8.1a), an assessment of the impact of the fishery upon biodiversity (management response 1.3e), a collaboration with other institutions to improve understanding of ecosystem function (management response 1.3c), and the recording of threatened species captures or sightings (management response 3.1a).

The need for improved valuation, pricing and incentive mechanisms

This principle recognises that environmental factors should be included in the valuation of assets and services. Essentially, this means that users should pay the full environmental costs of providing goods and services, including those relating to the use of natural resources and waste disposal. It also means that monetary incentives to achieve sustainability should be provided.

The implementation of share management provisions in the fishery (management response 5.3a) is an example of this principle being put into practice. By having shares in the fishery, fishers are provided with a greater incentive to ensure the long term sustainability of the resource as the value of shares when traded are likely to be linked to the health of the fishery and anticipated returns on investment.

2. Bycatch (non retained) Species

The major issue for bycatch in the Estuary Prawn Trawl Fishery has been the large quantity of juveniles of commercial and recreational species that are caught and discarded. The concern is that such discarding will reduce adult stocks of these species, impacting other commercial and recreational fishing sectors. A further issue is the impact on protected and threatened species by capture and destruction of their habitats. These issues have been identified in the draft FMS and a number of strategies have been suggested to address them. The effectiveness of these strategies is examined below.

a) Method based assessment of potential impacts

Trawling is a relatively non-selective method of fishing and therefore captures a wide variety of non-target fish and invertebrates referred to as bycatch, including both mobile and attached forms (e.g. Saila, 1983; Watson *et al*., 1990; Andrew and Pepperell, 1992; Kennelly, 1995a; Liggins and Kennelly, 1996; Liggins *et al*., 1996; Cappo *et al*., 1998). Trawling can impact bycatch by either direct capture or physical contact without capture. Ghost fishing from lost gear rarely occurs because trawling is an active method where the net is worked until it is retrieved. Ghost fishing can only occur when the net is snagged on an object and part of the netting is ripped from the net.

i) Direct capture

Trawling can impact bycatch by direct capture in three ways. These are the quantity of bycatch organisms caught, composition of juvenile commercial species in bycatch and discard mortality. In NSW there has been a paucity of data on the quantity, composition and fate of discards of bycatch in the five estuaries where prawn trawling occurs (Gray *et al*., 1990). However, more recent studies have revealed important trends that affect the management and perception of bycatch issues (Liggins and Kennelly, 1996; Liggins *et al*., 1996). Quantitative data for four of the five estuaries fished by the Estuary Prawn Trawl Fishery are available from the above published scientific papers. These studies were done before bycatch reduction devices (BRD) were compulsory in the fishery. The methodologies of these studies varied and so only qualitative comparisons between estuaries are possible. The quantity and composition of bycatch is discussed for each of the four estuaries; Hawkesbury, Clarence, Botany Bay and Port Jackson, and discard mortality is discussed in relation to all estuaries. Bycatch species for each estuary fished by the Estuary Prawn Trawl Fishery are listed in Tables AB1-7 of Appendix B1.

Quantity and composition of bycatch

Port Jackson and Botany Bay

Liggins *et al.* (1996) reported large quantities of bycatch taken in Botany Bay compared with Port Jackson (Figure E2). Botany Bay's bycatch was 3.5 to 3.9 times larger than that from Port Jackson during 1990-1991 and 1991-1992 respectively. Furthermore, in both estuaries the quantity of bycatch was substantially larger by weight than the prawn catch (Figure E2), with bycatch to prawn ratios of 1.5:1 (1990-1991) and 3.5:1 (1991-1992) for Botany Bay and 2:1 (1990-1991) and 1.7:1 (1991-1992) for Port Jackson. Variability of bycatch abundance was often species-specific (Liggins *et al*., 1996). For example, blue swimmer crabs were more abundant in Botany Bay during 1991-1992 than any other year or estuary. Variabilities of most species occurred between estuaries, years and within fishing season. Differences between these estuaries may be due to factors associated with different locations that are trawled within the estuaries.

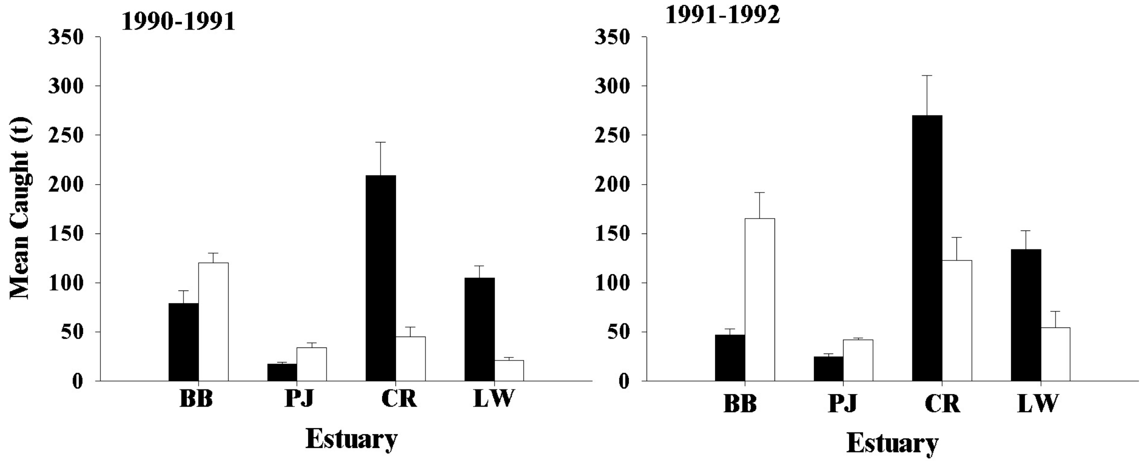

Figure E2. Mean weight of prawns and bycatch caught (t) in four estuaries of the Estuary Prawn Trawl Fishery.

BB – Botany Bay; PJ – Port Jackson; CR – Clarence River, LW – Lake Woolooweyah (part of Clarence estuary). ■ – prawn catch, □ – bycatch.

The proportion of commercial finfish, by number of individuals, in the bycatch was 29% (1990-1991) and 34% (1991-1992) in Botany Bay and 27% (1990-1991) and 25% (1991-1992) in Port Jackson (Figure E3). Ninety percent of individuals of seven commercially or recreationally important species were less than 20 cm in length and therefore unlikely to be retained. Furthermore, the ten most abundant species caught in the bycatch from these estuaries consisted mainly of species that would not have been retained by fishers as byproduct because they were either too small or not accepted by the market (Table E7). This suggests that large numbers of finfish and shellfish were discarded from these two estuaries.

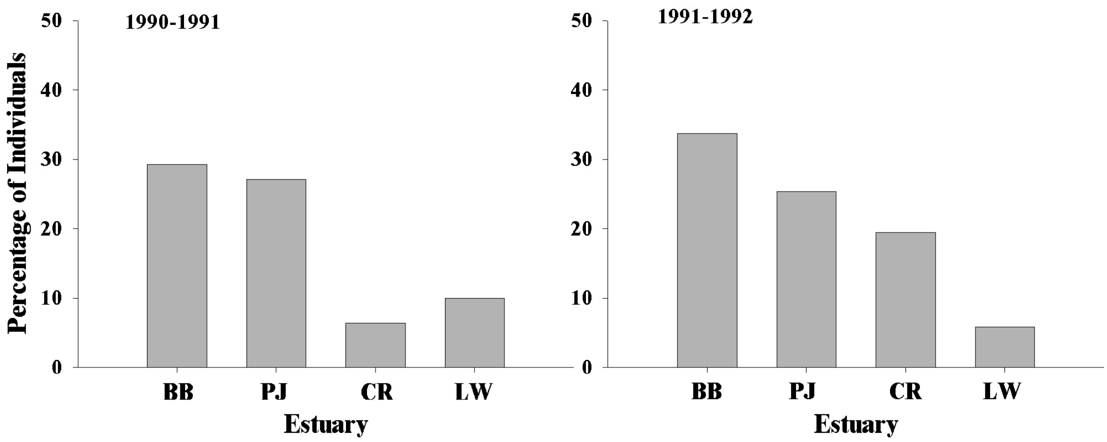

Figure E3. Percentage of individuals in bycatch that were commercial finfish species in four estuaries of the Estuary Prawn Trawl Fishery.

BB – Botany Bay; PJ – Port Jackson; CR – Clarence River, LW – Lake Woolooweyah (part of Clarence estuary).

Table E7. Ten most abundant species as mean number of individuals in the bycatch for four estuaries of the Estuary Prawn Trawl Fishery.

	1990-1991		Botany Bay			1991-1992				
Rank	**Species/Group**	**Byproduct**	**Mean**	**SE**	**% of total bycatch**	**Species/Group**	**Byproduct**	**Mean**	**SE**	**% of total bycatch**
	Total bycatch		4308	710		Total bycatch		5278	686	
	Commercial finfish bycatch		1259	192	29.22	Commercial finfish bycatch		1781	345	33.74
1	Yellowtail		644	273	14.95	Snapper		720	208	16.71
2	Mantis shrimp		574	203	13.32	Mantis shrimp		477	110	11.07
3	Eastern fortesque		308	117	7.15	Two spot crab		444	109	10.31
4	Three spot crab		273	115	6.34	Blue swimmer crab		412	56	9.56
5	Stout whiting		231	69	5.36	Eastern fortesque		373	134	8.66
6	Two spot crab		211	76	4.90	Common stinkfish		356	85	8.26
7	Common		183	33	4.25	Yellowtail		297	179	6.89
8	Bar tailed goatfish		177	54	4.11	Trumpeter		286	53	6.64
9	Bottle squid		157	49	3.64	Unidentified crabs		195	88	4.53
10	Blue swimmer		120	37	2.79	Three spot crab		171	41	3.97

	1990-1991		Port Jackson			1991-1992				
Rank	**Species/Group**	**Byproduct**	**Mean**	**SE**	**% of total bycatch**	**Species/Group**	**Byproduct**	**Mean**	**SE**	**% of total bycatch**
	Total bycatch		521	48		Total bycatch		1173	137	
	Commercial finfish bycatch		141	30	27.06	Commercial finfish bycatch		297	34	25.32
1	Mantis shrimp	Yes	163	28	31.29	Mantis shrimp	Yes	129	25	11.00
2	Silver biddy	Yes	48	13	9.21	Bridled goby		120	56	10.23
3	Trumpeter	Yes	38	14	7.29	Silver biddy	Yes	101	28	8.61
4	Yellowtail		25	6	4.80	Yellowtail		83	14	7.08
5	Bottle squid	Yes	22	8	4.22	Trumpeter whiting	Yes	79	26	6.73
6	Snapper		19	8	3.65	Bream		58	14	4.94
7	Bridled goby		18	7	3.45	Bottle squid	Yes	53	23	4.52
8	Blue swimmer crab	Yes	17	3	3.26	Snapper		49	9	4.18
9	Dusky flathead		16	3	3.07	Dusky flathead		32	5	2.73
10	Largetoothed flounder	Yes	14	3	2.69	Largetoothed flounder	Yes	30	7	2.56

	1990-1991		Clarence River			1991-1992				
Rank	**Species/Group**	**Byproduct**	**Mean**	**SE**	**% of total bycatch**	**Species/Group**	**Byproduct**	**Mean**	**SE**	**% of total bycatch**
	Total bycatch		3544	1087		Total bycatch		7422	3261	
	Commercial finfish bycatch		227	36	6.41	Commercial finfish bycatch		1441	320	19.42
1	Fork-tailed catfish	Yes	1028	629	29.01	Port Jackson perchlet		2128	659	28.67
2	Narrow banded sole		527	249	14.87	Southern herring		1435	451	19.33
3	Southern herring		464	145	13.09	Yellowfin bream		829	205	11.17
4	Port Jackson perchlet		345	196	9.73	Silver biddy	Yes	620	164	8.35
5	Ramsey's perchlet		344	88	9.71	Ramsey's perchlet		418	117	5.63
6	Silver biddy	Yes	303	105	8.55	Sand whiting		286	83	3.85
7	Yellowfin bream		114	22	3.22	Fork-tailed catfish	Yes	253	96	3.41
8	Sandy sprat		54	28	1.52	Narrow banded		243	84	3.27
9	Dusky flathead		44	11	1.24	Pink-breasted siphonfish		238	156	3.21
10	Bullrout		41	18	1.16	Sandy sprat		89	44	1.20

SE=standard error. Note: byproduct species were determined using historical data from catch records which does not include these data sets.

Table E7 cont.

	1990-1991		Lake Woolooweyah			1991-1992				
Rank	**Species/Group**	**Byproduct**	**Mean**	**SE**	**% of total bycatch**	**Species/Group**	**Byproduct**	**Mean**	**SE**	**% of total bycatch**
	Total bycatch		2092	196		Total bycatch		6177	957	
	Commercial finfish bycatch		208	23	9.94	Commercial finfish bycatch		358	47	5.80
1	Southern herring		635	102	30.35	Southern herring		3351	655	54.25
2	Pink-breasted siphonfish		285	67	13.62	Pink-breasted siphonfish		619	154	10.02
3	Ramsey's perchlet		285	50	13.62	Sandy sprat		492	116	7.97
4	Port Jackson perchlet		168	32	8.03	Fork-tailed catfish		329	165	5.33
5	Fork-tailed catfish	Yes	115	49	5.50	Silver biddy	Yes	282	93	4.57
6	Tailor		91	19	4.35	Striped trumpeter		174	107	2.82
7	Australian anchovy		43	8	2.06	Ramsey's perchlet		143	38	2.32
8	Silver biddy	Yes	40	17	1.91	Yellowfin bream		138	22	2.23
9	Yellowfin bream		39	6	1.86	Tailor		122	17	1.98
10	Sandy sprat		22	6	1.05	Australian anchovy		110	26	1.78

SE=standard error. Note: byproduct species were determined using historical data from catch records which does not include these data sets.

Clarence River

In the Clarence estuary Liggins and Kennelly (1996) reported bycatches that were large but, unlike the previous two estuaries, were substantially less than the prawn catch by weight (Figure E2). The bycatch to prawn ratio was 0.16:1 and 0.45:1 for the Clarence River and 0.20:1 and 0.40:1 for Lake Woolooweyah for 1990-1991 and 1991-1992 respectively. As for the previous two estuaries, variability in abundances of bycatch was species-specific and varied between years, locations and within fishing seasons. For example, early in a season large-toothed flounder were caught in abundance but late in a season yellowfin bream were abundant in some years.

The proportion of commercial finfish in the bycatch, by number of individuals, was 6% (1990-1991) and 19% (1991-1992) in the river and 10% (1990-1991) and 6% (1991-1992) in the lake. Ninety percent of individuals of six commercially or recreationally important finfish were less than 20 cm in length. Dusky flathead was one of a few species in this estuary that was caught in sufficient numbers greater than 20 cm. The ten most abundant species caught in the bycatch were mainly species that would not have been retained as byproduct (Table E7). As for Botany Bay and Port Jackson, large numbers of finfish and shellfish would have been discarded.

Hawkesbury River

The study by Gray *et al*. (1990) did not use the same methodology as Liggins *et al.* (1996) and Liggins and Kennelly (1996) and therefore direct comparisons in the quantities and composition of bycatch in the Hawkesbury with the previous estuaries are not possible. The total number of individuals taken as bycatch over a three year period was 10,473 finfish and shellfish (Figure E4). On a per year basis this was substantially less than what was caught in the three previous estuaries. However, as with the three previous estuaries, there was large temporal and spatial variability in the abundance of bycatch taken on the Hawkesbury. The number of bycatch individuals caught differed among areas in the estuary and between years (Gray *et al*., 1990) and was correlated with salinity regimes within the estuary. The seasonal differences in the number of individuals caught also varied between years. No prawn catch data was available from this study, so the bycatch to prawn catch ratio could not be calculated.

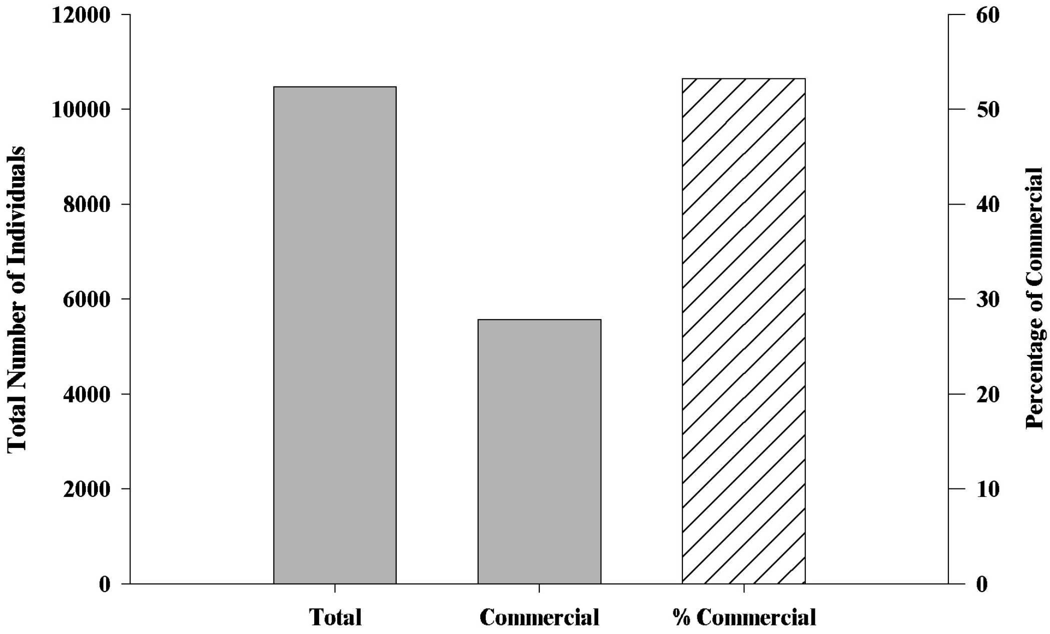

Figure E4. Number of individuals of total bycatch and commercial species in the Hawkesbury estuary between 1986-1988.

From Gray *et al*. (1990).

Fifty three percent of the total bycatch, individuals consisted of commercially important species (Figure E4). No length frequency data was available from the study by Gray *et al*. (1990) so it is not possible to determine what proportion of the bycatch would have been retained as byproduct and what would have been discarded. Species caught in large numbers included mulloway, Australian bass, snapper, yellowfin bream, silver trevally, pilchards and silver biddy (Table E8). Gray *et al.* (1990) also found significant seasonal and salinity related differences. More species were taken in autumn and winter of both years sampled, whilst species richness consistently declined with increased distance from the river mouth. This decline corresponded with a steep salinity gradient, and the bycatch clearly differed between saline and freshwater areas. Marine adapted species such as snapper were only caught in saline waters near the mouth, whilst a range of freshwater species (including Australian bass) dominated the upper reaches. The autumn/winter peak in the number of species taken may have resulted from a large number of species having juveniles attain a vulnerable size after previously recruiting from the plankton several months earlier (i.e. spring or summer; Hannan and Williams, 1998).

Table E8. Top ten most abundant species as number of individuals in the bycatch of the Hawkesbury estuary.

Note: byproduct species were determined using historical data from catch records that do not include these data sets.

Rank	Species	Byproduct	Number of Individual	% of total bycatch
	Total		10473	
	Commercial		5570	
1	Australian bass		1851	17.67
2	Long-tailed catfish	Yes	1458	13.92
3	Northern sand flathead		858	8.19
4	Mulloway		696	6.65
5	Snapper		654	6.24
6	Yellowfin bream		595	5.68
7	Silverbiddy	Yes	530	5.06
8	Whaler sharks		447	4.27
9	Herring	Yes	434	4.14
10	Flathead gudgeon		337	3.22

Overall composition

The perception by recreational and other commercial fishers that the discarded bycatch of prawn trawlers is large and therefore, is likely to reduce subsequent sizes of stocks in other fisheries (Gordon, 1988; Klima, 1993; Kennelly, 1995a) does not take into account the large spatial and temporal variability inherent in such catches. Bycatch species composition is highly variable among estuary prawn trawl fishing zones. Juveniles of commercial and recreational species do make up a substantial proportion of the overall bycatch (Table E9). However, Liggins and Kennelly (1996) and Liggins *et al*. (1996) caution that the accuracy of their estimates depends on several assumptions, of which not all can be validated. Similarly, Broadhurst and Kennelly (1996) warn that the unknown rates of natural mortality means that estimates of the impact of bycatch composition and quantity on future fish stocks are preliminary. Consequently, a precautionary approach to bycatch abundances in the Estuary Prawn Trawl Fishery is still warranted.

Table E9. Percentage of juvenile commercial finfish species caught as bycatch in four estuaries of the Estuary Prawn Trawl Fishery.

Estuary	Total No. Spp.	No. Commercial	% Commercial spp. of total
*Clarence River	60	18	30.0
*Lake Wooloweyah	56	18	32.1
✞Port Jackson	69	54	78.3
✞Botany Bay	119	42	35.3
❖Hawkesbury River	93	42	45.2

* From Liggins and Kennelly (1996); ✞ From Liggins *et al.* (1996); ❖ From Gray *et al*. (1990)

Discard mortality

Trawling has a greater impact on discard mortality than some other fishing methods such as seining (Broadhurst *et al*., 1999). The factors contributing to this mortality include:

- out of water whilst on deck

- crushed in the cod end (Cappo *et al*., 1998; Broadhurst *et al*., 1999)
- heavily stung by jellyfish trapped in the net
- injury (e.g. over-inflated swimbladder) from rapid depressurisation during net retrieval
- damage from contact with the net material (e.g. Broadhurst *et al*., 1999)
- poor handling, particularly in relation to scale loss
- predation on weakened/ disorientated animals returned to the water (Hill and Wassenberg, 1990).

Some species are better than others at surviving these rigours (Wassenberg and Hill, 1989; Hill and Wassenberg, 1990; Wassenberg and Hill, 1993; Greenstreet and Hall, 1996; Carrick, 1997; Cappo *et al*., 1998). Crustaceans are more likely to survive than most fish, although certain types of fish, including sharks, rays, triggerfish and at least one species of flounder have relatively high survival rates. In general, soft-bodied species survive poorly, as they are easily crushed (Cappo *et al*., 1998). Experiments in which animals were held in tanks (Wassenberg and Hill, 1993; Kennelly, 1995a) revealed crustacean survival rates of over 70% after 7 days, while the small-toothed flounder being the only fish to have a survival rate greater than 30%. Hyland (1985), in a study of Moreton Bay's beam trawl fishery for prawns, suggested that yellowfin bream survived trawling quite well, while river perch (a relative of mulloway) did not. In a study of the fate of trawler discards in Torres Strait, Hill and Wassenberg (1990) estimated that "nearly all" of the fish were dead when discarded, whilst about half of the crustaceans were alive. They also found that very few cephalopods (about 2%) were alive when returned to the water.

Various other factors influence survival, including trawl duration and depth, time of day (day verses night), cod-end weight, air temperature, composition of bycatch and handling methods (Wassenberg and Hill, 1989; Kennelly, 1995a; Cappo *et al*., 1998). However, even if an animal is able to swim away after being sorted and tossed back into the water, it is likely to have been seriously stressed as well as be injured in some way, making it more susceptible to subsequent disease (e.g. Broadhurst *et al*., 1999). Therefore, a precautionary approach to the fate of discards from prawn trawling is to assume little to no survival.

Mortality of undersize commercial species in bycatch is thought to reduce the subsequent sizes of stock in other fisheries that target these species (Kennelly, 1995a). However, it is difficult to measure the effects of bycatch related mortality on the ultimate populations of the species affected. Kennelly *et al*. (1993) incorporated natural mortalities and growth rates to assess the impact of juvenile snapper bycatch on the adult population. They concluded that an annual bycatch of 350,000 juvenile snapper is most likely to represent 60,000 legal sized fish three years later. But if natural mortality was equivalent to bycatch mortality for this species there may be no detectable effect on the subsequent fish stocks. To estimate the impact of discard mortality on commercial and recreational species the following information is required – estimate of natural mortality, proportion of biomass, ages at legal size and estimate of trawl induced mortality (Kennelly, 1995a). There are very few estimates of these relevant life history parameters of key species in NSW fisheries, making it difficult to estimate the impact of bycatch on fish stocks.

ii) Physical contact without capture

Escape from trawl net

Trawling results in certain size fish being ‘squeezed’ through net meshes. Fish that are too small to be retained by the net, yet too big to swim clean through the mesh, will be affected. Such fish suffer fin damage, scale loss and/or skin damage (Chopin and Arimoto, 1995; Broadhurst *et al*., 1997, 1999). The number of fish affected will vary according to the mesh of the net used and the sizes of fish present, although resultant mortality rates for fish escaping through meshes are likely to be relatively low (Chopin and Arimoto, 1995; Broadhurst *et al*., 1997, 1999). Seasonal patterns are also likely, with vulnerable size classes being prevalent at certain times of the year, depending on the life cycles of the species concerned (Cappo *et al*. 1998). Also, the effects of any trawl modification for bycatch reduction need to be considered (Kennelly, 1995a). The results of simulated escape through two types of modification, square meshes (Broadhurst *et al*., 1997) and a Nordmore-grid guiding panel (Broadhurst *et al*., 1999), suggest that mortalities would be relatively low.

Physical habitat disturbance

Trawling results in severe physical disturbance of the seafloor from direct net contact (e.g. 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. The three likely consequences of these events 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.

A detailed discussion of these effects is given in section 1c of Chapter F and so will not be repeated here.

b) Method based assessment of bycatch reduction strategies

Bycatch reduction strategies according to the National Bycatch Policy (Commonwealth, 2000) consist of three types – utilization, avoidance and reduction. Usually more than one type of strategy will be employed in a particular fishery to address the problems more effectively. In the Estuary Prawn Trawl Fishery avoidance and reduction have primarily been used.

Utilisation

Utilisation refers to the practice of retaining non-target species of fisher’s catch for sale rather than discarding them. As a strategy, utilisation reduces bycatch by redefining what is kept for sale and what is not. There is limited information on such utilisation in Australia (Kennelly, 1995a). The strategy of utilisation of non-targeted species does not actually reduce the bycatch of non-saleable organisms. Fishers will only land byproduct species if they are of a marketable quality (e.g. minimum length). Those that are not landed become part of the discarded catch or bycatch. Consequently, utilisation has limited effectiveness in achieving two of the core objectives of the National Policy on

Bycatch (Commonwealth, 2000); of improving protection of vulnerable and threatened species, and of minimising adverse impacts of fishing on the aquatic environment.

Utilisation in the Estuary Prawn Trawl Fishery draft FMS is not specifically identified as a bycatch reduction strategy. However, a number of bycatch species are designated as byproduct species (see Table C18, section 6e of Chapter C) which are therefore essentially being utilised. The problem with utilisation is that the byproduct species themselves might also be in danger of being over fished. Whilst these species have significantly contributed to the marketed catch of the Estuary Prawn Trawl Fishery, overall the fishery only takes a small percentage of these species compared with other fishing sectors (see Table E3, section 1a of Chapter E). All of the byproduct species listed have an uncertain exploitation status (see Table E1, section 1a of Chapter E), except yellowtail, which is fully fished. The Estuary Prawn Trawl Fishery exerts a high fishing pressure on these byproduct species (see Table E3, section 1a of Chapter E). However, given their uncertain exploitation status, a precautionary approach would be to limit and monitor the landings of these species in the Estuary Prawn Trawl Fishery to ensure there are not substantial increases which may cause overfishing. The draft FMS does incorporate these controls. The management response 4.2b limits the taking of byproduct species (see Table C2 of Chapter C) and management response 1.1c specifies fishing gear that minimises the taking of byproduct species. Management response 4.1a provides for the estimation of non-commercial catch and its impact on the resource. However, the strategy of utilisation, via byproduct species for bycatch reduction, may have no effect in reducing bycatch because of the unknown composition of the non-commercial catch. Further research into the quantity and composition of undersized byproduct species and how frequently undersized byproduct species occur under normal fishing conditions is needed in the draft FMS.

Avoidance

Avoidance refers to methods that prevent fishers from harvesting in areas of important habitat for bycatch species. This strategy usually takes the form of spatial and temporal closures to fishing. Closures are the most effective means of bycatch reduction because no fish are caught and, in the case of spatial closures, no habitat is damaged (Kennelly, 1995a). Conversely, however, closures can lead to an increase in fishing within open areas/times, possibly negating the desirable effects of the closures (Kennelly, 1995a).

There are numerous closures in the Estuary Prawn Trawl Fishery which are estuary specific (see Chapter B and Appendix B6). These closures were established for a number of reasons, not all related to bycatch reduction. For example, trawling is prohibited on weekends and public holidays to minimise fishing operations exposed to public view. Whilst these closures will have a general benefit in reducing bycatch, they may not be optimised to protect habitats or times important to the life history of organisms. Approximately 16% of the year is open to trawling over all five estuaries of the Estuary Prawn Trawl Fishery. Spatially, it is difficult to determine how much of these estuaries are closed to fishing or what habitats are being protected, as detailed habitat mapping has not been done. To redress this problem, the draft FMS plans to map key habitats within each estuary of the Estuary Prawn Trawl Fishery over the next two years. Such mapping will enable more effective spatial closures to be determined. This will lead to better management of where fishing can and can't take place.

There are two major problems in using closures as a bycatch reduction strategy in the Estuary Prawn Trawl Fishery. Firstly, closing areas to fishing potentially limits a fisher's catch and therefore their income. Identifying when and where closures should occur without closing off so much of the total fishing area that fishers become economically unviable is very difficult. Secondly, the large spatial and temporal variability in the composition and quantity of bycatch in the Estuary Prawn Trawl Fishery means that fixed closures will be of little use (Liggins *et al*., 1996). A more flexible approach to establishing closures to reduce bycatch would be more effective. Whilst recognising these problems, the draft FMS does not directly address evaluating the effectiveness of the current closure system in reducing bycatch in the Estuary Prawn Trawl Fishery.

Bycatch Reduction Devices

Bycatch reduction devices (BRDs) are modified gear types that allow unwanted organisms to escape a trawl net whilst retaining target species. The development of BRDs has been reviewed by Kennelly (1995a), Brewer *et al*. (1997) and Kennelly and Broadhurst (1998). Different BRDs have been developed to deal with specific types of bycatch. For example, Soft Turtle Exclusion Devices (TEDs) have been used to reduce jellyfish bycatch (Kennelly *et al*., 1993), while square mesh panels in cod ends have been shown to reduce juvenile fish bycatch substantially with only a minor loss of the targeted prawns (Broadhurst and Kennelly, 1994).

There have been significant reductions in bycatch as a result of using BRDs (Table E10). The Nordmore Grid BRD has been extensively tested in the Clarence and Hunter estuaries of the Estuary Prawn Trawl Fishery (Broadhurst and Kennelly, 1996b; Broadhurst *et al*., 1997c). These studies found that the Nordmore Grid significantly reduced bycatch by 58% and 70% for Hunter and Clarence estuaries respectively. Furthermore, there was a significant increase in catches of school prawns in the two estuaries of 24% and 10% respectively. In the Clarence estuary the Nordmore Grid caught significantly more prawns than the Blubber Chute BRD (Broadhusrt *et al*., 1996). The consistent improvement in bycatch reduction along with increased or maintained prawn catches using the Nordmore Grid over the traditional Blubber Chute strongly points to making the former BRD the preferred device for the industry.

Table E10. Summary of the effectiveness of different BRDs tested in three estuaries of the Estuary Prawn Trawl Fishery.

(From Broadhurst, 2000). ↓ decrease; ↑ increase.

Estuary	BRD	Effect on bycatch (wt)	Effect on prawn catch	Reference
Hawkesbury	Square mesh	Jew fish - ↓ 45-95%	16-52% ↓	Broadhurst and Kennelly, 1994
	Square mesh, 2 designs	Jew fish - ↓34-40%	5% ↓	Broadhurst and Kennelly, 1995
Clarence	Nordmore grid & blubber chute	up to 90% ↓	0-11%↓	Broadhurst and Kennelly, 1996b
Hunter	Nordmore grid & secondaries	Bream 67% ↓ up to 58%↓	up to 41% ↑	Broadhurst et al., 1997c

BRDs are now compulsory in all estuaries of the Estuary Prawn Trawl Fishery (NSW Fisheries, 1999a, b), with the exception of Broken Bay. In this section of the Hawkesbury River, prawn trawl fishers target squid as well as prawns and conventional BRDs are not suitable for squid trawling. However, commercial fishers, Sydney University and NSW Fisheries are currently collaborating in a research project to develop and trial appropriate BRDs for Broken Bay trawlers.

The use of common devices in the Estuary Prawn Trawl Fishery is summarised in Table E11. Broadhurst *et al*. (1999) reported a high rate of voluntary adoption of the Nordmore grid among Estuary Prawn Trawl fishers in the Clarence, Hunter and Hawkesbury estuaries. However, use of this BRD has declined over the past two years in favour of the blubber chute (Table E11). Reasons for this change in BRD use type are unknown.

Table E11. Percentage of time different BRDs were used in the Estuary Prawn Trawl Fishery from October 1997 to August 2001.

No. Licenced fishers	Zone (estuary)	Blubber Chute	Nordmore Grid	Panel	Port Jackson Screen	Quality Clarence	Unknown
50	Botany Bay	45.76	0.00	11.12	0.00	0.00	41.97
123	Clarence River	23.81	6.34	14.20	0.00	0.42	44.12
69	Hawkesbury River	20.24	0.00	16.74	0.22	1.07	61.51
34	Hunter River	87.79	0.36	0.81	0.00	0.00	8.80
3	Lake Wooloweyah	64.97	21.01	1.53	0.00	0.00	8.28
34	Sydney Harbour	5.35	1.90	0.00	52.36	0.00	35.33
	Overall zones	33.66	4.26	11.50	2.82	0.49	41.98

The draft FMS does not give clear guidelines as to which BRD is to be used by fishers nor does it highlight the advantages of one type of BRD over another. Hence it gives the impression that all types are similar in their effectiveness to reduce bycatch and maintain catches of target species. The studies discussed above clearly demonstrate that this is not the case (Broadhurst *et al.*, 1997). Broadhurst and Kennelly (1996) suggest that the widespread use of BRDs like the Nordmore Grid may increase the availability of commercial species to other fishing sectors because they significantly reduce the bycatch of juveniles of commercial and recreational fisheries. As BRDs are the primary strategy for reducing bycatch in the Estuary Prawn Trawl Fishery, greater effort needs to be placed on educating fishers as to the best device to use for their fishery. This emphasis needs to be reflected more strongly in the draft FMS.

c) Assessment of bycatch management measures in the draft FMS

The management measures employed in the draft FMS that respond to bycatch issues involve either controls on fishing or information gathering (Table E12). Control measures seek to minimise the impact of bycatch either by direct or indirect means. Information measures seek to improve the understanding of bycatch problems and the ecology of estuaries in order to manage the impacts of trawling more effectively.

The draft control management responses aim to improve gear types and BRDs, improve handling to increase survivorship of discards and protect key habitats leading to less bycatch and habitats damage (Table E12). These controls allow for flexibility in the use of appropriate BRDs and for fishers to experiment with new designs. This flexibility will improve bycatch reduction strategies as it encourages and facilitates the cooperation of industry in both finding solutions to the problem and affecting change in the future. The effectiveness of such cooperation with industry has already been demonstrated in the Clarence estuary (Kennelly and Broadhurst, 1996). However, not all fishers will want to experiment with new BRD designs, and the draft FMS lacks clear direction as to which of the currently available designs are most effective at reducing bycatch in each particular estuary. The draft FMS should incorporate information showing the advantages and disadvantages of different BRDs and should direct fishers to use the most effective design for their particular estuary.

Controls via legislation and policy ensure certain minimum standards for the conduct of fishers. However, these responses will only be effective in controlling bycatch to the extent of fishers' voluntarily compliance and the vigilance of NSW Fisheries in the monitoring, educating and policing of estuary prawn trawl fishers.

Table E12. Summary of draft management responses related to bycatch reduction.

Category	Objective	Management Response	Summary of Response
Control	1.1	b	Modify fishing practices to reduce impact upon organisms other than target species
	1.1	c	Develop alternate gears to minimise capture of primary and secondary species of unwanted quality.
	1.1	e	Best practice techniques for handling non-retained organisms (ban spikes)
	1.1	f	Closures to control area and time of fishing
	1.2	a	Protect areas of environmental sensitivity
	1.2	c	Continue the prohibition on wilfully damaging marine vegetation
	1.3	a	Implement incidental catch ratios
	2.1	b	Monitor quantity, length and/or age or sex composition of byproduct species
	2.5	a, b	NSW Fisheries will aim to minimise impacts on fishery resources from developments
	2.6	c	Implement precautionary actions during development period of recovery plans for overfished species
	3.1	b	Implement provisions of relevent threatened species recovery plans
	3.1	c	Continue the prohibition on protected shellfish and finfish
	4.2	c	Limit the quantities of annual landings of byproduct species
	6.4	a	Manage consistently with other jurisdictional or resource management requirements
	8.1	c	Issue section 37 Permits authorising modified fishing practices for research
Information	1.2	a	Map areas of environmental sensitivity
	1.3	c	Collaborate with other institutions on ecosystems
	1.3	e	Develop a research strategy to assess the impact of trawling upon biodiversity
	3.1	a	Modify catch and effort returns to collect information on sightings or captures of threatened species
	4.1	a	Assess the size of the non-commercial catch and catch of indigenous peoples
	7.2	a	Publish educational information on protection of shellfish and finfish habitat
	8.1	a	Develop a scientific observer program
	8.2	a	Periodically review catch and effort return forms
	8.2	b	Determine the accuracy of current recording of species identification

The information measures will increase our understanding of bycatch issues by providing for the gathering of data on composition and quantity of bycatch over different spatial and temporal scales. The observer programme is one of the key initiatives to provide this information. Other management responses will increase understanding of estuarine environments, and in particular biodiversity, species-habitat interactions, distribution of key habitats and sensitive areas to trawling. This improved understanding should lead to better management strategies by clearly identifying what, where and when components of estuaries need to be protected to promote biodiversity and economically sustainable development of the Estuary Prawn Trawl Fishery. Information gathering management measures for bycatch will be effective if:

(a) the observer programs are designed with clear objectives and their data analysed appropriately (Underwood, 1990; Kennelly, 1997)

(b) the results of these programmes and other research are clearly incorporated into future management responses and strategies.

The issue of research will be explored in more detail under section 4 of Chapter E.

One area that is not specifically addressed in the management responses of the draft FMS is the need to examine and assess the long term effectiveness of the use of BRDs in the fishery. Whilst there has been extensive research on the effectiveness of BRD designs (see Kennelly and Broadhurst, 1998 and Broadhurst, 2000) there has been no work looking at the level of compliance by estuary prawn trawl fishers and to what extent the use of these designs in the fishery has reduced bycatch. The studies by Liggins *et al*. (1996), Liggins and Kennelly (1996) and Gray *et al.* (1990) could form the basis of before-data for comparisons. The proposed scientific observer programme (management response 8.1a) could incorporate such a study, but clear objectives would need to be stated and the programme carefully designed to test precise hypotheses about the effectiveness of BRDs as used by fishers under normal fishing operations. Until this information has been collected, the effectiveness of BRDs in the Estuary Prawn Trawl Fishery remains uncertain.

A further area that the draft FMS does not specifically address is the fate of discards in the fishery. Whilst undersized fish and non-marketable fish may be returned to the water, as discussed in section 2a, their survival is likely to be very low due to damaged fins, scale loss and stress. The proposed observer programs will assist in quantifying what is discarded, but will provide no information on the fate of animals returned to the water under normal fishing operations. The draft FMS needs to incorporate specific studies that quantify the fate of discards returned to the water. Such information could contribute to designing BRDs and species specific strategies to reduce bycatch mortality and therefore the impact of the Estuary Prawn Trawl Fishery on other fishing sectors and the ecology of estuaries.

d) Use of indicator groups to monitor bycatch

The purpose of indicator species is to act as a surrogate for monitoring the “condition” of an assemblage of organisms or aspects of the environment in which they live (Ott, 1978; Jorgensen, 1992). It assumes that there is a relatively direct relationship between the “condition” of the indicator species and that of the wider environment or assemblage it represents (Suter, 1993). However, in marine environments, which are extremely complex, this assumption is rarely justifiable (Underwood *et al*., 2000). Using indicator species to monitor bycatch in the Estuary Prawn Trawl Fishery has the following problems:

(a) There is significant variability in the size and composition of bycatch between estuaries, within estuaries, and among years and fishing periods (Liggins and Kennelly, 1996; Liggins *et al*., 1996). Therefore, selecting only a few species would not be representative of the bycatch assemblage potentially caught at all spatial scales and times

(b) Direct causal relationships between species abundance and distribution and changes to fishing pressure/effort are based on a number of important assumptions, including mortality of the bycatch species after discarding, natural mortality, the proportion of the stock size that this bycatch represents and the level of under-reporting of fishing effort in the fishery (Liggins and Kennelly, 1996; Liggins *et al*., 1996). These assumptions have not been tested in the Estuary Prawn Trawl Fishery making the identification of adequate indicator species very difficult

(c) There are differences in the selectivity of fishing gear among fishers and estuaries, and these affect the composition of bycatch (Liggins and Kennelly, 1996; Liggins *et al*., 1996). Consequently, indicator species may only be caught by certain gear types in some estuaries, and may not be representative of the bycatch stock able to be caught in each estuary

These difficulties result in a high level of uncertainty and low reliability in the use of indicator species to monitor bycatch. Therefore there are no suitable indicator species to recommend with respect to the Estuary Prawn Trawl Fisher.

3. Bait Resources

Bait is not used in the Estuary Prawn Trawl Fishery and there is no intention of introducing the use of it in the foreseeable future. Therefore, this fishery does not impact bait resources by direct use.

4. Data, Monitoring and Research Adequacy

Data requirements occur in two major components within the draft FMS. The first is research, which incorporates knowledge gaps emerging from the draft FMS. The second is performance and monitoring which incorporates the effectiveness of the strategy in fulfilling its vision and goals for the fishery. Both these components will arise from the issues in the fishery that have been identified in the draft FMS. These two components will be discussed in turn.

a) Data and research

Data and information used to address impacts on fish resources was obtained from catch statistics for 1940-1992 (Pease and Grinberg, 1995), 1998/99 (Tanner and Liggins, 2000) and 1999/2000 (Tanner and Liggins, 2001), scientific papers by fishery scientists and FRDC reports. These are listed in the reference section. The reliability of the information for the stock assessments is given in Table E1. Except for prawns, the assessments of fishing level for all of the main target and byproduct species are classified as preliminary. The uncertainties associated with the data and assessments are due to the knowledge gaps for these species.

i) Knowledge gaps

The draft FMS has revealed substantial knowledge gaps that affect the management of the Estuary Prawn Trawl Fishery. The knowledge gaps cover four main areas - stock assessments of all retained species, bycatch, accuracy and precision of effort data and ecological interactions among species. Each of the gaps is discussed below in terms of their role scope for potential improvements in the management of the Estuary Prawn Trawl Fishery.

Stock assessments

All retained species in the Estuary Prawn Trawl Fishery require proper stock assessments. In particular, there is no stock assessment information for the targeted squid resource in the Hawkesbury River. Broadly information is needed to determine the current health of the stocks, recruitment variability and to design scientifically sound long-term monitoring and assessment procedures which will improve the future management of the fishery (Table E13) (Gray *et al.,* 2000).

Estimates of harvest rates (e.g. annual landings) are essential to the stock assessment process. Hilborn and Walters (1992, p. 160) state “it is almost impossible to perform stock assessment without knowing the history of the catch”. The primary source of harvest estimates for the commercial sector comes from monthly catch return reports filed by each fisher. Stock assessments should ideally include catch estimates from all sectors and the first estimates of state-wide recreational harvest will be available with the publication of the National Recreational and Indigenous Fishing Survey in late 2001 or early 2002.

There is also little understanding of how fishing pressure affects shellfish and fish stocks in the Estuary Prawn Trawl Fishery. Effects of fishing pressure are many and include recruitment and growth over-fishing, damage to habitats and changes to recruitment patterns (Dayton *et al.,* 1995). In addition, there is no understanding of how the effects of the Estuary Prawn Trawl Fishery interact with those of the Estuary General Fishery, Recreational fishers and Ocean Prawn Trawl Fishery. These other fishing sectors all aim for the target species of Estuary Prawn Trawl Fishery, sometimes at different stages in the life cycle of these species. Yet there has been little work done to examine the magnitude of the combined fishing pressure from all these sectors on the target species or its effects on these species. Knowledge of these effects would enable more specific input controls to be developed to manage the fishery and would contribute to more accurate stock assessments.

Table E13. Summary of biological data required and their role in providing robust stock assessments for retained species in the Estuary Prawn Trawl Fishery.

From Gray *et al.,* (2000)

	Purpose			
Biological information required	**Stock assessments**	**Desiging long-term strategies for monitoring & assessing stocks of fish in estuaries**	**Managing fish stocks**	**Forecasting future catch levels**
Size & age composition of catches	✓			
Variability among estuaries, gear types and time	✓	✓		
Spatial & temporal variation in recruitment & growth of juvenile species	✓	✓		
Spatial & temporal changes in abundances of different year classes			✓	✓
Changes in abundance of pre-recruits to the fishery				✓

Accuracy and precision of effort data

Currently, effort data is based on the monthly catch returns of the estuary prawn trawl fishers. The monitoring programs and many of the trigger points for the target species rely on the information in these returns. However, there are many factors that influence what fishers record, and which can lead to misreporting (Liggins *et al.,* 1996). There is therefore, a need to validate the precision and accuracy of catch returns on a estuary by fisher basis. Inaccurate catch data will seriously affect future catch predictions and the management of the fishery as a whole.

Bycatch

Whilst there is substantial information on the quantity and composition of bycatch in the Estuary Prawn Trawl Fishery there is little information on the fate of associated discards. The potential fate of discards include disease and mortality either immediately on or after release as might result from damaged scales or fins (Gray *et al.,* 2000). Discard mortality may have a substantial affect on fish stocks particularly if juveniles of commercial and recreational species make up a large proportion of the discards. Without quantifying the level and rate of discard mortality, both future catches and the capacity of the populations to recover from fishing pressure could be substantially over-estimated. Moreover, determining the nature and causes of discard mortality on an estuary by estuary basis will enable the most appropriate solutions to be found.

There is also no information on the effectiveness of BRDs under normal fishing operations nor whether they have a long term effect in reducing bycatch. Although BRDs are now compulsory in the fishery, there is no information about how they are used and whether fishers are using the most appropriate device for their estuary and operation. Without this information, bycatch reduction strategies cannot be properly assessed and modified if needed. In addition, such information can be used to inform fishers of the benefits of using BRDs and why they are necessary, thereby increasing compliance.

Ecological interactions among retained species and their habitats

Ecological interactions between retained species and their habitats includes predator prey relationships, competition for food and territory and the distribution and abundance of species with respect to each other. Whilst there is some basic knowledge about the general biology of the eastern king prawn in the Estuary Prawn Trawl Fishery (Montgomery *et al.*, 1995) there is little knowledge about how this species interacts with others. Interactions among species and their habitats including trophic interactions) may change if one species is being fished more than another (Pauly, 1988; Dayton *et al.,* 1995; Castilla, 2000). These and other changes could result in recruitment failure of a species for one or more years, which could substantially impact the sustainability of shellfish and finfish stocks (Fogarty and Murawski, 1998). Therefore, knowledge of ecological interactions among species will lead to an improved ability to sustain stocks of the Estuary Prawn Trawl Fishery.

ii) Research assessment

The draft FMS proposes six areas of research, four of which are directed at filling knowledge gaps about the fishery resource (section 6 of Chapter C) and two of which are focused on knowledge gaps relating to impacts on the environment. In general, the research areas cover all of the knowledge gaps identified above. However, there are three specific areas that are not clearly addressed by the proposed research.

Firstly, determining the accuracy and precision of catch returns is not addressed directly. Instead emphasis is placed on developing better methods for stock assessment. In the long term, stock assessments that do not primarily rely on fishery dependent data will be a vast improvement. However, it is also recognised that fishery dependent catch returns will continue, in the short to medium term, to be used as the most efficient means of collecting long term data for catch per unit effort calculations. So the draft FMS will still rely on this information to manage the fishery. It is therefore essential that part of the research proposed for stock assessments addresses the issue of the accuracy and precision of catch returns.

Secondly, the proposed research on bycatch and discards does not address discard mortality. However, it is proposed that specific problems relating to bycatch and discards will be investigated using targeted research projects. The level, rate and impacts of discard mortality in the Estuary Prawn Trawl Fishery should be addressed by these targeted research projects.

Thirdly, the methods by which levels of uncertainty will be measured or identified in the stock assessments have not been made explicit within the outlines of the proposed research. Consideration of uncertainty in the information provided by scientists to managers has become increasingly important for fisheries management world wide (Patterson *et al.,* 2001). Therefore, research programs need to address the recognition of uncertainty, its quantitative measurement and how it would be incorporated into the information provided to managers and stakeholders.

There are three broad approaches to how the research will be done. Firstly, observer programs will be used to quantify bycatch and discards in all methods of the fishery. These programs are considered the most reliable and accurate way to assess bycatch and discarding. Secondly, fishery independent methods will be developed for future stock assessments. The current use of fishery-dependent methods to supply data for assessments has numerous short-comings which are identified in the draft FMS. These short-comings substantially affect the ability to make reliable assessments or predict future catch trends. Consequently, there is an urgent need to develop methods that overcome these problems. The proposed research makes a strong commitment to developing fishery independent methods. Thirdly, targeted research projects will be aimed at addressing specific problems identified in the fishery. These projects would primarily involve manipulative experiments or mensurative studies over appropriate spatial and temporal scales. Such experiments are regarded as the most productive way to resolve specific problems in a fishery (Underwood, 1990, 1993; Underwood *et al.,* 2000). The combination of these three broad approaches should adequately address knowledge gaps relating to the Estuary Prawn Trawl Fishery.

It is difficult to assess the sufficiency of the proposed research as there are few details regarding what specific research will be done, the relevant spatial and temporal scales, who it will be done by and the specific null hypotheses to be tested. However, it is noted that the overall research needs of all fisheries in NSW are currently being assessed and prioritised and further details on the proposed research programs will be available after this process has been completed in 2002 .

b) Performance and monitoring

i) Performance indicators and trigger points

Performance indicators are used to gauge whether the goals of the strategy are being met. Trigger points for each indicator set the level at which a review into a particular aspect of the management goals is instigated.

In general, the indicators are appropriate for the goal they are tracking. However, there are some indicators that are either inadequate or inappropriate to measure the performance of particular goals. These are discussed below.

For Goal 1 it is suggested that a performance indicator(s) be developed to monitor impacts on biodiversity. In order to monitor such impacts, they need to be identified and described. However, the research proposed does not explicitly state that an indicator for biodiversity impacts will be developed. Such research would come under the area of impacts of fishing on trophic interactions and ecosystems. As Table C3 in Chapter C states that an indicator for biodiversity impacts will be developed, it is important that the research proposed follows this through.

The number of MAC meetings held in a year is a measure of Goal 6, which is to ensure a cost-effective and efficient estuary prawn trawl management and compliance program. Whilst the associated trigger point is a regulatory requirement, the number of meetings does not necessarily indicate whether the Estuary Prawn Trawl Fishery is being managed efficiently and cost-effectively. More appropriate indicators should be determined in relation to the function of the committee to advise, monitor and assess (see *Fisheries Management Act 1994*, No. 38, Part 8, Division 2, Section 230). For example, an indicator could be developed that monitors how thoroughly and frequently the MAC checks that the objectives of the draft FMS are being met. Any indicators regarding the effectiveness of the MAC should take into account that MAC meetings deal with many contentious issues, which are not always resolved to every members satisfaction.

The first performance indicator for Goal 7 (to measure the improvement in the knowledge of the community about operations of the fishery) may not be adequate. Whilst disseminating information to the community is important it will be of no value if the information is not conveyed in an accurate and understandable manner. Therefore, there needs to be an indicator and trigger that tracks the quality, content and means of disseminating information to the community.

For Goal 8 there are three performance indicators that relate to the level of funding for research projects, the number of research grant applications submitted and the level of funding committed to research. These indicators are not an adequate measure of Goal 8, which is to improve knowledge of the Estuary Prawn Trawl Fishery and its resources. If grant applications do not involve properly designed research programs (i.e. world's best practice), they will do little to improve knowledge of the fishery. A more important measure is whether the research applications submitted and approved are appropriately designed to address the issue they are investigating, in terms of a set of best research practice criteria (e.g. Underwood, 1990). In addition, there needs to be a measure of whether the outcomes of the research are incorporated appropriately into the management of the fishery. At present there is no explicit explanation in the draft FMS as to how research and review are connected to managing the fishery nor what alternatives are proposed if the funding from external sources is not received. Measuring these indicators, in addition to those already suggested, will ensure that high quality and robust research is done, which will more likely result in improved knowledge of the fishery.

With the above exceptions, the trigger points for each performance indicator appear to be appropriate for what they measure. The trigger levels used to monitor the total catch of the target species of the Estuary Prawn Trawl Fishery are dependent on catch return data. Given the inherent problems with these data sets, as outlined above, an estimation of the uncertainty associated with these indicators and triggers needs to be incorporated into the monitoring programmes (Patterson *et al.,* 2001).

A performance indicator that is not mentioned explicitly in the draft FMS, although inferred, is the implementation of all the management responses. This will be monitored via the implementation plan and presumably will be overseen by the MAC and fisheries managers.

ii) Monitoring and review

There is a specific monitoring programme for each performance indicator (see Chapter C). The proposed monitoring involves observer based programmes, analysis of catch returns on a regular basis and other specific reviews of regulations and their outcomes. All the proposed monitoring adequately covers the performance indicators. However, reliance on catch returns for a large proportion of the monitoring programmes for target species makes these programs vulnerable to errors and uncertainty. There is no scope in the proposed monitoring programmes for estimating sources and levels of uncertainty associated with detecting trigger point breaches (Patterson *et al.,* 2001). Given that significant management decisions will be made based on the results of these monitoring programmes, any lack of understanding of the sources and level of uncertainty in the information could lead to inadequate management of the Estuary Prawn Trawl Fishery.

The proposed review process incorporates several important aspects which are:

- decision on what factors to review
- recognising the different possible outcomes
- actions required depending upon different outcomes
- allowance for modifications to be made to the strategy depending upon results

- contingencies for unpredictable events
- regular review and update of performance indicators and trigger points in light of on-going development of the strategy and outcome of research.

If these wide ranging aspects are diligently incorporated into the review process the draft FMS should work properly.

c) Relationship between research, performance indicators and review

An important aspect of assessing the research and monitoring strands of the draft FMS is whether the link between research, performance indicators and review is clear. Whist different categories of research (see Underwood, 1995; 1998) have not been explicitly identified in the draft FMS a relationship between research and review can be identified. Figure E5 is one possible model that shows the pathways by which the results of research and reviews feed back into each other to produce better management responses. For example, as research provides improved stock assessments for target species tighter or even different performance indicators and trigger points can be set. Similarly, as trigger points are reached the review process may discover knowledge gaps that have not previously been identified and which need to be addressed by further research. The dual feedback system of these links between research and review is crucial in the future development and better management of the Estuary Prawn Trawl Fishery. The model presented (Figure E5) is only one possible structure set out in the draft FMS. There are alternate models (e.g. Fairweather, 1991; Huenneke, 1995; Peters, 1991; Underwood, 1995; 1998) which could also could be used.

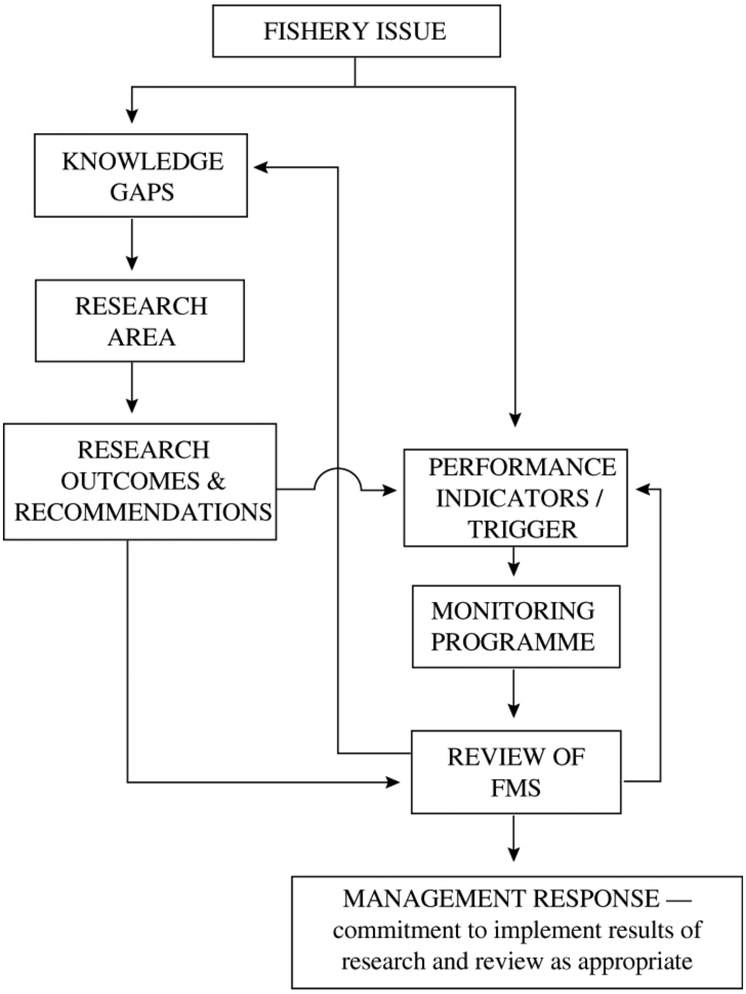

Figure E5 Flow diagram showing links between research, performance indicators and review.

One important element that has not been clearly addressed in the draft FMS is how to measure whether relevant results of research have been adopted into the draft FMS. Chapter C outlines circumstances that will trigger a review of the draft FMS. It includes contingencies for unpredictable events, one of which is the results of research programmes. However, this is presented in terms of unpredictable circumstances. Therefore, research results can only trigger a review of the draft FMS under contingency circumstances determined by either the Minister or the Estuary Prawn Trawl MAC. Under these circumstances, there is a danger that significant recommendations of research to improve the FMS could be overlooked simply because they were not deemed to require contingency measures. A more useful approach to incorporating research outcomes is to include in the draft FMS either an annual or bi-annual review by the MAC of the recommendations of research programmes relevant to the Estuary Prawn Trawl Fishery. Furthermore, justification should be given as to why recommendations of research programmes were not adopted. The proportion of research programme outcomes reviewed (out of the total number produced within a review period) would be one appropriate measure to monitor the incorporation of research results. In addition, a list of the research outcomes reviewed, adopted or not adopted and their justification would be another useful measure.

d) Timetable for developing information

The draft FMS details monitoring programmes for the Estuary Prawn Trawl Fishery in Table C12 of Chapter C. Most have been timetabled to begin in 2002 after the new FMS begins to be implemented. As many of the knowledge gap areas are dependent on using long term data sets the sooner monitoring and research programmes are instigated the sooner more accurate stock and fishing pressure estimates can be determined.

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.

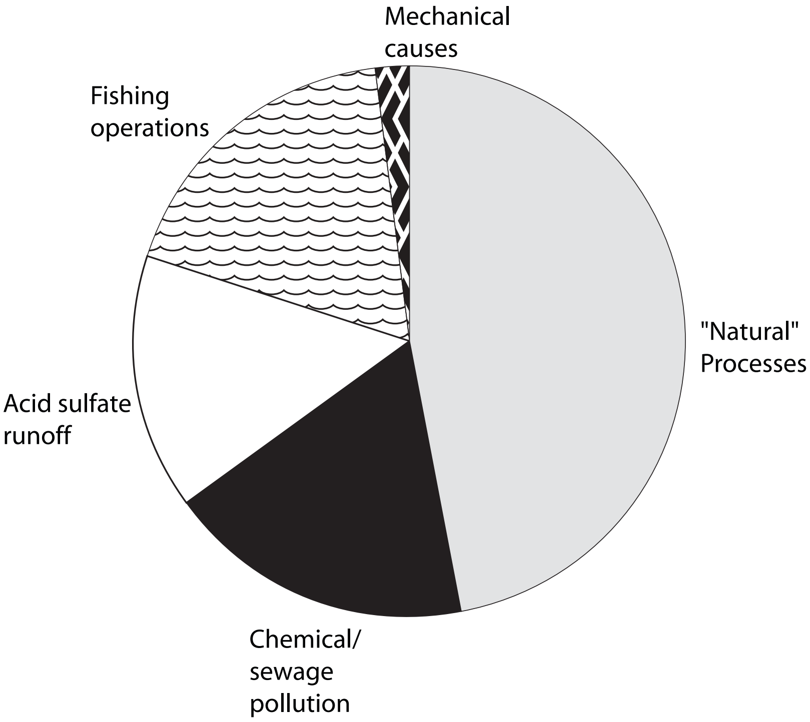

Figure F1. Breakdown of all fish kills in NSW estuaries attributable to a particular cause (data from 1970 to 2000 inclusive).

'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.

CHAPTER G. ECONOMIC ISSUES

This is only the third incorporation of an economic and social assessment of a management plan in the fisheries of NSW. It has been compiled from a limited amount of existing information, augmented by the results of economic and social surveys initiated by NSW Fisheries and undertaken by Roy Morgan Research (Roy Morgan, 2001a,b).

The following summary is based on the detailed consultants report prepared by Dominion Consulting Pty Ltd and presented in Appendix CG. The report on economic issues is in two sections; a review of existing information and then an assessment of the draft FMS against the Planning NSW guidelines.

1. Existing Information

Existing information is available from NSW Fisheries records and provides information on licensing, effort and catches at the primary level. Price, at first sale in Sydney, is also available and this enables an imputed Sydney fish price to be generated. Potentially, all "Sydney index" data in this report may understate revenue by 10% across all estuaries, as estimated by the recent economic survey (Roy Morgan, 2001a), and by 29% in regions 4 and 5. More accurate data is required on squid and prawn prices outside Sydney. Data on the fish processing industry is limited, being collected from annually renewed Registered Fish Receiver forms. The seafood processing, wholesale and retail industry in NSW requires further study.

An economic survey was undertaken by mail to enable a profile of the commercial fishers to be undertaken (Roy Morgan, 2001b). This had a response rate of 15.2%, 250 of 1,640 fishers statewide completing the surveys, of which 46 (15.6%) were from estuary prawn trawling endorsed businesses. This enabled the economic performance of businesses in the estuary prawn trawling catching sector to be appraised and gave an indication of the position of industry to pay additional charges and purchase shares under the draft FMS.

A rapid social appraisal telephone survey was undertaken by Roy Morgan Research (Roy Morgan, 2001a) and had a response rate of 50%, 870 fishers completing the questionnaire of which 171 estuary prawn trawling fishers (20%) completed surveys. This enabled the assessment process to have up to date information on industry, it's social profile and an indication of the potential social impact of changes under the draft FMS, which are examined in Chapter H.

The review of existing catch, effort and endorsement information, indicated the Estuary Prawn Trawl Fishery is based in five estuaries north of Sydney, and it is seasonal with a high period between November and May. It is predominantly one person businesses, with business partnerships (8.3%) and a limited number of companies (3%). Approximately 22% of estuary prawn trawling fishers work in other industries.

There were 289 businesses in the Estuary Prawn Trawl Fishery in 2001, with 302 entitlements across the five estuaries. For the 310 estuary prawn trawling endorsement holders, 223 were actively fishing in a range of commercial fisheries in 1999-2000 and 87 were latent. Of the 223 active fishers, 48 could have fished in the fishery, but chose to catch fish in other fisheries for which they were endorsed. Of the 175 fishers who fished in the Estuary Prawn Trawl Fishery in the year 1999-2000, 62 fished only in the Estuary Prawn Trawl Fishery and 113 fished in estuary prawn trawling and other fisheries.

The employment associated with estuary prawn trawling endorsed fishing businesses was examined in the social survey. Between 257 to 474 persons are employed full-time and part-time in fishing businesses which hold an estuary prawn trawling endorsement. There is no indication as to the extent of part-time employment in this seasonal fishery. This estimate also includes processing staff and needs further research as a statewide profiling exercise in order to avoid double counting of employment in the fishing and processing sectors.

The economic survey obtained data on industry operating costs, revenues and capital for one financial year only. The fishery is highly variable in activity and capital investment levels, some fishers having low capital investment. Survey returns were analysed to measure economic profit and to estimate a net economic contribution to the economy.

Estimates of operating profit were made, as many operators did not include owner’s payment from fishing. An economic approach was used to review long term viability. The economic test of long term viability subtracts economic costs from revenues and tests for evidence of a surplus. The economic costs have operating costs, fixed costs, including opportunity costs of capital, labour and economic depreciation. Having imputed a 7% risk adjusted opportunity cost of capital and imputed labour costs for all days worked from survey information, an estimate of economic depreciation was applied to test for long run viability, evidence of capacity to replace capital in the long term. Given the variation in the scale and scope of fishing operations, results were divided into estuary prawn trawling endorsed businesses receiving more than 20% of total revenue from estuary prawn trawling and estuary prawn trawling endorsed businesses with less than 20% of total revenue from estuary prawn trawling.

Long run economic surplus exists for 10% of all estuary prawn trawling fishing businesses examined, being greatest in the businesses which obtained less than 20% of total revenue from estuary prawn trawling. These businesses had an economic rate of return to capital of -13%, while businesses with more than 20% of revenue from the Estuary Prawn Trawl Fishery had an economic rate of return to capital of -30%. The average economic rate of return to capital across all the estuary prawn trawling businesses was -18%, the median being -25%. These results may under estimate the profitability of prawn fishing, due to possible under reporting of the prawn catch or other sources of income not detected in the survey.

Further economic annual surveying is required to monitor catch recording and economic performance between different years and in the longer term. The businesses currently operating below the long term viability criteria, are effectively subsidised by forgoing returns on capital and particularly on labour. This may be to accommodate lifestyle, or indicate barriers to fishers exiting the industry, such as lack of alternative employment in rural areas.

For the less viable operators, increased charges and requirements to purchase shares, will significantly reduce operational viability. There is a large range of operator performance given numerous part-time fishers, multiple fishing interests, and fishers with involvement in industries outside fishing, including subsidies from welfare. This is common in other rural industries, such as the NSW dairy industry, and requires on-going research on social structure of the industry and the economics of fishing households and communities.

Trends in licence values show no significant rise in estuary prawn trawling entitlement values in the last eight years, but this is a limited measure of economic performance, due to the restriction on transfers of endorsements and poor perceptions of management among fishers.

Limited information is available on non-Sydney fish market prices and shows higher prices for squid/calamari and school prawns, sold as high quality bait, particularly in the Hawkesbury River. Exports of seafood out of Australia by estuary prawn trawling fishers, was estimated as 8.1% of gross sales (Roy Morgan, 2001b).

Regional economic information on the NSW fishing industry is limited to several studies in northern and southern NSW in the late 1980s. Economic multipliers in the fishing industry are generally between 1.5 and 2.0 times the direct effect (Tamblyn and Powell, 1988; Powell *et al.*, 1989). Existing information from expenditures outside local towns infers that approximately 70% of expenditure stays in the local communities generating local multiplier effects (McVerry, 1996).

The social survey examined the type and location of major expenditure and regional purchase behaviour for major purchases made by estuary prawn trawling fishers, showing the importance of business links between estuary prawn trawling fishers in the Clarence and Brisbane, and between fishing centres and Sydney, Newcastle and Grafton in the north of the state. Nets, electronics and fuel/oil were 53% of the major purchase items for the estuary prawn trawling fishers interviewed.

2. Assessment

The assessment of the draft FMS draws on this background information and the responses under the draft FMS are ranked on their potential for larger scale economic impacts. There is insufficient cost and benefit information for a definitive ranking. The following issues are assessed:

- the intention under the draft FMS is to continue the annual 3% reduction in the number of fishing businesses seen under the Registered Fishing Operation policy, to decrease effort in industry through the category 2 share management regime and give the remaining fishers improved fishing rights. For assessment purposes a 15% reduction in business numbers under the first five years of the FMS is envisaged, reducing 289 fishing businesses in 2001, to 246 in 2006. The basis of share allocation has yet to be decided. It is envisaged that minimum share holdings may translate into businesses having to pay between $900-$1,200 per year to purchase shares to remain in the fishery, in addition to new management charges. Some businesses will exit, the most likely being latent effort holders and those businesses grossing below $10,000 per year. Shares will be more readily purchased by the 10% of businesses in economic surplus. To the majority of fishers without an economic surplus, there is an incentive to increase effort to cover the new payments. It is essential to monitor latent effort and contain active effort levels within historical guidelines, as stated in the strategy. Given the low output associated with exiting fishers, the economic flow-ons from exiting businesses will be low. Social costs are reported in Chapter H, social issues
- effort management will be implemented regionally through a total allowable effort for each estuary. A minimum shareholding provision at the endorsement level will be implemented within each estuary to address the level of effort in each of the fishery estuaries. A 5% reduction has been envisaged for assessment purposes, equating to a payment of $300-$400 per year, for five years, to retain an endorsement in a given estuary. It is likely that latent effort holders and those businesses grossing less than $10,000 per year, fishing less than 40 days a year will sell. If 5% of 310 endorsement holders exited in the first five years of the strategy, 16 fishers would be impacted to some degree, depending on their other fishing endorsements
- medium impacts may come from the establishment of the Prawn Resource Forum and alteration towards more optimal prawn harvesting practices. Changes in food safety practices are also envisaged
- low impact parts of the draft FMS, involve closures for species protection and also weekend and public holiday closures. Recovery plans and the implementation of an owner-operator policy may also impact fishers.

The costs and benefits of the major elements of the draft FMS are appraised through an environmental management cost account of the management of the fishery. To the estimate of economic surplus from fishing operations, the subsidised costs of management, research and compliance are added. Any change in the level of stocks is also counted to give a statement of current fishery status under environmental accounting principles. New costs to industry from the draft FMS and share purchase, are estimated and incorporated in the cost-benefit account.

The fishery has an economic deficit at the commencement of the draft FMS and seeks to have sound economic viability by 2006. Costs to fishers from new management charges and share purchase are substantial, as the fishery moves towards full cost recovery after the first five years of the plan (2006-2008).

The economic achievement of the objectives of the draft FMS depends on the category 2 shareholding proposal being as effective as envisaged in the plan. This is new territory in fisheries management and fuller economic investigation of share allocation and subsequent monitoring of restructuring is warranted. Mitigation may involve shares being related to an amount of total effort, as proposed under the draft FMS.

By 2006, changes arising from the draft FMS will alter industry operations and cost recovery policy will address subsidies, moving towards full cost recovery by 2008. The draft FMS enables this process to occur and monitors the health of stocks underpinning industry and fishery viability. The draft FMS is a first step towards a more economically sustainable fishery in accordance with ESD principles.

3. Conclusions

This economic analysis of the draft FMS is done against a background of little available economic information with an economic survey indicating an economic loss for those businesses with less than 20% of revenue from estuary prawn trawling. The draft FMS will assist industry to remain economically viable by following the rate of adjustment under the established RFO process and addressing sustainable harvesting by controlling effort through a total allowable effort limit in each region and minimum shareholding provisions as required.

The analysis of the costs and benefits of the management plan, indicate that the fishery will be more profitable by 2006-07. The level of achievement of the draft FMS, through the new category 2 share management regime, needs to be monitored. There may also be cumulative impacts on estuary prawn trawling businesses from the restructuring of the Estuary General Fishery and from the recreational fishing area process. These will likely assist in reducing latent effort among estuary prawn trawling endorsement holders at limited cost to estuary prawn trawling fishers.

There are economic costs and social impacts for industry under the plan, as 44 to 58 of 289 businesses exit the Estuary Prawn Trawl Fishery in the 2002-2007 period. Many of these will be low catch or latent effort businesses, leading to minimal regional economic impacts due to their low output. The draft FMS should be seen as a significant step on the longer path towards achieving ESD objectives. The social issues are presented in Chapter H.

4. Data Requirements in Relation to the Assessment of the Impacts on the Economic Issues

a) Reference to technical data and other information relied upon to assess impacts

The data used in the assessment is from several sources. The catch and effort data is from NSW Fisheries and is logbook data joined with licensing data for tables that have fisher endorsements. The catch and effort data are segmented into each estuary. When licence data is used for spatial analysis and segmented by fisher district from general records there may be occasions that fishery activity in an estuary traverses two districts.

Effort data at the days fished level is complicated by the logbook system where fishing three methods in one day ends up being records as one day of effort against each of three methods. This limits the potential for accurate production modelling, or bio-economic analysis in the Estuary Prawn Trawl Fishery and other fisheries.

A significant issue for fishers is the use of the Sydney index for price imputation on declared catches. The monthly average price for a species from Sydney Fish Market is multiplied by the declared catch for a species. This enables both fishery wide and individual fisher revenue estimation. There are some inherent problems in this approach. Some species, such as calamari/squid may not have a representative monthly average price. The imputed price will likely be a minimum estimate of the price of species which are in strong demand. For example seafood such as larger prawns, are unlikely to be sent to Sydney market as local demand is strong at higher prices, without commission and freight. In some cases fishers in areas outside Sydney may receive prices closer to Sydney retail levels for valuable species.

The economic survey was done over a short time period and the responses may have been less accurate than verification of declared data through accounting records. The economic survey asked fishers to declare gross revenue from catch in 1999-2000 and this was compared with the predicted Sydney index for each fisher to see the inter relationship. The Sydney index may under estimate actual prices in estuary prawn trawling businesses by 10% and this varies by estuary, with regions 4 and 5 exceeding the Sydney index by 30% to 54%.

There are also uncertainties in the value of fishery businesses and endorsement values. Diversity among business packages mean the true value of access is difficult to determine. The move to share management will require examination of the structure of business and endorsement values.

b) Important knowledge gaps

Several gaps are apparent. The major one is the lack of an industry wide profile and input-output analysis of the seafood industry in NSW, including processing, wholesaling and the movements and values of seafood in the marketing chain. This would enable an evaluation of the secondary stages of the fish catch including transport, wholesaling, processing, exports, imports and employment derived from the NSW fish resource. It could also potentially extend to retailing.

Multiplier estimates could be verified and contribute to future assessments. The regional importance of the seafood industry in each zone could be evaluated. Part of this could use the Register

Fish Receiver annual renewal forms to include more information on processing activity in relation to the fisheries under management.

Fish price information outside Sydney needs to be collected on a regional and fishery basis. This is required, as several of the future assessment issues, such as the optimal harvesting time of prawns will require bio-value models using biological and size and price information for different prawn species during their migrations.

Economic viability is part of the objectives of the *Fisheries Management Act 1994* and annual surveys of economic profit are needed to account for strong annual variation. Business, endorsement and shares values is an area requiring more research. Similarly, longer term planning needs to be able to monitor the cost of operations and this could use existing survey information to establish a representative fishing cost index. This would monitor cost changes for producers and could parallel the Sydney price index for fish revenues. Economic linkages between fishing communities and within the fishing industry have been briefly addressed in the current social survey and could be augmented through time.

c) Timetable for developing the data sets

Data needs can be addressed in the next five year period through development of a strategy for improving the following data:

- investigation of available prawn species price data and establishment of price data monitoring system to enable valuation and modelling of resource management scenarios, such as maximising prawn bio-value through alternative harvesting regimes
- examination of the viability of businesses, business values, endorsement and share values and the basis of share allocation prior to trading. Subsequently, monitoring of share values to ensure industry viability and the achievement of the draft FMS objectives
- surveying the economic performance of businesses after the implementation of the plan (annual or biannual)
- develop a state-wide fishing industry economic restructuring model for predicting and appraising fishing business adjustments across fishery administrative divides
- revising the collection of effort data to enable more sensible modelling of catch per unit effort and productivity data. This would involve changing the fishery data logbook system and needs to happen within five years in preparation for long term sustainability issues, including economic modelling and monitoring
- developing an economic profile of the regional fishing and seafood processing industry in NSW. This could include marketing, economic infrastructure and regional benefits. This needs to be progressed by area and in conjunction with social community profiling as a basis for longer term planning.

CHAPTER H. SOCIAL ISSUES

This is the third formal incorporation of a social assessment of a management plan in the fisheries of NSW. It has been compiled from a limited amount of existing information, augmented by the results of a social survey initiated by NSW Fisheries and undertaken by Roy Morgan Research (Roy Morgan, 2001a,b).

The following summary is based on the detailed consultants report prepared by Dominion Consulting Pty Ltd and Umwelt (Australia) Pty Ltd and presented in Appendix CH1 and CH2, respectively. The report on social issues is in multiple sections; a review of existing information, an assessment of the draft FMS against the Planning NSW guidelines, health issues, heritage issues, Indigenous issues and data issues.

1. Existing Information

The regional and community location of fishers was identified from licensing data and compared with the ABS data for a range of social indices, at the post code level. This included local population, unemployment and fisher employment data from the 1996 national census and the SEIFA[9] index of disadvantage for rural communities (ABS, 1996). The fishing communities tend to focus around key estuaries and towns, though a significant number of fishers reside in smaller communities. More in depth studies of fishing communities is an area for future work. A rapid social assessment telephone survey contacted 171 estuary prawn trawling fishers with a range of questions relevant to the draft FMS.

Total employment in businesses with an estuary prawn trawling endorsement, is estimated as between 257 and 474 persons (full-time and part-time), though those directly associated with the Estuary Prawn Trawl Fishery would be less. Some of the employees are probably in processing and there is no measure of the extent of part-time involvement. This requires further studies as recommended.

A demographic profile of estuary prawn trawling fishers was generated describing age, education levels, marital status and dependent children and relatives. The way of life of estuary prawn trawling fishers was investigated through questions on working hours in the normal, high and low seasons, and details of industrial injury through fishing. The estuary prawn trawling fishers were found to be an aged, highly resident population, with substantial fishing experience and strong family involvement with fishing, 30% of fishers having had more than two generations of family in the fishing industry. However, 47% are first generation fishers. Fishers in excess of 60 years of age, are 20% of all estuary prawn trawling fishers and a wide range of fishers of all ages are evident in the fishery.

The skill sets of fishers were examined through the social survey and 22% of fishers worked outside fishing, 13% being capable of working in another occupation full-time. Further investigation suggests that up to 26% of the estuary prawn trawling fisher population could consider working in other industries full-time or part-time. However, approximately 83% were insistent about their identity as fishers and were unable, or unwilling, to consider re training. This "psychic income" from fishing

[9] (Socio-Economic Index For Areas)

and problems in mobility of fishers are similar to NSW dairy farmers and a range of issues are discussed. These require future research. Regional unemployment in NSW is higher on the North coast of NSW (15%) and areas outside Sydney, and is a significant issue for aging fishers considering alternative employment to fishing.

There is little independent opinion on community perceptions of fishing activities. In a community telephone survey in 1999, there was general concern among a random selection of the population for the well being of the fishery environment and for the need to manage and conserve fish stocks (Roy Morgan, 1999). Other community opinion about fishers, is less formal and is an area requiring development. Much commercial fishing activity is not evidenced by the public.

Recreational fishers are more aware of the commercial fishery and conflict over commercial prawn trawling in estuaries is common. The draft FMS seeks to reduce the conflict among commercial fishers and between commercial and recreational fishers. The recreational fishing area program is addressing these issues outside the FMS process.

The outcomes of the Prawn Resource Forum will assist in the management decisions of the Estuary Prawn Trawl Fishery to ensure that the management and harvest of prawns is equitable and efficient. The views of local people and representatives of community groups will also be incorporated into the management process.

2. Assessment

The social assessment followed the Planning NSW guidelines, but as there is no established social impact assessment framework for fishery management plans, an approach was developed from guidelines and available literature. The draft FMS management responses were ranked into high, medium and low impacts: firstly, those socio-economic issues arising from policy changes that could have broad impacts; secondly, issues of social process, where policy changes require these processes to function properly for management to be most effective.

The most highly impacting issues include the use of minimum business shareholdings and minimum shareholdings to reduce effort in each estuary. Each of these changes has the capacity to impact many families, local communities and regions, the assessment being able to examine regional and predicted family impacts from available data. Each of the impacts are assessed and mitigation is suggested where applicable.

The major social changes in the draft FMS involve the displacement of between 45 and 62 fishers in the first five years of the strategy, through the implementation of minimum business shareholdings and minimum shareholdings related to effort adjustment. These will probably impact part-time, and older fishers as 20% of fishers are over 60 years old and of pensionable age. A diverse range of people, who are either latent endorsement holders, or fishing businesses grossing less than $10,000 per year will be impacted.

The predicted social impacts assume a 20% displacement of fisher numbers over the first five years of the FMS. The numbers of dependants associated with between 45 and 62 typical estuary prawn trawling fishers is between 86 and 122. This is an upper estimate, as if older fishers exit the fishery, then the number of dependants reduce to approximately 20 persons. Exiting fishers are likely to be low catchers, or have other income sources, if they are latent effort. This reduces the proportion of social impact attributable to the exiting of fishers under the draft FMS. The cumulative impacts of the estuary general FMS and the funds from the recreational fishing area process may impact the adjustment process indirectly and to an unknown extent.

The draft FMS will have different regional community impacts as indicated by the SEIFA index of disadvantage for fishing communities. On implementation of the draft FMS, the estuary prawn trawling fishing communities in Clarence River and Hunter River are most vulnerable to changes from the socio-economic impacts under the draft FMS, though other estuary prawn trawling fishing communities in Sydney and the Hawkesbury, are also potentially disadvantaged to some extent. Social impacts on communities will also depend on the economic responses of fishers to category 2 share management and to effort limitations, which will not be uniform between areas. The social impacts of the draft FMS may be mitigated by the rate at which adjustment of minimum shareholdings occurs.

Other measures in the draft FMS will require functioning social processes to ensure effective management. Responses involving communication, compliance and closing areas require cooperation between management and industry and a reduction in conflict to make the draft FMS successful. The draft FMS seeks to reduce conflict between estuary prawn trawling commercial fishers and recreational fishers through weekend and public holiday fishing closures. This needs to be monitored to ensure the effective implementation of the plan.

3. Conclusions

This is the third social assessment of a FMS in NSW. Available information, data and specially commissioned survey results, are used to describe the fishers and communities in the Estuary Prawn Trawl Fishery. It is notable that several rural areas away from Sydney in the Clarence River area, are socio-economically disadvantaged and will be less resilient to impacts under the draft FMS.

Most of the social issues arise from reallocation under category 2 share management and will impact fishers, employees, families and communities associated with the exiting of between 44 and 58 estuary prawn trawling businesses, with up to 62 fishers. It is predicted that older fishers, businesses earning less than $10,000 per year and latent effort holders, will be likely to exit, with low levels of regional economic impact, due to the small loss of output associated with these fishers. An estimated 45-62 fishers, with between 86-122 dependents, will be impacted to differing extents in proportion to their age and income dependence on the Estuary Prawn Trawl Fishery.

The social impact will be noticeable in estuary prawn trawling fishing communities, given the lack of alternative employment for many aged fishers, though elderly fishers will now be able to retire with a payment from the sale of shares. Other social aspects of estuary prawn trawl fishing and NSW fishing communities, require further research in the next five years. This should prioritise understanding of fishing communities, as a base to appraise the cumulative impacts of successive fishery plans on a community as opposed to a series of impacts from different Fisheries Management Strategies in isolation. The current draft FMS is a step towards ESD objectives in the management of the Estuary Prawn Trawl Fishery.

4. Health Issues

a) Health risks related to the environment

The seafood safety scheme is based on the premise that some species and/or activities represent a potentially higher food safety risk than others. The highest food safety risk is associated with bivalve molluscan shellfish because they can readily accumulate harmful contaminants (bacteria, viruses, algal toxins and heavy metals) from their environment and transmit these to the consumer. Bivalve molluscs are not retained in the Estuary Prawn Trawl Fishery and the species that are targeted in the fishery do not need any special management arrangements. With the introduction of the Seafood Safety Scheme Regulation, responsibility for this fishery in terms of food safety will pass to SafeFood Production NSW.

i) Handling and processing health risks

As food producers, the provisions of current NSW food legislation, namely the *Food Act 1989* and the *Food Regulations 2001*, bind participants in the fishery. Vessels are included in the definition of "vehicles" in the *Food Act 1989*. There are no specific provisions relating to seafood specifically in the context of this fishery but general requirements about hygiene and cleanliness, keeping good records and keeping products cool apply to the handling of all foods including fish.

The *Food Production (Seafood Safety Scheme) Regulation 2001* due to be introduced by September 2001 will require all seafood businesses including those in the catching/harvest sector to be licensed with SafeFood Production NSW and prepare a Food Safety Program in respect of their activities.

With respect to the fishery, this will apply from the point at which the catch is brought on board the vessel. Where the same business or individual further processes or handles products on shore (after landing) the Food Safety Program will have to encompass each and all of those other activities.

For most participants who simply catch fish and transport them to land, the basic requirements would already be understood and met since they involve good handling and hygienic practices. Given the range of scale and sophistication of vessels and businesses engaged in the fishery, however, it is likely that some improvements will need to be made, primarily of a minor nature. Most such changes would probably be accommodated in the draft FMS.

Essentially the major food safety requirements on all participants in the fishery are to keep the catch clean, keep it cold and keep good records. The current level of compliance is largely unknown but with the introduction of the Seafood Safety Scheme all participants will be licensed and subject to audit and inspection.

ii) Health risks to fishers

There are a variety of occupational health and safety (OH&S) risks associated with the activity of fishing in the Estuary Prawn Trawl Fishery. These are related to the use of machinery, boats, powered winches, etc. Workcover administers the legislation, which controls these activities and protects workers' health. The fishing businesses are required by law to operate in a manner consistent with the OH&S legislation. The draft FMS is not required to provide additional specific management responses to OH&S issues.

5. Heritage Issues

The following summary is based on the detailed consultants report prepared by Umwelt (Australia) Pty Ltd presented in Appendix CH2.

a) European heritage

This section reports the results of a review of the historic heritage that is located within the precincts of the five estuaries in which prawn trawling activities occur. The review of historic heritage has defined those elements of the resource that are, or appear to be, located in such a position that either estuarine prawn trawling operations might have some impact on an element or vice versa.

For the purposes of this report, historic heritage has been differentiated between the transport and structural contexts. This differentiation is essentially dictated by the base source(s) or recording database(s) from which data has been derived. The transport context is specifically represented in the record of shipwrecks. The structural environment includes such resources as boatsheds, landing ramps, seawalls, breakwaters, wharves and boat harbours, but also includes such developments as structures for oyster culture, groynes and piles. This latter group of structures may have no physical connection to the shoreline.

i) The interaction of commercial fishing with historic heritage resources

The activities associated with the fishery are limited to associated boating, foreshore access and the use of trawl nets.

The physical and spatial presence of heritage resources within estuaries is likely to have only a marginal effect on commercial prawn trawling operations. With regard to shipwrecks, it appears likely that commercial prawn trawling in estuaries will have no impact on residual material evidence, having regard to the likely nature, bulk and mass of any residual material and the potential for sub-surface material to be covered by silt/sand. Nonetheless, in the reverse situation, it is possible for residual wreckage to pose a hazard, as a potential snag for nets.

b) Aboriginal Heritage

In general, the archaeological and ethnographic evidence clearly indicates that fishing and shell fish gathering were of great importance to Aboriginal people in pre-European times, right along the NSW coast, and the evidence suggests an increasing use of the full diversity of coastal resources over time. The evidence also suggests distinct differences in the styles of accessing the estuary and coastal fishery resources on the north and south coasts (e.g. in terms of seasonality and targeted species). Sullivan (1982) attributes these differences in the first instance to significant geomorphic differences between the north and south coasts.

i) Interactions between the Estuary Prawn Trawl Fishery and Aboriginal heritage sites

There are many Aboriginal sites along the banks of estuaries that provide abundant evidence of the value of estuarine resources to Aboriginal people, and in fact these sites underestimate the values of estuaries because no plant materials are preserved and only a portion of the more robust animal parts remain. There is, for instance, no archaeological evidence of prawn fishing and consumption, just as there is no archaeological evidence of the widespread use of plant materials as foods, medicines, tools and equipment by Aboriginal people.

Estuary prawn trawling techniques involve the setting, towing and retrieval of nets. The nets are operated from small boats. In the large estuaries where prawn trawling is permitted, these fishery activities are most unlikely to impact on the stability of estuary banks or beds. Most prawn trawling areas, for instance, are within open estuary reaches where wind waves and tidal or flood currents are the dominant causes of bed and bank instability. The slow passage close to the bank of small trawling vessels would have relatively minimum impacts. There is some potential for boat passage to exacerbate bank erosion in narrow channels that may provide access to other parts of the estuary (e.g. along the narrow channels leading into Wooloweyah Lagoon), although prawn trawling vessels comprise only a small portion of total boating activity in these waterways.

The nature of estuary prawn trawling means that although the banks of estuaries are lined with known Aboriginal sites, there is a low risk that sites will be impacted by estuary prawn trawling activities.

There is potential for fishery related activities to impact on Aboriginal sites at restricted locations along estuarine waterways, for instance at boat ramps, and localities that are used for storage and maintenance of equipment. The extent of the risk associated with these activities will vary from one estuary to another and definition of the risk for an individual estuary will depend heavily on the availability of local knowledge (e.g. provided by discussions with local Aboriginal people and local NPWS officers).

Where potential impacts on Aboriginal sites are known to exist, it is important that they are addressed by liaison and management actions at the local level. This will ensure compliance with the requirements of the *National Parks and Wildlife Act 1974* (NPW Act) and will also enhance co-operation and understanding of cultural concerns.

In general, the physical evidence of past Aboriginal occupation of estuary banks is most severely threatened by land uses and activities other than estuary prawn trawling. Large midden sites in the Hunter estuary and north coast estuaries were exploited for lime in the nineteenth Century, and sometimes also for road base. Many sites have also been destroyed by agricultural land uses, urban and tourist development and some have been destroyed by bank erosion (that may have natural or anthropogenic causes).

In the cases of both Aboriginal sites along the banks of estuaries, the overall risk that activities authorised by the draft FMS will detrimentally impact on cultural heritage evidence is considered to be very small.

ii) Protocols to reduce the risk of harm to sites

Notwithstanding the low risk of impact on Aboriginal cultural heritage, several management actions are proposed to ensure that risks to archaeologically sensitive areas are minimised. These include:

- consultation with local Aboriginal community representatives in relation to any proposed commercial fishery facility that would be located on an estuary bank or foreshore. This would include maintenance of existing ramps, new launching ramps, wharves and regional boat storage or maintenance sites. In general, such facilities will require separate environmental assessment and development consent including assessment of potential impacts on Aboriginal cultural heritage

- ongoing consultation with local Aboriginal communities about developments in the commercial sector. This will occur, for instance, through Aboriginal representation on regional management advisory committees (MAC).

6. Indigenous Issues

The following summary is based on the detailed consultants report prepared by Umwelt (Australia) Pty Ltd presented in Appendix CH2.

It is important to note that there are several other concurrent policy development initiatives by NSW Fisheries that will affect the interaction of Aboriginal fishers with the Estuary Prawn Trawl Fishery. In particular, NSW Fisheries is currently working with the Aboriginal community to develop an Indigenous Fisheries Strategy, that will provide a new framework for the management of Indigenous fishing. The information presented in this assessment draws on the work in progress towards the Indigenous Fisheries Strategy, and outlines a process for ongoing review of regulatory relationships, but in no way pre-empts the outcomes of that strategy.

a) Current access of Aboriginal communities to estuary fishing

Commercial fishing has existed in NSW estuaries since the mid nineteenth century, and by historical accounts from the late nineteenth century, it existed initially as a locally based activity because of the lack of effective refrigerated transport to bring catches to the Sydney or export markets. Commercial fishing operations moved to more remote estuaries early in the twentieth century. Commercial prawn trawling commenced in Port Jackson in 1926, spreading to the other four estuaries in the 1940s. There have been substantial increases in prawn trawling fishery effort since that time. Thus, although the interaction of traditional Aboriginal fishing activity with the commercial estuary sector in estuaries spans approximately 150 years in the Sydney area, and 100 years elsewhere on the NSW coast, the interaction with prawn trawling activities is restricted to only five estuaries and a period of 60 to 80 years.

From the late nineteenth century, a number of estuaries (or parts of estuaries) were closed to commercial fishing and prawn trawling, generally to conserve or to allow the regeneration of fish stocks. Traditional Aboriginal fishers (not holding commercial licences) would have continued to have access to the aquatic resources of these waterways during periods of commercial closure.

Since the mid 1980s, a number of new regulations have been introduced by NSW Fisheries. The broad objective of these regulations was to enhance the efficiency of the commercial fishery, and introduce greater control over fishing effort and impact. The number of Aboriginal people who are licensed as commercial fishers in the Estuary Prawn Trawl Fishery and the relative scale of their fishing effort, is not known.

The introduction of greater regulation in the fishery from the mid 1980s had several unintended consequences in relation to the access of Aboriginal communities to the estuary fishery. The impacts of the regulations continue to be of concern to Aboriginal fishers.

b) Management of interactions between Indigenous fishing and the Estuary Prawn Trawl Fishery

i) Outstanding issues of concern to coastal Aboriginal communities

The level of Aboriginal participation in the commercial fishery sector (based on interview data) appears to have declined substantially over the last twenty years. There are now perhaps less than fifteen active fishing licences (estuary general and estuary prawn trawl) held by Aboriginal families along the coast. However, the lack of commercial participation is not an indication of declining Indigenous participation in fishing and prawning generally. There are four main categories of outstanding issues of concern to the Aboriginal community in relation to their participation in the management of fisheries in NSW (NSW Fisheries, 2000c) and each of these is also relevant to the impact of the draft FMS on Aboriginal communities:

- lack of recognition and accommodation of traditional Indigenous fishing practices
- declining participation of Aboriginal people in commercial, recreational and aquaculture fisheries
- insufficient meaningful presence and participation of Aboriginal people in the process for managing and conserving fisheries resources
- need for better communication and consultation with Aboriginal people.

Actions to address Aboriginal concerns in the draft FMS

The draft FMS identifies Indigenous people as stakeholders in the Estuary Prawn Trawl Fishery, noting that these interests arise from:

- direct participation in the fishery as commercial fishers
- traditional fishing practices, whereby people catch fish and prawns on behalf of themselves and their community
- lodgement of Native Title claims over estuarine areas that are used for commercial prawn trawling (e.g. the Banjalang claim in the Clarence estuary).

NSW Fisheries legislation does not currently recognise Indigenous fishers as a separate sector of the fisher population, and this is the main reason why none of the legislative reviews to date have given extensive consideration to Aboriginal community concerns.

The draft FMS does not specifically address the Aboriginal community's view that the evolution of the fisheries legislation in NSW has gradually but consistently undervalued the interests of Aboriginal people in the estuary fishery. The draft FMS does, however, foreshadow future amendments to the strategy to better accommodate Aboriginal community interests. For example, objective 4.3 specifically addresses Indigenous concerns:

> *Objective 4.3: To minimise any impacts of the Estuary Prawn Trawl Fishery on Aboriginal cultural heritage.*
>
> *(a) participate in the development and subsequent reviews of the Indigenous Fisheries Strategy and make adjustments to this fisheries management strategy where needed.*

This and other objectives demonstrate a commitment by the fishery to operate in an ecologically sustainable manner that recognises the needs of other stakeholders and the need for excellent communication and understanding of the perspectives of those stakeholders.

In the draft FMS the performance indicator listed for appropriate sharing of the fishery resource is the catch level (including estimates) of the commercial, recreational and Indigenous fishing sectors. A trigger point for review is noted as a shift in relative catch levels of 25% between sectors over the term of the strategy. It is important to note that such a shift in relative catch is unlikely to occur without significant changes to policies affecting access to the resource.

The performance indicators and trigger points will be reviewed when the overall strategy is reviewed to ensure that they provide appropriate guidance on the interaction between the estuary prawn trawl fishery and Indigenous fishers.

ii) Towards a NSW Indigenous Fisheries Strategy

NSW Fisheries has recognised that coastal Aboriginal communities have long standing and legitimate interests in the fishery resources of estuaries. The NSW Government now also acknowledges that Indigenous community interests in the estuary fishery are contemporary and do not only relate to past history. The traditional access of Aboriginal communities to natural resources has been restricted by existing fisheries management policies and legislation.

A recent working paper prepared by NSW Fisheries (2000c) indicates that consultation is progressing about how best to recognise and accommodate the rights and interests of Aboriginal people in the estuary fishery and other commercial fisheries. The working paper is part of the process for the development of an Indigenous Fisheries Strategy for NSW.

Interaction of the draft FMS and the Indigenous Fisheries Strategy

The time frame for the finalisation of the Indigenous Fisheries Strategy is not clear, and there are many complex issues to be resolved before the stakeholders agree to a sustainable strategy. It is most probable that the draft FMS will be assessed and will commence implementation before negotiations about the Indigenous Fishery Strategy are complete.

The preliminary indications are that the Indigenous Fisheries Strategy will, subject to Government funding, address many of the issues that remain as outstanding concerns to the Aboriginal community in relation to the Estuary Prawn Trawl Fishery. It is also possible that the strategy will include a staged series of actions to gradually improve Indigenous access to the natural resources of estuaries and other fisheries, ensuring that any necessary changes to the FMS will also be gradual.

Ongoing review of the FMS will be essential to ensure that any changes in the policy approach to Indigenous fisheries are adopted. It is proposed that the draft FMS will be reviewed in two years, with particular attention to ensuring consistency between any Indigenous Fisheries Strategy that exists at that time, and the management protocols contained in the FMS.

c) Summary

As noted above, the risk of impacts on Aboriginal sites from activities in the Estuary Prawn Trawl Fishery is considered to be low at the whole of industry level, although specific local issues may emerge that need careful management.

Many of the concerns of Aboriginal communities about the impact of current commercial fishery regulations on their livelihoods and lifestyles are being addressed through the partnership with NSW Fisheries to develop an Indigenous Fishery Strategy. However, this process may take some time, both to finalise to the satisfaction of all stakeholders, and to implement through changes to other strategies and legislation.

In the shorter term, several actions are recommended to minimise the risks of adverse interactions between Estuary Prawn Trawl Fishery activity, Aboriginal heritage and contemporary Indigenous community issues. These include:

- focus on enhancing communication between NSW Fisheries and Aboriginal communities at all levels
- prepare cultural awareness material for commercial fishers in the estuary prawn trawl sector (and other sectors) highlighting risks to Aboriginal sites and how these can be minimised
- ensure close co-ordination of the preparation of new fishery management strategies for commercial, conservation, recreational and Indigenous sectors, to enhance opportunities for identifying innovative cross sectoral management options
- explore opportunities for further Indigenous fishing or recreational fishing development in estuaries that are currently subject to a low level of commercial fishing activity
- the FMS should be reviewed after two years, so that changes to Indigenous fishing policies can be accommodated.

7. Data Requirements in Relation to the Assessment of the Impacts on the Social Issues

a) Reference to technical data and other information

Prior to this study there was little social information on commercial fishers in NSW. The survey data comes from a rapid social appraisal questionnaire executed by a telephone survey, which is a first step towards the incorporation of social information in the management of fishers in NSW. The survey is not a definitive social profiling exercise. Given the complexity of the fisheries production inter relationships, multiple communities and political climate among industry members facing significant allocation issues, the survey sought to gain a rapid over view of social issues raised under the draft FMS.

The survey revealed some inconsistencies in answers involving fisher income and these have been investigated by matching with the available Sydney price index information and preliminary results from the economic survey. There are some occasions in which the absence of a fisher submitting a catch return in the required time period will give inconsistent results.

b) Important knowledge gaps

The social profile of estuary prawn trawl fishers can be augmented through time by further studies. Regional analysis of fisher communities is a priority integrating with economic information on the importance of the fishing activity to the community infrastructure of towns in NSW. Other approaches examine expenditures by businesses and employees, and examines employee residential locations, social infrastructure services and existing social networks (Fenton and Marshall, 2001). Future social survey work should address community structure and inter-relationships at a regional level and articulate with regional economic studies previously recommended in section G. This could be developed to monitor community impacts through all the fishery management strategies being developed in the next few years.

c) Timetable for developing the data sets

More comprehensive social profiles and regional analysis should be undertaken in the next five years to assist in monitoring the impacts of adjustment and in preparation for appraisal of future management strategies. The survey information recently obtained can have existing NSW Fisheries data added to it for analysis, but has a limited shelf life.

More complete regional industry and fishing community studies need to be undertaken recognising that the fishing communities can be cumulatively impacted by multiple fishery management strategies. In time it is desirable for the fishing community profile and characteristics to be more clearly identified. This would enable impacts from different fisheries management strategies to be monitored. In the longer term repeating social impact assessments for each strategy risks ending up as a piecemeal and duplicative process if progress is not made in more fundamental fishery community profiling and monitoring in the next five years.

CHAPTER I. JUSTIFICATION FOR THE PROPOSED COMMERCIAL FISHING ACTIVITY

1. The Need for the Estuary Prawn Trawl Fishery

This section examines the need for the fishing activity proposed in the draft Fishery Management Strategy (FMS) for the Estuary Prawn Trawl Fishery and the consequences of not undertaking the activity. The Estuary Prawn Trawl Fishery exists because it satisfies a number of significant community needs, each of which are discussed under separate headings below. First it will be useful to consider the fate of the prawns if there were no Estuary Prawn Trawl Fishery.

Should the Estuary Prawn Trawl Fishery not continue, a proportion of the prawn stocks taken by this fishery would likely be caught by other fisheries. The extent to which this would occur would vary between the estuaries. If the fishery were not to operate in the Clarence River, then it is likely that the Estuary General Fishery which also targets prawns in the estuary, and the Ocean Prawn Trawl Fishery which operates in adjacent waters offshore, would take greater shares of the stocks. Similarly, the Ocean Prawn Trawl Fishery that operates in waters adjacent to the Hunter River would be expected to catch a proportion of the catch foregone in the estuary by not having an Estuary Prawn Trawl Fishery. The economic loss from no catch by the Estuary Prawn Trawl Fishery may in the circumstances where there is an adjacent ocean going prawn fleet, be offset by the greater share of prawns taken by the Ocean Prawn Trawl Fishery coupled with generally higher prices for bigger prawns.

The consequences to production from prawns by having no Estuary Prawn Trawl Fishery in the Hawkesbury River and Port Jackson is less clear. Eastern king prawns are the main prawn species caught in Port Jackson and these also contribute significantly to the prawn catch in the lower reaches of the Hawkesbury River. This species migrates northwards to south-east Queensland and so is considered a unit stock along the east coast of Australia. It is reasonable to expect therefore that some of catch of this species foregone by having no Estuary Prawn Trawl Fishery would form part of the catch of offshore prawn trawl fleets, including those in waters off Queensland. What would happen to the school prawn catch in the Hawkesbury River if there were no estuary Prawn Trawl fishery is unknown. Prawn trawling occurs only occasionally in waters off the Hawkesbury River because there are few trawl grounds and it is not known whether school prawns would migrate far enough to form part of the stock of prawns fished by the Ocean Prawn Trawl Fishery fleet from Newcastle. Similarly, it is unknown whether the loss of production through no trawling for squid in the Hawkesbury River would be compensated for in some other fishery. Little is known about the movements of the squid species involved and therefore whether the resource would be available to other fisheries.

If there were no Estuary Prawn Trawl Fishery it could be expected that there would be less disturbance of species and communities that make up the incidental catch of prawn trawlers. Some of these species are important to other fisheries and to the recreational fishery. There is a possibility that if there were no Estuary Prawn Trawl Fishery, the catches of certain species by these other fisheries may increase.

From an ecosystem perspective no trawling may help to conserve biodiversity in the estuaries of the Estuary Prawn Trawl Fishery. However, it is not yet known whether the Estuary Prawn Trawl Fishery in NSW has a detrimental impact upon these ecosystems. There may be less disturbance of benthic and epibenthic communities and of those species which make up the incidental catch of the Estuary Prawn Trawl Fishery. The shellfish and finfish that are no longer captured in any fishery could add to the stock and make it more secure. There may also be additional quantities of food available for predators of prawns and species in the incidental catch of the Estuary Prawn Trawl Fishery.

a) Employment

There have been no targeted social surveys done in relation to the NSW fishing industry, and there is little available information on which to estimate social impacts of fisheries management changes. The economic and social survey done by Roy Morgan Research and analysed by Dominion Consulting Pty Ltd on behalf of NSW Fisheries has provided some information however, which allows a preliminary assessment of the nature and scale of employment associated with the fishery.

There are currently 289 fishing businesses in NSW that hold one or more endorsements to fish in the Estuary Prawn Trawl Fishery, comprising approximately 302 individual licensed fishers. Including the number of people who assist in the operation of fishing businesses with entitlements in the Estuary Prawn Trawl Fishery (both directly and indirectly), there are between 257 and 474 persons employed in association with the Estuary Prawn Trawl Fishery. This does not include people employed in subsidiary industries such as fish processing, transport or the retail sector. The estuary prawn trawling community tends to focus around the Clarence River, Hunter River, Hawkesbury River, and Port Jackson, where trawling is permitted and a significant number of fishers reside in communities adjacent to these estuaries.

While the total employment estimate shows a significant number of people who are involved in the fishery, fishers operating in NSW generally operate in a number of different fisheries. Apart from the Hawkesbury River, the Estuary Prawn Trawl Fishery is a seasonal fishery and fishers rely only partly upon it to make their annual income. About 29% of endorsement holders in the Estuary Prawn Trawl Fishery also operate in other fisheries, whilst 22% of Estuary Prawn Trawl fishers responding to a social survey (see Chapter G) worked in other industries. Chapter G and associated appendices document the relative activity of entitlement holders in the Estuary Prawn Trawl Fishery. The precision of the estimates of parameters in some cases is reduced by the low level of response to some questions by survey participants.

It is not known how fishers would change their business structure if the Estuary Prawn Trawl Fishery ceased to operate. It is reasonable to expect however, that Estuary Prawn Trawl fishers with endorsements to fish in other fisheries would put more fishing effort into these other fisheries to compensate from their lost income. This may increase the risk of conflict between fishers as they compete for a share of the stocks and may result in the need to implement additional effort controls in the other fisheries.

It is also reasonable to expect that a number of people would have to find alternative employment. It is estimated that this would be between 36 and 48 fishers, though a considerable number of the fishers are of retirement age. A social survey found that 67% of estuary prawn trawl fishers responding to the survey believe they would be unable to gain employment outside of fishing, and 83% of these people have stated that they would not consider retraining (refer to Chapter G).

b) Supply of seafood to the community

Catches in the Estuary Prawn Trawl Fishery vary significantly year to year in correlation with rainfall and river discharge. The fishery produces a large quantity of high quality product consisting mainly of school and eastern king prawns and squid (approximately 500 tonnes in the 98/99 season). Most of the product taken is used for local (NSW) consumption or for use as bait with very little being exported. The supply of shellfish and finfish to local markets by commercial fishers satisfies demand from consumers who do not wish to, or are unable to, venture out and catch the fish themselves. There is also a strong demand for bait by the commercial and recreational fishing sectors. Whilst some of this demand may be met by the probable increased share of the resource by especially the Estuary General Fishery, an Estuary General Fishery for prawns does not operate in all estuaries of the Estuary Prawn Trawl Fishery.

A survey of the importance of local seafood to the catering and tourism industries in NSW has shown that 40% of businesses felt it was important to offer NSW caught seafood to visitors. Fifty percent of businesses promote the local product (Ruello, 1996). A repeat survey four years later has indicated that this trend has continued to increase and the importance of fresh local seafood to both consumers and businesses has increased (Ruello & Associates Pty Ltd, 2000). This trend is also found in North Queensland where 78% of restaurateurs said customers expect local seafood on the menu (JCU, 1993).

The importance of commercial fishing to local communities is often overlooked. Annual per capita fish and seafood consumption (from all sources) in Sydney increased between 1991 and 1999 from 13.5 kg to 15.1 kg edible weight, an increase of 12.7%. In-home consumption rose by 8.4% while the increase in out-of-home consumption was much greater at 19.0% (Ruello & Associates Pty Ltd, 2000).

The Estuary Prawn Trawl Fishery supplies local markets with moderately priced prawns for human consumption and, prawns and bottle squid for the bait market. A high value market for broad squid has developed for Hawkesbury River fishers who marketed approximately 45 tonnes of product from this fishery in the 98/99 season. Fishers working in the Port Jackson fishery have developed a small but lucrative market supplying live prawns to restaurants within the Sydney metropolitan area. A viable Estuary Prawn Trawl Fishery will continue to satisfy the high community demand for seafood.

c) Economic benefits

The average value of the catch from the Estuary Prawn Trawl Fishery is very difficult to estimate due to its' variable nature with catches linked to rainfall and river discharge (see Appendix B6). In the 1998/99 season the fishery was estimated to have a total revenue at time of first sale of approximately $4 million (see section 1 of Chapter G for an explanation of the basis for this figure). The results of the economic survey done as part of this EIS (see Chapter G) found that 10% of businesses surveyed which had a long run economic surplus contributed to Gross Domestic Product. All businesses contributed to the local economy through the purchase on inputs and factors of production. This revenue for the fishery provides an important source of employment for fishers and has multiplier effects in regional communities. Economic multipliers in the fishing industry are, however, low and total effects are generally between 1.5 and 2 times the direct effect (Tamblyn and Powell, 1988; Powell *et al*., 1989).

The economic survey done during the preparation of this EIS, and other studies undertaken on the expenditure of fishers in NSW (see McVerry, 1996), have shown that 27% of expenditure from fishing businesses moves outside the region of operation. Approximately 70% of the first sale value of the catch stays within the communities where fishing takes place. This translates to approximately $3 million of fishing revenue generated from the Estuary Prawn Trawl Fishery that is potentially spent in the local regions.

2. Sensitivity Analysis

Based on the discussion and logic presented in Chapter D in relation to alternative management strategies, it is apparent that there are few high level feasible and economically viable or appropriate alternatives to the suite of controls proposed in the draft FMS. Therefore, the sensitivity analysis focuses on the 84 proposed management responses in section 4 of Chapter C.

The alternative management regimes discussed in Chapter D to address each of the key management issues typically involves using one or more of the responses already proposed in the draft FMS, but to a much greater (or lesser) extent relative to other controls. Consequently, the sensitivities of most of the alternative management regimes are covered in the sensitivity analysis carried out with respect to the management regime proposed in the draft FMS. There are a few exceptions to this and they are discussed at the end of this section.

In each case, a qualitative sensitivity analysis has been done as insufficient quantitative data exists for all three components of ecologically sustainable development (ESD): biological, economic costs and benefits, and social (see Table I1). A qualitative analysis has been undertaken as proposed in the guidelines set out by Planning NSW (previously known as the Department of Urban Affairs and Planning or DUAP) for environmental assessment of commercial fisheries (DUAP, 2001).

In this analysis, the qualitative sensitivity is the relationship between the degree of change in the management responses (the variable) versus the likelihood of achieving the FMS goals (the desired outcome) within an ESD framework. In this context, each of the management responses have been assessed in terms of their likelihood in achieving the following target:

> *The proposed harvest strategy in the Estuary Prawn Trawl FMS aims to manage the fishery in a way that maintains sustainable shellfish and finfish stocks and a healthy ecosystem, while maximising the biological and economic yield and appropriately sharing the resource.*

In this sensitivity analysis, the linkages between goals and responses which are presented in the draft FMS (in section 4 of Chapter C) have been incorporated as the cross reference between a specific management response for a goal and the other seven goals. That is, in the analysis, goals 1, 2, 3, 7 and 8 relate to biological considerations, goals 5, 6 and 8 relate to economic factors and goals 4, 6 7 and 8 relate to social factors.

A common mistake in interpreting the analysis in Table I1 is to confuse 'sensitivity' with the 'impact' of the management response on the biophysical, economic and social environment. The clearest way to interpret the table is to remember: "if a little change in the management response causes a big change in the likelihood of achieving the above target, then the sensitivity is high. If a little change in the management response causes only a little change in achieving the target, then the sensitivity is low."

Table I1. Qualitative sensitivity analysis of the proposed FMS management responses.

(H = high sensitivity, M = medium sensitivity, L = low sensitivity, ? = unknown sensitivity, - = not applicable.

Note: * The management responses outlined here have been abbreviated for the purpose of completing the table. Please refer to section 4 of Chapter C for the complete wording of each response.

Management Response		Biological	Economic	Social
1.1a	Continue the restrictions on the use of fishing gear within the Fisheries Management Act 1994	M	L	L
1.1b	Modify fishing practices to reduce impact upon organisms other than primary species	H	-	H
1.1c	Develop alternate gears to minimise capture of target and byproduct species of unwanted quality	H	M	M
1.1d	Ban the riddling of cooked prawns and investigate banning the riddling of green prawns	M	L	L
1.1e	Best practice techniques for handling non retained organisms (ban spikes)	M	-	H
1.1f	Closures to control area and time	H	H	H
1.1g	Continue the probition on the use of firearms, explosives and electrical devices	M	-	H
1.2a	Map areas of environmental sensitivity	M	-	M
1.2b	No increase in the trawlable area within the boundaries within each estuary	H	-	H
1.2c	Continue the prohibition on wilfully damaging marine vegetation	H	-	M
1.2d	Prohibit the removal of woody debris	M	-	L
1.2e	Develop a code of conduct	L	-	M
1.3a	Implement incidental catch ratios	H	-	H
1.3b	Develop a research strategy to assess the impact of fishing upon the general environment	L	L	M
1.3c	Collaborate with other institutions on ecosystems	M	L	M
1.3d	Develop a performance indicator to measure the impact of trawling upon biodiversity	L	L	M
1.3e	Develop a research strategy to assess the impact of trawling upon biodiversity	L	L	M
1.3f	MAC to be consulted on marine protected areas	M	-	L
1.4a	Implement in consultation with MAC any NSW marine pest management plans	H	H	M
2.1a	Maintain the dimensions of the fishing gear permitted to be used in the Estuary Prawn Trawl Fishery	M	L	L
2.1b	Monitor quanity, length, age, and/or sex composition of commercial landings	M	L	L
2.1c	Review status of squid stocks	H	M	M
2.1d	Promote research that contributes to more robust stock assessments	M	L	M
2.1e	Implement maximum counts on prawns taken for sale	H	H	H
2.1f	Review maximum counts on prawns for sale in light of new information	M	L	L
2.1g	Ascertain the need for a legal minimum length on squid	M	L	L
2.1h	Encourage complementary counts and sizes in other fisheries	M	L	M
2.1i	Develop stock assessments for target species	H	M	M

Table I1 cont.

	Management Response	Biological	Economic	Social
2.2a	Encourage other prawn harvest sectors to adopt appropriate levels of fishing effort on spawing stocks	L	L	M
2.3a	Implement separate management rules for each estuary	M	-	H
2.3b	Require the Total Allowable Catch Committee to determine the total allowable effort	H	H	H
2.3c	Implement minimum shareholdings to control effort	H	H	H
2.3d	Continue current licensing arrangements	H	M	M
2.3e	Restrict engine power in Port Jackson	M	L	L
2.4a	Implement an owner-operator rule	M	H	L
2.4b	Establish minimum shareholdings for entrants at the fishing business level	H	H	H
2.5a	NSW Fisheries will aim to minimise impacts on fishery resources from developments	M	L	M
2.5b	EPT MAC will bring impacts detrimental to the fishery to the attention of NSW Fisheries	L	M	M
2.5c	EPT MAC contributes to NSW Fisheries reviews of habitat management	L	L	M
2.5d	EPT MAC contribute to the policy or legislation of other agencies to ensure fish and habitat are considered	M	L	M
2.6a	If a major harvester of an overfished species, implement a recovery program within specified timeframes	H	M	H
2.6b	If a minor harvester of an overfished species, contribute to recovery programs and adopt measures as required	H	M	M
2.6c	Implement precautionary approach whilst recovery program is developed	H	H	M
3.1a	Modify catch returns to monitor threatened species interactions	H	L	M
3.1b	Implement provisions of relevent threatened species recovery plans and threat abatement plans	H	L	H
3.1c	Continue the prohibition on protected fish	H	-	H
3.1d	Continue the prohibition on taking spp. protected under other jurisdictions	H	-	H
4.1a	Assess the size of the non-commercial catch	H	L	H
4.2a	Monitor catches of target species by other fisheries outside NSW jurisdiction	L	L	M
4.2b	Monitor catches of target species by other fisheries in NSW	L	L	M
4.2c	Limit the quantities of annual reported landings of byproduct species	M	-	H
4.2d	Use the Prawn Resource Forum to discuss cross-fishery management issues	L	L	H
4.3a	Participate in Indigenous Fisheries Strategy and adjust management	-	L	H
4.3b	Respond to new information on areas of cultural significance	L	L	M
4.4a	Investigate closing estuaries on weekends and public holidays	L	H	H
5.1a	Determine appropriate size at first capture of king and school prawns	L	L	-
5.1b	Implement maximum counts for school and king prawns at the codend	H	H	-

Table I1 cont.

	Management Response	Biological	Economic	Social
5.2a	NSW Fisheries to develop a performance indicator to measure economic viability at the fishery business level	-	M	H
5.2b	NSW Fisheries to develop a cost recovery framework	-	M	L
5.3a	Implement share management provisions of the FMA	-	H	H
5.3b	Prohibit any one shareholder from owning more than 5% of the total number of shares	-	H	H
5.4a	Co-operate with Safefood Production NSW-food safety programs	-	H	H
5.4b	Continue the prohibition on the processing or mutilation of fish	L	L	-
6.1a	Implement compliance audit scheme and operational plans	L	M	H
6.1b	Implement endorsement suspension and share forfeiture scheme	L	H	H
6.1c	Publish successful prosecutions for nominated offences	L	L	H
6.1d	Continue the requirement that fish taken in this fishery are marketed through a Registered Fish Receiver or a Restrcited Registered Fish Receiver	L	M	L
6.2a	Continue using conditions on licences to ensure authority is consistent with the FMS	M	L	L
6.2b	Continue the requirement that fishers comply with directives from Fisheries Officers	-	L	L
6.3a	Use EPT MAC as the primary consultative body	-	L	M
6.3b	Continue to utilise an independent chair in the MAC	-	L	M
6.4a	Manage consistently with other jurisdictional or resource management requirements	M	M	M
7.1a	Make the FMS and EIS widely available to the public	L	L	M
7.1b	Produce brochures, newsletters, signs, education programs etc for fishery	M	L	H
7.1c	Respond to inquiries from industry and the public	L	L	H
7.2a	Publish educational info on protection of fish habitat	M	L	H
8.1a	Develop an industry funded scientific observer-based survey program	H	L	L
8.1b	Develop industry funded fishery independent surveys	H	L	L
8.1c	Issue section 37 permits for research and other purposes	M	-	M
8.1d	Determine research priorities	M	M	L
8.1e	Allocate research resources according to priorities and seek additional	M	M	L
8.2a	Periodically review catch and effort recording	H	L	M
8.2b	Determine the accuracy of current recording of species ID	H	L	L
8.3a	Implement a "basic skills" course	L	L	M

There are seven management responses in Table I1 that show high sensitivity to all three facets of ESD. These proposals include two management responses to do with fishing closures, two that deal with sizes at first capture, two that deal with the application of minimum shareholdings for access to fishing and one that deals with the determination of fishing effort through the Total Allowable Catch Setting and Review Committee. The sizes at first capture address the issue of sharing resources and economic yield whilst at the same time being mindful of stock sustainability. The closures relate to the general application of fishing closures as needed, the use of closures to protect areas of key habitat, target and incidental species, avoid interactions with threatened species, populations or ecological communities, to equitably share the resources between stakeholders and to create harmony amongst stakeholders and the community.

The sensitivity analysis indicates that fishing closures are a very effective tool for achieving the biological, economic and socially orientated goals in the FMS, as are the direct application of minimum shareholdings and the use of an independent body such as the Total Allowable Catch Setting and Review Committee to control fishing effort.

There are several management responses that have a high sensitivity with respect to two facets of ESD, indicating that they are an important part of the overall proposed harvesting strategy. These include:

- modifying fishing practices to reduce impact upon species other than target species (1.1b)
- providing for no increase in trawlable area (1.2b)
- implementing incidental catch ratios (1.3a)
- implementing measures required under any marine pest or disease management plan (1.4a)
- implementing precautionary actions during the development of a recovery program for a overfished species (2.6c)
- implementing the provisions of any threatened species recovery plans or threat abatement plans (3.1b)
- continuing the prohibition on the taking of protected shellfish or finfish, or shellfish or finfish protected from commercial fishing (3.1c)
- continue the prohibition of taking any species in commercial fishing operations protected under other jurisdiction's arrangements (3.1d)
- assessing the size of the non-commercial catch (4.1a)
- investigating closing estuaries to trawling on weekends and public holidays (4.4a)
- implementing maximum counts for school and eastern king prawns (5.1b)
- implementing the share management provisions of the *Fisheries Management Act 1994* (5.3a)
- prohibiting any one shareholder from owning more than 5% of the total number of shares (5.3b)
- implementing an endorsement suspension and share forfeiture scheme based upon demerit points (6.1b).

These programs, along with the use of fishing closures, minimum shareholdings, sizes at first capture and the use of the Total Allowable Catch Setting and Review Committee address each of the key high risk areas that were identified in early iterations of this EIS, namely:

- protection and enhancement of key habitat
- ensuring stock sustainability
- reduction of the incidental catch
- minimising the multi-species character of the fishery
- latent effort activation and major effort shift
- effects of trawling
- resource allocation
- impacts on threatened and protected species
- conflict with recreational fishers and with the community

- information needs and research

a) Sensitivity of major alternative management approaches

The sensitivity of the aspects of the alternative management approaches discussed in Chapter D but not covered in Table I1 are presented in Table I2 below.

Table I2. Qualitative sensitivity analysis of the alternate management controls not already covered in the sensitivity analysis of the draft FMS proposals

(H = high sensitivity, M = medium sensitivity, L = low sensitivity, ? = unknown sensitivity.

Alternative Management Control	Biological	Economic	Social
Introduce a total allowable catch	H	H	M
Prohibit trawling and use passive gears	H	H	H
Provide alternative habitats-"mitigation banking"	M	M	M
Provide stronger reliance on fishery-dependent catch data for stock assessment	M	M	L
Incorporate the Estuary Prawn Trawl Fishery into the Ocean Prawn Trawl Fishery or the Estuary General Fishery	L	L	M

The analysis in Table I2 shows that introducing a Total Allowable Catch and using only passive fishing gears to catch prawns had a high sensitivity with respect to two of the three facets of ESD, and would be quite powerful management controls for the Estuary Prawn Trawl Fishery. These are not considered appropriate management responses at this stage for the reasons outlined in Chapter D. Providing alternative habitats had medium sensitivity across the three facets of ESD whilst a stronger reliance upon fishery dependent data had medium sensitivity across two of the facets. These sensitivity analyses would suggest these alternatives are not as useful in the Estuary Prawn Trawl Fishery as closures and fishery independent data.

3. Justification of Measures in Terms of ESD Principles

The impact of the Estuary Prawn Trawl Fishery upon the carrying capacity of the estuarine environment is assessed in the EIS by an analysis of the risks associated with the proposed harvest strategy outlined in section 6 of Chapter C. The risks associated with the draft FMS are partitioned into two components related primarily to (1) the retained species and (2) the ecological impacts of the harvest methods used in this multi-species but single method fishery on incidental catch, threatened and protected species, habitat damage and other associated activities. The estimated risk of over exploitation at the species level is fully detailed in Chapter E of the EIS.

The Estuary Prawn Trawl Fishery is primarily managed by using temporal and spatial fishing closures and controls on gear use which have been adopted on a precautionary basis to provide an "insurance policy" against overexploitation. The estimated impact of the Estuary Prawn Trawl Fishery on incidental catch, threatened and protected species and habitat is fully reviewed and discussed in Chapter E section 2 and Chapter F sections 1 to 9 of this EIS.

The draft FMS objectives and management responses are presented in section 4 of Chapter C. It directly addresses these levels of risk to the ecosystem through Objectives:

1.1 To minimise the impact of fishing activities on non-retained shellfish and finfish (including prohibited size, unwanted fish protected from commercial fishing)

1.2 To minimise the impact of activities in the fishery on marine and estuarine habitat

1.3 To reduce the likelihood of species, populations and ecological communities from being changed in a manner which threatens ecosystem integrity (i.e. composition and function)

1.4 To prevent the introduction and translocation of marine pests and diseases

2.1 To maintain the stocks of target and byproduct species of the Estuary Prawn Trawl Fishery at or above a level that minimises the risk of overfishing

3.1 To minimise any impacts of fishing activities in the fishery on threatened species, populations and ecological communities (including mammals, birds, reptiles, amphibians, shellfish and finfish, and vegetation), and where possible promote their recovery

8.1 To promote appropriate scientific research and monitoring to collect information about target, byproduct and bycatch species.

The preferred rules in the draft FMS which provide for an appropriate allocation of the resource and incorporate the measures necessary to achieve resource sustainability, address the principles of ESD in the following ways:

a) Precautionary principle

The precautionary principle is defined in the May 1992 *Intergovernmental Agreement on the Environment* as "where there are threats of serious or irreversible environmental damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation" (Deville and Harding, 1997). The introduction of the precautionary principle has, as described by Deville and Harding (1997), shifted the 'onus of proof' regarding impacts away from regulatory bodies and more towards those whose actions may cause damage. Those undertaking the activity are required to provide a convincing argument that their actions will not have serious or irreversible impacts on the environment exceeding long-term benefits.

As recognised in the assessment guidelines under which this EIS was prepared, scientific research into the size and characteristics of shellfish and finfish stocks is inherently complex and costly. Shellfish and finfish populations and the aquatic environment inhabited by them are extremely dynamic. This means that the level of scientific uncertainty associated with shellfish and finfish stocks and aquatic communities is generally very high, especially for species that are of low commercial or recreational value. This situation is by no means unique to NSW or indeed Australian fisheries.

Many of the management rules that have historically operated in the Estuary Prawn Trawl Fishery, have been adopted on a precautionary basis to provide an 'insurance policy' against over exploitation. The measures proposed in the draft FMS embrace this approach by continuing the existing controls on fishing and by proposing new initiatives to deal with the uncertainty surrounding the impact of trawling on target species, incidental species and habitat. Maintaining gear dimensions as they currently are, encouraging research into improving BRDs and developing a suitable net for the Hawkesbury River squid fishery are positive precautionary steps that will minimise the impacts (known and presumed) of these gear types on the environment. Additionally, the proposed research programs investigating the impacts of fishing gear on habitats and bycatch reduction, pro-actively address the information deficiencies in those areas.

The performance monitoring system established by the proposed FMS also provides a necessary safeguard in case there are changes in the operation of the fishery or shellfish and finfish stocks which could compromise the long term sustainability of the fishery.

b) Intragenerational equity

Intragenerational equity relates to distributing the costs and benefits of pursuing ESD strategies as evenly as practicable within each generation.

Intragenerational equity in the context of the Estuary Prawn Trawl Fishery is complex, due to the multi-species, nature of the fishery but also because many of the species retained by the fishery are taken in other commercial fisheries or by other sector groups, such as the recreational fishery. As well as the question of allocation of shellfish and finfish stocks, there are issues relating to the allocation and management of often conflicting user activities (i.e. commercial fishing, charter boat/recreational fishing, boating, swimming, etc).

The FMS contains proposals to assess the size of the non-commercial catch so that the distribution of the resource is known, and performance measures are in place to monitor and manage the distribution of catches of the retained species over time.

The proposed measures in the draft FMS distribute, as far as practicable, a fair and equitable sharing of the fisheries resource amongst fishers and the community. The operation of the fishery provides fresh local seafood to satisfy an ever increasing consumer demand for seafood. Fishing closures are used extensively to share the resource between users by specifying times or places when and where estuary trawling can occur (e.g. many areas of the five estuaries where fishers in this fishery work are subject to fishing closures either permanently or seasonally).

The closures that are proposed in the draft FMS promote equity of access to the physical environment used by estuary prawn trawling fishers and others in the community.

c) Intergenerational equity

Intergenerational equity relates to the present generation ensuring that the health, diversity and productivity of the environment are maintained or enhanced for the benefit of future generations.

In the context of the Estuary Prawn Trawl Fishery, intergenerational equity consists of ensuring that the fishery operates in a manner that minimises the impact of gear use on habitat, bycatch and threatened species, populations and ecological communities, as well as maintaining stocks of byproduct and target species at viable levels.

The draft FMS contains eight broad goals which, if realised, will provide future generations with the same or improved opportunities to benefit from the valuable natural resources. Management measures proposed within the draft FMS to achieve the specified goals and hence intergenerational equity include:

- implementation of more secure fishing rights to promote resource stewardship
- modification of fishing gear and the manner in which the gear is used to minimise any impacts on the general environment (including bycatch and habitat)
- continued use of fishing closures
- incidental catch ratios
- introduction of new compliance and advisory programs to deter illegal activity and educate the broader community
- a comprehensive performance monitoring and review program, the results of which will be publicly available.

Furthermore, future generations will benefit from the data collected through the monitoring programs and future research proposed by the draft FMS. There will also be substantial benefits to future generations from the declaration of a comprehensive, adequate and representative system of marine protected areas (such as marine parks, aquatic reserves and intertidal protected areas) that includes a full range of marine biodiversity at ecosystem, habitat and species levels (Marine Parks Authority, 2000).

d) Conservation of biodiversity and ecological integrity

This principle incorporates the notion that conservation of biological diversity and ecological integrity should be a fundamental consideration in resource decision making. The draft FMS strongly adopts this principle, with one of the eight major goals being "to manage the Estuary Prawn Trawl Fishery in a manner that promotes the conservation of biological diversity in the estuarine environment". There are four objectives beneath that goal which specifically aim to address the following issues:

- minimising the impact of the fishery on incidental species
- minimising the impact of the fishery on marine and estuarine habitat
- reducing the likelihood of the fishery changing species, populations and ecological communities in a manner that threatens ecosystem integrity (i.e. composition and function)
- preventing the introduction and translocation of marine pests and diseases.

In order to achieve those goals and objectives, there are 11 management responses in the draft FMS that directly address biodiversity and ecological integrity issues, including modifying the gear permitted in the fishery and the use of gear, establishing a scientific observer program to record actual levels of bycatch and interactions with threatened species, using best practice techniques for handling non retained animals, using fishing closures to protect areas of key habitat, continue the prohibition on wilfully damaging marine vegetation, undertaking monitoring and research on ecosystem functioning, and marine pest and disease management.

The draft FMS also contains proposals which attempt to monitor the impact of the fishery on biodiversity including developing a research project to target this, assessing; species composition in areas where trawling is permitted, levels of incidental catch, trophic levels of the commercial catch, and has mechanisms for taking action if the performance changes to a significant degree.

In conclusion, the proposed FMS contains a comprehensive package of measures for ensuring that the impacts of estuary prawn trawling on biodiversity are properly managed.

e) Improved valuation, pricing and incentive mechanisms

This principle relates to the use of schemes like user pays and incentive structures to promote efficiency in achieving environmental goals. The Estuary Prawn Trawl Fishery, along with most other marine commercial fisheries in NSW, was proclaimed a category 2 share management fishery on 23 March 2001. This management framework provides for the issue of long term (15 year) shares to eligible fishers and provides for the existence of a market based trading scheme. The share management scheme for the Estuary Prawn Trawl Fishery will provide greater incentives for stewardship and long term sustainability of the resource because the value of shares when traded are likely to be linked to investor's views about the health of the fishery and the anticipated returns on investment.

The share management regime also provides greater flexibility for shareholders in the fishery to be able to trade shares with each other. This will enable fishers to change the structure of their fishing businesses more efficiently. It enables fishers to sell shares in the fisheries (or parts of fisheries) that they do not rely on in order to purchase shares in the fisheries (or parts of fisheries) that are important to their fishing businesses.

The share management scheme incorporates the notion of a user pays system as there is a $100 annual rental charge payable by each shareholder additional to the normal licensing and management fees, and the current Government policy is to phase in full cost recovery in the fishery between the years 2005 and 2008.

CHAPTER J. REFERENCES

Articles that have not been externally peer reviewed are denoted *

*Adam, P., Urwin, N., Weiner, P. and Sim, I. (1985). Coastal Wetlands of New South Wales. A survey and report prepared for the Coastal Council of New South Wales.

Adam, P., Wilson, N.C. and Huntley, B. (1988). The phytosociology of coastal saltmarsh vegetation in New South Wales. *Wetlands (Australia)* **7(2)**, 35-85.

*AFFA (1999). AQUAPLAN – Australia's National Strategic Plan for Aquatic Animal Health 1998-2003. Agriculture, Forestry, Fisheries, Australia, Canberra ACT. 72 pp.

*AFFA (2000). Report of the National Taskforce on the Prevention and Management of Marine Pest Incursions. Environment Australia/Agriculture, Forestry, Fisheries, Australia, Canberra ACT. 231 pp.

Alabaster, J.S. and Lloyd, R. (1980). *Water Quality Criteria for Freshwater Fish.* Butterworths, London. 297 pp.

Allen, G.R. (1989). *Freshwater Fishes of Australia.* Tropical Fish Hobbyist Publications. 240 pp.

*Allen, J., Harris, J. and McEnally, J. (1992a). Coastal Resource Atlas for Oil Spills from Point Danger to the Clarence River. Environmental Protection Authority, Sydney. 107 pp.

*Allen, J., Harris, J., McEnally, J. and Zekanovic, I. (1992b). Coastal Resource Atlas for Oil Spills in Broken Bay, Pittwater and the Hawkesbury River. Environmental Protection Authority, Sydney. 58 pp.

Alverson, D.L., Freeberg, M.H., Murawski, S.A. and Pope, J.G. (1994). *A Global Assessment of Fisheries Bycatch and Discards*. FAO Fisheries Technical Paper, No. 339. 233 pp.

Andrew, N.L. and Pepperell, J.G. (1992). The by-catch of shrimp trawl fisheries. *Oceanography and Marine Biology Annual Review* **30**, 527-565.

*Anon. (1981). Amateur Angling in Botany Bay. Botany Bay Study No. 24. SPCC and NSW State Fisheries.

*Anon. (2000). National Strategy for the Management of Coastal Acid Sulfate Soils. NSW Agriculture Wollongbar Agriculture Institute Bruxner Highway, Wollongbar, NSW, Australia. 39 pp.

*Anon (2001). Management Rules for the Clarence River Estuary Prawn Trawl Fishery. Unpublished Document.

*ANZECC (1998). Interim Marine and Coastal Regionalisation for Australia: an Ecosystem Based Classification for Marine and Coastal Environments. Version 3.3, IMCRA Technical Group, Environment Australia, Canberra. 80 pp.

*ANZECC (1999). Strategic Plan of Action for the National Representative System of Marine Protected Areas: a Guide for Action by Australian Governments. Environment Australia, Canberra. 80 pp.

*Astles, K.L., Winstanley, R.K., Harris, J.H. and Gehrke, P.C. (2000). Regulated Rivers and Fisheries Restoration Project – Part 1: Experimental Study of the Effects of Cold Water Pollution on Native Fish. Unpublished Report, Project No. SW 1. NSW Fisheries Office of Conservation and CRC for Freshwater Ecology, Taylors Beach NSW. 51 pp.

*Australian Bureau of Meterology (2002). Main Climatic Zones of Australia. Bureau of Meterology, Australia. {http://www.bom.gov.au/climate/environ/travel/map.shtml}.

*Australian Greenhouse Office (AGO) (2001). Factors and Methodologies, the Greenhouse Challenge. Commonwealth of Australia, Canberra.

*Bannister, J.L., Kemper, C.M. and Warneke, R.M. (1996). The Action Plan for Australian Cetaceans. Australian Nature Conservation Agency.

*Bell, F.C. and Edwards, A.R. (1980). An Environmental Inventory of Estuaries and Coastal Lagoons in New South Wales. Total Environment Centre, Sydney. 187 pp.

Bell, J.D. and Pollard, D.A. (1989). Ecology of fish assemblages and fisheries associated with seagrasses. **In**: *Biology of Seagrasses* (eds. Larkum, A.W.D., McComb, A.J. and Shepherd, S.A.) pp. 565-609. Elsevier, Amsterdam.

Bell, J.D., Pollard, D.A., Burchmore, J.J., Pease, B.C., and Middleton, M.J. (1984). Structure of a fish community in a temperate tidal mangrove creek in Botany Bay, New South Wales. *Australian Journal of Marine and Freshwater Research* **35(1)**, 33-46.

Bell, J.D., Steffe, A.S. and Westoby, M. (1988). Location of seagrass beds in estuaries: effect on associated fish and decapods. *Journal of Experimental Marine Biology and Ecology* **122**, 127-146.

Birch, G.F. (1996). Sediment-bound metallic contaminants in Sydney's estuaries and adjacent offshore, Australia. *Estuarine, Coastal and Shelf Science* **42**, 31-44.

Birch, G.F., Evenden, D. and Teutsch, M.E. (1996). Dominance of point source in heavy metal distributions in sediments of a major Sydney estuary (Australia). *Environmental Geology* **28(4)**, 169-174.

Birch, G.F., Ingleton, T. and Taylor, S. (1997). Environmental implications of dredging in the world's second largest coal exporting harbour, Port Hunter, Australia. *Journal of Marine Environmental Engineering* **4**, 133-145.

Birch, G.F., Shotter, N. and Steetsel, P. (in press). The environmental status of Hawkesbury River sediments. *Australian Geographical Studies.*

Blaber, S.J.M. and Blaber, T.G. (1980). Factors affecting the distribution of juvenile estuarine and inshore fish. *Journal of Fish Biology* **17**, 143-162.

Blaber, S.J.M. and Wassenberg, T.J. (1989). Feeding ecology of the piscivorous birds *Phalacrocorax varius*, *P. melanoleucos* and *Sterna bergii* in Moreton Bay, Australia: diets and dependence on trawler discards. *Marine Biology* **101(1)**, 1-10.

Blaber, S.J.M., Brewer, D.T., Salini, J.P. and Kerr, J. (1990). Biomasses, catch rates and abundances of demersal fishes, particularly predators of prawns, in a tropical bay in the Gulf of Carpentaria, Australia. *Marine Biology* **107(3)**, 397-408.

Blaber, S.J.M., Milton, D.A., Smith, G.C., and Farmer, M.J. (1995). Trawl discards in the diets of tropical seabirds of the northern Great Barrier Reef, Australia. *Marine Ecology Progress Series* **127**, 1-13.

Borowitzka, M.A.B. and Lethebridge, R.L. (1989). Seagrass epiphytes. **In**: *Biology of Seagrasses* (eds. Larkum, A.W.D., McComb, A.J. and Shepherd, S.A.). pp. 458-499. Elsevier, Amsterdam.

Brewer, D.T., Blaber, S.J.M. and Salini, J.P. (1991). Predation on penaeid prawns by fishes in Albatross Bay, Gulf of Carpentaria. *Marine Biology* **109**, 231-240.

Brewer, D.T., Blaber, S.J.M., Salini, J.P. and Farmer, M.J. (1995). Feeding ecology of predatory fishes from Groote Eylandt in the Gulf of Carpentaria, Australia, with special reference to predation on penaeid prawns. *Estuarine, Coastal and Shelf Science* **40(5)**, 577-600.

*Brewer, D.T., Eayrs, S.J., Rawlinson, N.J.F., Salini, J.P., Farmer, M., Blaber, S.J.M., Ramm, D.C., Cartwright, I. and Poiner, I. (1997). Recent advances in environmentally friendly trawl gear research in Australia. **In**: *Developing and Sustaining World Fisheries Resources: The State of Science and Management.* (eds. Hancock, D.A., Smith, D.C., Grant, A. and Beumer, J.P.). pp. 537-543. 2nd World Fisheries Congress proceedings, 1996 Brisbane, Qld. CSIRO Australia.

Broadhurst, M.K. (1998). Bottlenose dolphins, *Tursiops truncatus,* removing by-catch from prawn-trawl codends during fishing in New South Wales, Australia. *Marine Fisheries Review* **60(3)**, 9-14.

Broadhurst, M.K. (2000). Modifications to reduce by-catch in prawn trawls: A review and framework for development. *Reviews in Fish Biology and Fisheries* **10**, 27-60.

Broadhurst, M.K. and Kennelly, S.J. (1994). Reducing the by-catch of juvenile fish (mulloway *Argyrosomus hololepidotus)* using square-mesh panels in codends in the Hawkesbury River prawn-trawl fishery, Australia. *Fisheries Research* **19**, 321-331.

Broadhurst, M.K. and Kennelly, S.J. (1995). A trouser-trawl experiment to assess codends that exclude juvenile mulloway *(Argyrosomus hololepidotus)* in the Hawkesbury River prawn-trawl fishery. *Marine and Freshwater Research* **46**, 953-958.

Broadhurst, M. K. and Kennelly, S. J. (1996). Rigid and flexible separator panels in trawls that reduce the by-catch of the small fish in the Clarence River prawn-trawl fishery, Australia. *Marine and Freshwater Research* **47**, 991-998.

Broadhurst, M.K., Kennelly, S.J. and Isaken, B. (1996). Assessments of modified codends that reduce the by-catch of fish in two estuarine prawn-trawl fisheries in New South Wales, Australia. *Fisheries Research* **27**, 89-111.

Broadhurst, M.K., Kennelly, S.J., Watson, J.W. and Workman, I.K. (1997). Evaluations of the Nordmore grid and secondary bycatch-reducing devices (BRD's) in the Hunter River prawn-trawl fishery, Australia. *Fishery Bulletin* **95(2)**, 209-218.

Broadhurst, M.K., Barker, D.T. and Kennelly, S.J. (1999). Scale-loss and survival of juvenile yellowfin bream, *Acanthopagrus australis*, after simulated escape from a Nordmore-grid guiding panel and release from capture by hook and line. *Bulletin of Marine Science* **64(2)**, 255-268.

Bucher, D. and Saenger, P. (1991). An inventory of Australian estuaries and enclosed marine waters: an overview of results. *Australian Geographical Studies* **29(2)**, 370-381.

Burchmore, J.J., Pollard, D.A, Bell, J.D., Middleton, M.J., Pease, B.C. and Matthews, J. (1985). An ecological comparison of artificial and natural rocky reef fish communities in Botany Bay, New South Wales, Australia. *Bulletin of Marine Science* **37(1)**, 70-85.

*Bureau of Resource Science (2000). Aquatic Pests and Diseases. Bureau of Rural Sciences, Agriculture, Forestry and Fisheries, Australia, {http://www.brs.gov.au:80/fish/status99/aquatic.html}. June 2000.

Butler, A. (1995). Subtidal rocky reefs. **In**: *Coastal Marine Ecology of Temperate Australia.* (eds. Underwood, A.J. and M.G. Chapman). pp. 83-105. UNSW Press.

Callinan, R.B., Fraser, G.C. and Virgona, J.L. (1989). Pathology of red spot disease in sea mullet, *Mugil cephalus* L. from eastern Australia. *Journal of Fish Diseases* **12** 467-479.

*Callinan, R.B., Fraser, G.C. and Melville, M.D. (1993). Seasonally recurrent fish mortalities and ulcerative disease outbreaks associated with acid sulphate soils in Australian estuaries. **In**: *Selected papers from the Ho Chi Minh City Symposium on acid sulphate soils* (eds. Dent, D.L. and van Mensvoort, M.E.F.) pp. 403-410. ILRI Publication. No. 53.

Callinan, R.B., Paclibare, J.O., Bondab-Reantaso, M.G., Chin, J.C. and Gogolewski, R.P. (1995a). *Aphanomyces* species associated with epizootic ulcerative syndrome (EUS) in the Philippines and red spot disease (RSD) in Australia: preliminary comparative studies. *Diseases of Aquatic Organisms* **21**, 233-238.

*Callinan, R.B., Paclibare, J.O., Reantaso, M.B., Lumanlan-Mayo, S.C., Fraser, G.C. and Sammut, J. (1995b). EUS outbreaks in estuarine fish in Australia and the Philippines: associations with acid sulphate soils, rainfall and *Aphanomyces*. **In**: *Diseases in Asian aquaculture II* (eds. Shariff, M.A., Arthur, J.R. and Subasinghe, R.P.) pp. 291-298. Asian Fisheries Society, Manilla.

*Cappo, M., Alongi, D.M., Williams, D.M. and Duke, N. (1998). A Review and Synthesis of Australian Fisheries Habitat Research. FRDC Project No. FRDC 95/055. Australian Institute of Marine Science, Townsville, Queensland. 3 Vol.

*Carrick, N. (1997). A Preliminary Assessment of the By-catch from the Spencer Gulf Prawn Fishery. South Australian Fisheries Assessment Series, 97/02. pp. 1-14.

*Carter, S. (1994). Coastal Resource Atlas for Oil Spills in Port Jackson. Environmental Protection Authority, Sydney. 39 pp.

*Carter, S. (1995). Coastal Resource Atlas for Oil Spills in Brisbane Waters. Environment Protection Authority, Sydney. 33 pp.

Castilla, J. C. (2000). Roles of experimental marine ecology in coastal management and conservation. *Journal of Experimental Marine Biology and Ecology* **250**, 3-21.

Chapman, M.G. and Underwood, A.J. (1995). Mangrove forests. **In**: *Coastal Marine Ecology of Temperate Australia*. (eds. Underwood, A.J. and Chapman, M.G.). pp. 187-204. UNSW Press.

*Chapman, M.G. and Blockley, D. (1999). Intertidal Assemblages on Seawalls at Berry Island and Blues Point Before and After the Oil Spill, August 1999. Uncommissioned Report for the NSW Environment Protection Authority.

Chopin, F.S. and Arimoto, T. (1995). The condition of fish escaping from fishing gears – a review. *Fisheries Research* **21**, 315-327.

*Christy, F. (2000). Common property rights: an alternative to ITQs. **In**: *Use of Property Rights in Fisheries Management* (ed. Shotton, R.) Proceedings of the Fishrights99 Conference. Fremantle, Western Australia, 11-19 November 1999. Mini-course lectures and core conference presentations. FAO Fisheries Technical Paper. No.404/1. Rome, FAO. 342 pp.

Churchill, J.H. (1989). The effect of commercial trawling on sediment resuspension and transport over the Middle Atlantic Bight continental shelf. *Continental Shelf Research* **9(9)**, 841-865.

Coleman, M.A. and Connell, S.D. (2001). Weak effects of epibiota on the abundances of fishes associated with pier pilings in Sydney Harbour. *Environmental Biology of Fishes* **61**, 231-239.

Coles, R.G. and Greenwood, J.G. (1983). Seasonal movement and size distribution of three commercially important Australian prawn species (Crustacea: Penaeidae) within an estuarine system. *Australian Journal of Marine and Freshwater Research* **34**, 727-743.

Collie, J.S., Escanero, G.A. and Valentine, P.C. (1997). Effects of bottom fishing on the benthic megafauna of Georges Bank. *Marine Ecology Progress Series* **155**, 159-172.

*Commonwealth (2000). Bycatch (Commonwealth policy and National policy). Department of Agriculture, Fisheries and Forestry – Australia.

Connell, S.D. and Glasby, T.M. (1999). Do urban structures influence local abundance and diversity of subtidal epibiota? A case study from Sydney Harbour, Australia. *Marine Environmental Research* **47**, 373-387.

Connolly, R.M. (1994). A comparison of fish assemblages from seagrass and unvegetated areas of a southern Australian estuary. *Australian Journal of Marine and Freshwater Research* **45**, 1033-1044.

Connolly, R.M., Dalton, A. and Bass, D.A. (1997). Fish use of an inundated saltmarsh flat in a temperate Australian estuary. *Australian Journal of Ecology* **22**, 222-226.

Courtney, A.J., Montgomery, S.S., Die, D.J., Andrew, N.L., Cosgrove, M.G. and Blount, C. (1995). Maturation in the female eastern king prawn *Penaeus plebejus* from coastal waters of eastern Australia, and considerations for quantifying egg production in penaeid prawns. *Marine Biology* **122**, 547-556.

*CRIMP (2000a). Vessel and Gear Fouling. CRIMP Infosheet 3, Centre for Research on Introduced Marine Pests, CSIRO, Hobart. 2 pp.

*CRIMP (2000b). Aquarium Caulerpa (*Caulerpa taxifolia*). CRIMP Infosheet 13, Centre for Research on Introduced Marine Pests, CSIRO, Hobart. 1 pp.

*CRIMP (2000c). Japanese Seaweed (*Undaria pinnatifida*). CRIMP Infosheet 12, Centre for Research on Introduced Marine Pests, CSIRO, Hobart. 1 pp.

*CRIMP (2000d). Northern Pacific Seastar (*Asterias amurensis*). CRIMP Infosheet 4, Centre for Research on Introduced Marine Pests, CSIRO, Hobart. 1 pp.

*CRIMP (2001a). Black-striped Mussel (*Mytilopsis sallei*). CRIMP Infosheet 10, Centre for Research on Introduced Marine Pests, CSIRO, Hobart. 1 pp.

*CRIMP (2001b). Broccoli Weed (*Codium fragile* ssp. *tomentosoides*). CRIMP Infosheet 14, Centre for Research on Introduced Marine Pests, CSIRO, Hobart. 1 pp.

Cryer, M., Whittles, G.N. and Williams, R. (1987). The impact of bait collection by anglers on marine invertebrates. *Biological Conservation* **42**, 83-93.

*CSIRO (1994). Jervis Bay Baseline Studies, Volume 2. CSIRO Division of Fisheries, Commonwealth of Australia. 406 pp.

*Currie, D.R. and Parry, G.D. (1995). The Effects of Scallop Dredging on a Soft Sediment Community: a Large-scale Experimental Study. Internal Report. July 1995. DCNR. pp. 1-25.

Dame, R., Alber, M., Allen, D., Mallin, M., Montague, C., Lewitus, A., Chalmers, A., Gardner, R., Gilman, C., Kjerfve, B. and Pinckney, J. (2000). Estuaries of the South Atlantic coast of North America: their geographical signatures. *Estuaries* **23**, 793-819.

Das, P., Marchesiello, P. and Middleton, J.H. (2000). Numerical modelling of tide-induced residual circulation in Sydney Harbour. *Marine and Freshwater Research* **51**, 97-112.

Day, J.H. (1980). What is an estuary? *South African Journal of Science* **76**, 198.

*Dayton, P. K. (1996). Environmental impacts of fishing on marine communities: Working group report. **In**: *Solving Bycatch: Considerations for Today and Tomorrow*, pp.121-128. Alaska Sea Grant College Program Report No. 96-03, University of Alaska Fairbanks. ISBN 1-56612-038-1.

Dayton, P.K., Thrush, S.F., Agardi, M.T. and Hofman, R.J. (1995). Viewpoint: environmental effects of fishing. *Aquatic Conservation: Marine and Freshwater Ecosystems* **5**, 205-232.

Deville, A. and Harding, R. (1997). *Applying the Precautionary Principle*. The Federation Press, Sydney. 79 pp.

*DNRE (2000). Marine Pests in Local Ports. Pamphlet. Department of Natural Resources and the Environment, Victoria. 2 pp.

*DUAP (2001). Guidelines for the Environmental Impact Assessment of Draft Fishery Management Strategies for Commercial Designated Fishing Activities. Department of Urban Affairs and Planning, 6 June. 31 pp. (Note: DUAP is now known as Planning NSW).

Edgar, G.J. and Shaw, C. (1995a). The production and trophic ecology of shallow-water fish assemblages in southern Australia I. Species richness, size-structure and production of fishes in Western Port, Victoria. *Journal of Experimental Marine Biology and Ecology* **194**, 53-81.

Edgar, G.J. and Shaw, C. (1995b). The production and trophic ecology of shallow-water fish assemblages in southern Australia II. Diets of fishes and trophic relationships between fishes and benthos at Western Port, Victoria. *Journal of Experimental Marine Biology and Ecology* **194**, 83-106.

Edgar, G.J. and Shaw, C. (1995c). The production and trophic ecology of shallow-water fish assemblages in southern Australia III. General relationships between sediments, seagrasses, invertebrates and fishes. *Journal of Experimental Marine Biology and Ecology* **194**, 107-131.

Eliot, I., Finlayson, C.M. and Waterman, P. (1999). Predicted climate changes, sea-level rise and wetland management in Australian wet-dry tropics. *Wetlands Ecology and Management* **7**, 63-81.

Engel, J. and Kvitek, R. (1998). Effects of otter trawling on a benthic community in Monterey Bay National Marine Sanctuary. *Conservation Biology* **12(6)**, 1204-1214.

*Environment Australia (1998). Draft Recovery Plan for Marine Turtles in Australia. Environment Australia, Canberra. 107 pp.

*Environment Australia (2000a). Draft Recovery Plan for Grey Nurse Sharks *Carcharias taurus* in Australia.

*Environment Australia (2000b). Draft Recovery Plan for Great White Sharks *Carcharodon carcharias* in Australia.

Erichsen Jones, J.R. (1969). *Fish and River Pollution.* Butterworths, London. 203 pp.

Fairweather, P.G. (1991). A conceptual framework for ecological studies of coastal resources: an example of a tunicate collected for bait on Australian seashores. *Ocean and Shoreline Mangement* **15**, 125-142.

*Faragher, R.A. (1995). A Survey of the Threatened Fish, Australian Grayling *Prototroctes maraena* Gunther: Distribution and Abundance in New South Wales. Report prepared for the Cooperative Research Centre for Freshwater Ecology, NSW Fisheries Research Institute, Cronulla, NSW.

*Fenton, M. and Marshall, N. (2001). A Guide to the Fishes of Queensland (Draft report). CRC Reef Research Centre, James Cook University, Townsville, Queensland.

Ferrell, D.J. and Bell, J.D. (1991). Differences among assemblages of fish associated with *Zostera capricorni* and bare sand over a large spatial scale. *Marine Ecology Progress Series* **72**, 15-24.

*Ferrell, D. and Sumpton, W. (1997). Assessment of the Fishery for Snapper (*Pagrus auratus*) in Queensland and New South Wales. Fisheries Research and Development Corporation report No. 93/074. NSW Fisheries and Queensland Department of Primary Industries. 143 pp.

*Fisheries Scientific Committee (1998). Recommendation, *Caroharodon carcharias* – Great White Shark. Fisheries Scientific Committee, New South Wales. { http://www.fsc.nsw.gov.au/recommend/pdf/great-white-shark.pdf}.

*Fisheries Scientific Committee (1999). Recommendation, *Carcharias taurus* – Grey Nurse Shark. Fisheries Scientific Committee, New South Wales. { http://www.fsc.nsw.gov.au/recommend/pdf/grey-nurse-shark.pdf} .

Fitzpatrick, J. and Kirkman, H. (1995). Effects of prolonged shading stress on growth and survival of seagrass *Posidonia australis* in Jervis Bay, New South Wales, Australia. *Marine Ecology Progress Series* **127**, 279-289.

*Fletcher, W. and McVea, T. (eds) (2000). NSW Fisheries 1998/99 Status of Fisheries Resources. NSW Fisheries Research Institute. 219 pp.

Fogarty, M.J. and Murawski, S.A. (1998). Large-scale disturbance and the structure of marine systems: fishery impacts on Georges Bank. *Ecological Applications* **8**, S6-S22.

Fonseca, M.S., Fisher, J.S., Zieman, J.C. and Thayer, G.W. (1982). Influence of the seagrass *Zostera marina* L., on current flow. *Estuarine and Coastal Shelf Science* **15**, 357-364.

Fonesca, M.S., Thayer, G.W. and Chester, A.J. (1984). Impact of scallop harvesting on eelgrass *(Zostera marina)* meadows: implications for management. *North American Journal of Fisheries Management* **4**, 286-293.

*Fonseca, M.S., Thayer, G.W. and Kenworthy, W. (1985). The use of the ecological data in the implementation and management of seagrass restorations. **In**: *Proceedings of the Symposium on Subtropical – Tropical Seagrasses of the Southeastern United States*. pp. 175-188.

*Frances, J. (2001). Identification of Candidate Sites for Estuarine Aquatic Reserves in the Hawkesbury and Batemans Shelf Bioregions. Report prepared for Environment Australia by the Office of Conservation, NSW Fisheries, Sydney. 126 pp.

Francis, R.I.C.C. and Shotton, R. (1997). 'Risk' in fisheries management: a review. *Canadian Journal of Fisheries and Aquatic Sciences* **54(8)**, 1699-1715.

*Friedlander, J.C. (1980). A Study of the Community in the *Zostera capricorni* Beds of Myuna Bay, in Lake Macquarie, New South Wales. Unpublished MSc Thesis. University of NSW, Sydney. 212 pp.

*Furlani, D. (1996). A Guide to the Introduced Marine Pests in Australian Waters. Tech Report Number 5, Centre for Research on Introduced Marine Pests, June 1996, CSIRO.

*Gibbs, P. (1997). A Review of Information on NSW South Coast Estuarine Fisheries. NSW Fisheries Research Institute, Cronulla. 74 pp.

Gibbs, P.J., Collins, A.J. and Collett, L.C. (1980). Effects of otter prawn trawling on the macrobenthos of a sandy substratum in a NSW estuary. *Australian Journal of Marine and Freshwater Research* **31**, 509-516.

*Gibbs, P., McVea, T. and Louden, B. (1999). Utilisation of Restored Wetlands by Fish and Invertebrates. FRDC Project No. 95/150. NSW Fisheries Office of Conservation, Pyrmont, Australia.

Gill, A.C. and Reader, S.E. (1992). Fishes. In: Reef Biology. A Survey of Elizabeth and Middleton Reefs, South Pacific, by the Australian Museum. *Kowari* **3**, 90-92. ANPWS, Canberra.

Gillanders, B. (1999). Blue groper. **In**: *Under Southern Seas*: *The Ecology of Australia's Rocky Reefs*. (ed. Andrew, N.) pp. 188-193. UNSW Press.

*Glaister, J.P. (1977). Ecological Studies of *Metapenaeus macleayi* (Crustacean, Decapoda, Penaeidae) in the Clarence River Region, Northern New South Wales. MSc Thesis, University of New England. 80 pp.

Glaister, J.P. (1978a). Impact of river discharge on distribution and production of the school prawn *Metapenaeus macleayi* (Haswell) (Crustacea: Penaeidae) in the Clarence River region, northern New South Wales. *Australian Journal of Marine and Freshwater Research* **29**, 311-323.

Glaister, J.P. (1978b). Movement and growth of tagged school prawns *Metapenaeus macleayi* (Haswell)(Crustacea:Penaeidae) in the Clarence River region, northern New South Wales. *Australian Journal of Marine and Freshwater Research* **29**, 645-657.

Glaister, J.P., Montgomery, S.S. and McDonnall, V.C. (1990). Yield-per-recruit analysis of eastern king prawns *Penaeus plebejus* Hess, in eastern Australia. *Australian Journal of Marine and Freshwater Research* **41(1)**, 175-197.

Glasby, T.M. (1999). Differences between subtidal epibiota on pier pilings and rocky reefs at marinas in Sydney, Australia. *Estuarine, Coastal and Shelf Science* **48**, 281-290.

Glasby, T.M. (2000). Surface composition and orientation interact to affect subtidal epibiota. *Journal of Experimental Marine Biology and Ecology* **248**, 177-190.

Gordon, A. (1988). Discard of shrimp by-catch at sea. *Bay of Bengal News* **12**, 9-11.

Gordon, G.N.G., Andrew, A.L. and Montgomery, S.S. (1995). A deterministic compartmentalised model for the eastern king prawn, *Penaeus plebejus* (Hess). *Australian Journal of Marine and Freshwater Research* **46**, 793-807.

*Goulstone, A. (1996). Fisheries Management Techniques. Fishnote DF 61. NSW Fisheries, March 1996.

Gray, C.A. and McDonall, V.C. (1993). Distribution and growth of juvenile mulloway, *Argyrosomus hololepidotus* (Pisces: Scianidae), in the Hawkesbury River, south-eastern Australia. *Australian Journal of Marine and Freshwater Research* **44(3)**, 401-409.

Gray, C.A., McDonall, V.C. and Reid, D.D. (1990). By-catch from prawn trawling in the Hawkesbury River, New South Wales: species composition, distribution and abundance. *Australian Journal of Freshwater Research* **41**, 13-26.

Gray, C.A., McElligott, D.J. and Chick, R.C. (1996). Intra- and inter-estuary difference in assemblages of fishes associated with shallow seagrass and bare sand. *Journal of Marine and Freshwater Research* **47**, 723-735.

*Gray, C.A., Pease, B.C., Stringfellow, S.L., Raines, L.P., Rankin, B.K. and Walford, T.R. (2000). Sampling Estuarine Fish Species for Stock Assessment. NSW Fisheries Final Report Series, No. 18, FRDC Project No. 94/042.

Greboval, D and Munro, G. (1999). Overcapitalization and excess fishing capacity in world fisheries: Underlying economics and methods of control. **In**: *Managing Fishing Capacity: Selected Papers on Underlying Concepts and Issues* (ed. Greboval, D.). FAO Fisheries Technical Paper. No.386. Rome, FAO. 206 pp.

Greenstreet, S.P.R. and Hall, S.J. (1996). Fishing and the ground-fish assemblage structure in the north-western North Sea: an analysis of long-term and spatial trends. *Journal of Animal Ecology* **65**, 577-598.

*Grey, D (2001). Invasive weed prompts response actions. *Fisheries New South Wales*, Spring 2000/Summer 2001 edition. pp. 4-5.

*Grey, D.L., Dall, W. and Baker, A. (1983). A Guide to the Australian Penaeid Prawns. Department of Primary Industries, Darwin. 139 pp.

Guillen, J.E., Ramos, A.A., Martinez, L. and Sanchez Lizaso, J.L. (1994). Anti-trawling reefs and the protection of *Posidonia oceanica* (L.) meadows in the western Mediterranean Sea: demands and aims. *Bulletin of Marine Science* **55**, 645-650.

*Hair, C.A. and Bell, J.D. (1992). Jervis Bay Marine Ecology Study: Enhancing the Settlement of Fish to Artificial Structures. Final Report, December 1992. Fisheries Research Institute, NSW Fisheries, Cronulla. 67 pp.

Hall, S.J. (1999). *The Effects of Fishing on Marine Ecosystems and Communities.* Blackwell Science Ltd. Carlton, Victoria. 274 pp.

Hall, S.J., Robertson, M.R., Basford, D.J. and Heaney, S.D. (1993). The possible effects of fishing disturbance in the northern North Sea: an analysis of spatial patterns in community structure around a wreck. *Netherlands Journal of Sea Research* **31(2)**, 201-208.

*Hamer, G. (1986). Abalone Biology and Management. Agfact F1.0.1, 1st edition. Department of Agriculture New South Wales, Division of Fisheries, Sydney. 6 pp.

*Handmer, J. (1995). Risk and uncertainty in environmental management. **In**: Fenner Conference on the Environment (eds. Norton, T.W., Beer, T. and Dovers, S.R.) pp. 86-171. Australian Academy of Science, November 1995, Canberra.

*Hannan, J. (1985). A Comparison of Shallow Water Fish Fauna in Mannering Hole and Nearby Lake Macquarie (New South Wales). Unpublished BSc (Hons.) Thesis. University of NSW, Sydney. 111 pp.

*Hannan, J. (1989). The Seagrass Fish Fauna of Lake Macquarie, New South Wales. Unpublished MSc Thesis. University of NSW, Sydney. 49 pp. plus figures and tables.

*Hannan, J.C. (1997). A Status Report on the Key Fish Habitats in the Hawkesbury-Nepean Catchment. NSW Fisheries, Sydney. 68 pp.

*Hannan, J.C. (In prep). Policy and Guidelines for Jetties, Ramps, Pontoons and Similar Foreshore Structures. NSW Fisheries.

Hannan, J.C. and Williams, R.J. (1998). Recruitment of juvenile marine fishes to seagrass habitat in a temperate Australian estuary. *Estuaries* **21(1)**, 29-51.

*Hannan, J. and Simpson, A. (1999). Scarred seagrass. *Fisheries NSW* **2(4)** Spring 1999, 32.

Harding, R. (1998). *Environmental Decision-making: the Roles of Scientists, Engineers and the Public*. Federation Press. 366 pp.

Harlin, M.M. (1975). Epiphyte-host relations in seagrass communities. *Aquatic Botany* **1**, 125-131.

Harrigan, K.E. (1992). Causes of mortality of little penguins *Eudyptula minor* in Victoria. *Emu* **91(5)**, 273-277.

Harris, A.N. and Poiner, I.R. (1990). By-catch of the prawn fishery of Torres Strait; composition and partitioning of the discards into components that float or sink. *Australian Journal of Marine and Freshwater Research* **41**, 37-52.

Harris, J.H. (1984). Impoundment of coastal drainages of south-eastern Australia, and a review of its relevance to fish migrations. *Australian Zoologist* **21(3)**, 235-250.

Harris, J.H. (1986). Reproduction of the Australian bass, *Macquaria novemaculeata* (Perciformes: Percichthyidae), in the Sydney Basin. *Australian Journal of Marine and Freshwater Research* **37**, 209-235.

*Hawkesbury Trawl Association (2001). Environmental Action Plan. Hawkesbury Trawl Association. 57 pp.

Heemstra, P.C. and Randall, J.E. (1993). *FAO Species Catalogue Volume 16 Groupers of the World (family Serranidae, Subfamily Epinephelidae)*. Food and Agriculture Organisation of the United Nations, Rome. 382 pp.

Hemminga, M.A., Harrison, P.G. and Vanlent, F. (1991). The balance of nutrient losses and gains in seagrass meadows. *Marine Ecology Progress Series* **71**, 85-96.

*Henrisson, C. and Smith, A. (1994). Black Rock Cod – a Protected Fish. Fishnote DF/39. NSW Fisheries, Sydney. 2 pp.

*Henry, G.W. (1984). Commercial and recreational fishing in Sydney estuary. *Fisheries Bulletin* No. 1. Department of Agriculture and Fisheries.

*Henry, G.W. (1987). Recreational Fishing in Lake Conjola. NSW Fisheries, unpublished report.

*Henry, G.W. and Virgona, J.L. (1980). The Impact of Munmorah Power Station on the Recreational and Commercial Fisheries of Tuggerah Lakes. Report prepared for the Electricity Commission by NSW State Fisheries.

*Henry, G.W and Virgona, J.L. (1984). Why is angling so popular? *Australian Fisheries* **43(5)**, 32-33.

*Henry, G.W., Neave, P. and House, R. (1987). A Survey of Recreational Fishing in the Port Hacking Estuary. Internal Report No. 40. Department of Agriculture and Fisheries.

Hilborn, R. and Walters, C.J. (1992). *Quantitative Fisheries Stock Assessment: Choice, Dynamics and Uncertainty*. Chapman and Hall, New York. 563 pp.

Hill, B.J. and Wassenberg, T.J. (1990). Fate discards from prawn trawlers in Torres Strait. *Australian Journal of Marine and Freshwater Research* **41**, 53-64.

Hillman, K., Walker, D.I., McComb, A.J. and Larkum, A.W.D. (1989). Productivity and nutrient availability. **In**: *Biology of Seagrasses* (eds. Larkum, A.W.D., McComb, A.J. and Shepherd, S.A.). pp. 458-499. Elsevier, Amsterdam.

Hoedt, F.E., Dimmlich, W.E. and Dann, P. (1995). Seasonal variation in the species and size composition of the clupeoid assemblages in Western Port, Victoria. *Marine and Freshwater Research* **46(7)**, 1085-1092.

Howells, G. (1994). *Water Quality for Freshwater Fish: Further Advisory Criteria.* Gordon and Breach SciencePublishers. 115 pp.

Huenneke, L.F. (1995). Involving academic scientists in conservation research: perspectives of a plant ecologist. *Ecological Applications* **5**, 209-214.

Hughes, P. and Brundrit, G. B. (1995). Sea level rise and coastal planning: a call for stricter control in river mouths. *Journal of Coastal Research* **11**, 887-898.

Hutchings, P. (1990). Review of the effects of trawling on macrobenthic epifaunal communities. *Australian Journal of Marine and Freshwater Research* **41**, 111-120.

Hutchings, P.A. and Recher, H.F. (1974). The fauna of Careel Bay with comments on the ecology of mangrove and seagrass communities. *Australian Zoologist* **18**, 99-128.

Hutchings, P.A. and Saenger. P. (1987). *Ecology of Mangroves.* University of Queensland Press, St Lucia, Queensland.

Hutchins, B. and Swainston, R. (1986). *Sea Fishes of Southern Australia.* Swainston Publishing, Perth, W.A. 180 pp.

*Hyland, S.J. (1985). The Moreton Bay, Queensland, beam trawl fishery for penaeid prawns. **In**: *Second Australian National Prawn Seminar* (eds. Rothlisberg, P.C., Hill, B.J. and Staples, D.J.) pp. 205-211. Cleveland, Queensland.

Hyne, R. V. and Wilson, S. P. (1997). Toxicity of acid-sulphate soil leachate and aluminium to the embryos and larvae of Australian bass *(Macquaria novemaculeata)* in estuarine water. *Environment Pollution* **97**, 221-227.

Inglis, G.J. (1995). Intertidal muddy shores. **In**: *Coastal Marine Ecology of Temperate Australia*. (eds. A.J Underwood and M.G. Chapman) pp. 171-186. UNSW Press.

*Intergovernmental Panel on Climate Change (IPCC) (2001a). Summary for Policy Makers – A Report of Working Group 1 of the Intergovernmental Panel on Cliamte Change. United Nations Environment Programme and the World Meteorological Organisation. [http://www.ipcc.ch/pub/spm22-01.pdf] .

*Intergovernmental Panel on Climate Change (IPCC) (2001b). Summary for Policy Makers – Climate Change 2001: Impacts, Adaptation, and Vulnerability. United Nations Environment Programme and the World Meteorological Organisation. [http://www.gcrio.org/OnLnDoc/pdf/wg2spm.pdf].

Irvine, I. and Birch, G.F. (in press). Distribution of heavy metals in surficial sediments of Port Jackson, Sydney, New South Wales. *Australian Journal of Earth Sciences*.

*IUCN (1995). IUCN Position Statement on Translocation of Living Organisms. International Union for the Conservation of Nature. Gland, Switzerland. 9 pp. [http://www.iucn.org/themes/ssc/pubs/policy/transe.htm].

*JCU (1993). An Examination of Links Between Tourism, Tourist Expectations and the Importance of Seafood in Restaurants of the Cairns Region. James Cook University Geography Department. Report for the Queensland Commercial Fishermen's Organisation. 54 pp.

Jennings, S. and Kaiser, M.J. (1998). The effects of fishing on marine ecosystems. *Advances in Marine Biology* **34,** 203-352.

Johnson, J.W. (1999). Annotated checklist of the fishes of Moreton Bay, Queensland, Australia. *Memoirs of the Queensland Museum* **43(2)**, 709-762.

Jones, A.R. (1997). Botany Bay benthos: status and management. *Wetlands (Australia)* **16(1)**, 11-24.

Jones, A.R., Watson-Russell, C.J. and Murray, A. (1986). Spatial patterns in the macrobenthic communities of the Hawkesbury estuary, New South Wales. *Australian Journal of Marine and Freshwater Research* **37**, 521-543.

Jones, G. and Candy, S. (1981). Effects of dredging on the macrobenthic infauna of Botany Bay. *Australian Journal of Marine and Freshwater Research* **32**, 379-398.

Jones, G.P. and Andrew, N.L. (1990). Herbivory and patch dynamics on rocky reefs in temperate Australasia: the roles of fish and sea urchins. *Australian Journal of Ecology* **15**, 505-520.

Jones, J.B. (1992). Environmental impact of trawling on the seabed: a review. *New Zealand Journal of Marine and Freshwater Research* **26**, 59-67.

Jorgensen, S.E. (1992). Ecological indicators and ecological modelling. **In**: *Ecological Indicators, Volume 1.* (eds. McKenzie, D.H., Hyatt, E.D. and MacDonald, J.V.) pp. 201-209. Elsevier Applied Science, London.

Kailola, P.J., Williams, M.J., Stewart, P.C., Reichelt, R.E., McNee, A. and Grieve, C. (1993). *Australian Fisheries Resources.* Bureau of Resource Sciences and the Fisheries Research and Development Corporation. Commonwealth of Australia. 422 pp.

Kaiser, M.J. (1998). Significance of bottom-fishing disturbance. *Conservation Biology* **12(6)**, 1230-1235.

Kaiser, M.J. and Spencer, B.E. (1996). The effects of beam-trawl disturbance on infaunal communities in different habitats. *Journal of Animal Ecology* **65**, 348-358.

Kaiser, M.J. and de Groot S.J. (2000). *The Effects of Fishing on Non-target Species and Habitats: Biological, Conservation and Socio-economic Issues.* The European Commission Fisheries, Agriculture and Agroindustrial Research Program (FAIR). 399 pp.

*Kaufmann, B., Geen, G. and San, S. (1999). Fish Futures: Individual Transferable Quotas in Fisheries. Fisheries Research and Development Corporation and Fisheries Economics, Research and Management Pty Ltd. Kiama, Australia. 240 pp.

Kennelly, S.J. (1987). Physical disturbances in an Australian kelp community: I. Temporal effects. *Marine Ecology Progress Series* **40**, 145-153.

*Kennelly, S.J. (1993). Study of the By-catch of the NSW East Coast Trawl Fishery. Final report to the Fisheries Research and Development Corporation. Project No: 88/108.

Kennelly, S.J. (1995a). The issue of by-catch in Australia's demersal trawl fisheries. *Reviews in Fish Biology and Fisheries* **5**, 213-234.

Kennelly, S.J. (1995b). Kelp beds. **In**: *Coastal Marine Ecology of Temperate Australia.* (eds. Underwood, A.J. and Chapman, M.G.) pp. 106-120. UNSW Press.

*Kennelly, S.J. (1997). A framework for solving by-catch problems: examples from New South Wales, Australia, the eastern Pacific and the northwest Atlantic. **In**: *Developing and Sustaining World Fisheries Resources: The State of Science and Management.* 2nd World Fisheries Congress proceedings. (eds. Hancock, D.A., Smith, D.C., Grant, A. and Beumer, J.P.) pp. 544-550. CSIRO Press.

Kennelly, S.J. and Underwood, A.J. (1992). Fluctuations in the distributions and abundances of species in sublittoral kelp forests in New South Wales. *Australian Journal of Ecology* **17**, 367-382.

Kennelly, S.J. and Broadhurst, M.K. (1996). Fishermen and scientists solving by-catch problems: examples from Australia and possibilities for the northeastern United States. **In**: *Solving Bycatch: Consideration for Today and Tomorrow*. pp. 121-128. Alaska Sea Grant College Program Report No. 96-03, University of Alaska Fairbanks. ISBN 1-56612-038-1.

*Kennelly, S.J. and Broadhurst, M.K. (1998). Development of By-catch Reducing Prawn Trawls and Fishing Practices in NSW's Prawn-trawl Fisheries (and Incorporating an Assessment of the Effect of Increasing Mesh Size in Fish Trawl Gear). FRDC Project No. 93/180. NSW Fisheries Final Report Series No. 5, July 1998.

*Kennelly, S.J., Kearney, R.E., Liggins, G.W. and Broadhurst, M.K. (1993). The effect of shrimp trawling by-catch on other commercial and recreational fisheries – an Australian perspective. **In**: *International Conference on Shrimp By-catch* (ed. Jones, R.P.) pp. 97-114. Lake Buena Vista, Florida. Tallahassee, FL: Southeastern Fisheries Association. May 1992.

Keough, M.J. and Jenkins, G.P. (1995). Seagrass meadows and their inhabitants. **In**: *Coastal Marine Ecology of Temperate Australia*. (eds. Underwood, A.J. and Chapman, M.G.) pp. 221-239. UNSW Press.

Keough, M. J. and Quinn, G. P. (1998). Effects of periodic disturbances from trampling on rocky intertidal algal beds. *Ecological Applications* **8**, 141-161.

*Kerr, R.J. (1994). Water Quality, Hawkesbury-Nepean River System, June 1990 to June 1993. Environment Protection Authority, Sydney. 193 pp.

King, R.J. (1981a). Marine angiosperms: seagrasses. **In**: *Marine Botany: an Australian Perspective* (eds. Clayton, M.N. and King R.J.) pp. 201-210. Longman Cheshire, Australia.

King, R.J. (1981b). Mangroves and saltmarsh plants. **In**: *Marine Botany: an Australian Perspective* (eds. Clayton, M.N. and King R.J.) pp. 308-328. Longman Cheshire, Australia.

King, R.J. (1986). Aquatic angiosperms in coastal saline lagoons of New South Wales. Part I: the vegetation of Lake Macquarie. *Proceedings of the Linnean Society of New South Wales* **109(1)**, 11-23.

*Klima, E. F. (1993). Shrimp by-catch: hopes and fears. **In**: *International Conference on Shrimp Bycatch, May 1992*. (ed. Jones, R.P.) Lake Buena Vista, Florida, Southeastern Fisheries Association, Tallahassee, FL. pp. 5-12.

Klumpp, D.W., Howard, R.K. and Pollard, D.A. (1989). Trophodynamics and nutritional ecology of seagrass communities. **In**: *Biology of Seagrasses. A Treatise on the Biology of Seagrasses with Special Reference to the Australian Region*, (eds. Larkum, A.W.D., McComb, A. J. and Shepherd, S. A.) pp. 394-437. Elsevier, New York /Amsterdam.

Kuiter, R. (1993). *Coastal Fishes of South-Eastern Australia.* Crawford House Press, Bathurst. 437 pp.

*Kumar. M. (1997). Status of biology, research and development of the blue crab (*Portunus pelagicus*) fishery in South Australia. **In**: *Proceedings of the First National Workshop on Blue Swimmer Crab Portunus pelagicus*. SARDI Research Report Series Number 16, 77-92.

*Lal, P., Holland, P. and Power, P. (1992). Competition Between Recreational and Commercial Fishers: Management Options and Economic Research. Australian Bureau of Agricultural and Resource Economics. Research Report, No. 92.11, p. 70.

Larkum, A.W.D. (1981). Marine primary productivity. **In**: *Marine Botany: an Australian Perspective* (eds. Clayton, M.N. and King, R.J.) pp. 369-385. Longman Cheshire, Australia.

Larkum, A.W.D and West, R.J. (1983). Stability, depletion and restoration of seagrass beds. *Proceedings of the Linnean Society of NSW* **106**, 201-212.

Last, P.R. and Stevens, J.D. (1994). *Sharks and Rays of Australia.* CSIRO, Melbourne. 513 pp.

*Laurenson, L.J.B, Unsworth, P., Penn, J.W. and Lenanton, R.C.J. (1993). The Impact of Trawling for Saucer Scallops and Western King Prawns on the Benthic Community in Coastal Waters off Southwestern Australia. Fisheries Research Report, Western Australian Fisheries Department. 100: 93 pp.

*Leadbitter, D., Ward, T. and Ridge, K. (1999). Maintaining Biodiversity in Sustainable Marine Fisheries - A Review and Scoping of Future Directions. Department of the Environment and Heritage, Commonwealth of Australia. 86 pp.

Lenanton, R.C.J., Robertson, A.I. and Hansen, J.A. (1982). Nearshore accumulations of detached macrophytes as nursery areas for fish. *Marine Ecology Progress Series* **9**, 51-57.

Liggins, G.W. and Kennelly, S.J. (1996). By-catch from prawn trawling in the Clarence River estuary, New South Wales, Australia. *Fisheries Research* **25**, 347-367.

Liggins, G.W., Kennelly, S.J. and Broadhurst, M.K., (1996). Observer-based survey of by-catch from prawn trawling in Botany Bay and Port Jackson, New South Wales. *Marine Freshwater Research* **47**, 877-888.

Lincoln Smith, M.P. and Jones, G.P. (1995). Fishes of shallow coastal habitats. **In**: *Coastal Marine Ecology of Temperate Australia*. (eds. Underwood, A.J. and Chapman, M.G.) pp. 240-253. UNSW Press.

Lincoln Smith, M.P., Bell, J.D., Pollard, D.A. and Russell, B.C. (1989). Catch and effort of competition spearfishermen in southeastern Australia. *Fisheries Research* **8**: 45-61.

*Lincoln Smith, M.P., Hair, C.A. and Bell, J.D. (1992). Jervis Bay Marine Ecology Study. Project 4: Fish Associated with Natural Rocky Reefs and Artificial Breakwaters. Final Report, December 1992. Fisheries Research Institute, NSW Fisheries, Cronulla. 210 pp.

Lindegarth, M., Valentinsson, D., Hansson, M., and Ulmestrand, M. (2001). Interpreting large scale experiments on the effects of trawling on benthic fauna: an empirical test of the potential effects of spatial confounding in experiments without replicated control and trawled areas. *Journal of Experimental Marine Biology and Ecology* **245(2)**, 155-169.

Lloyd, R. (1992). *Pollution and Freshwater Fish.* Blackwell Scientific Publications. London. 176 pp.

Loneragan, N.R., Bunn, S.E. and Kellaway, D.M. (1997). Are mangroves and seagrasses sources of organic carbon for penaeid prawns in a tropical Australian estuary? A multiple stable-isotope study. *Marine Biology* **130**, 289-300.

*McDonall, V.C. and Thorogood C.A. (1988). The Hawkesbury River. **In**: *A Summary of the Research Conducted on Estuarine Prawn Trawl Fisheries in New South Wales and Recommendations for their Future Management*. (eds. Montgomery, S.S. and McDonall, V.C.) pp. 88-106. NSW Fisheries.

McDowall, R.M. (1996). *Freshwater Fishes of South-Eastern Australia.* Reed Books, Sydney. 247 pp.

*McEnally, J., Thompson, G. and Zekanovic, I. (1989). Coastal Resource Atlas for Oil Spills in and around the Port of Newcastle. State Pollution Control Commission, Sydney. 32 pp.

*McEnally, J., Eskdale, I., Thompson, G., Harris, J., Zekanovic, I. and Otto, K. (1992). Coastal Resource Atlas for Oil Spills from the Clarence River to Smoky Cape. Environment Protection Authority, Sydney. 102 pp.

McGhie, T. K., Crawford, C. M., Mitchell, I. M. and O'Brien, D. (2000). The degradation of fish-cage waste in sediments during fallowing. *Aquaculture* **187**, 351-366.

McNeill, S.E., Worthington, D.G., Ferrell, D.J. and Bell, J.D. (1992). Consistently outstanding recruitment of five species of fish to a seagrass bed in Botany Bay, NSW. *Australian Journal of Ecology* **17**, 359-366.

*McVerry, S. (1996). A Socio-economic Evaluation of the Clarence River Commercial Fisheries. Unpublished undergraduate study, Faculty of Resource Science and Management, Southern Cross University.

Marchant, S. and Higgins, P.J. (1993). *Handbook of Australian, New Zealand and Antarctic Birds.* Oxford University Press, Melbourne.

*Marine Parks Authority (2000). Draft Framework for Establishing a System of Marine Protected Areas in NSW. NSW Fisheries and National Parks and Wildlife Service, June 2000. 64 pp.

*Mather, G. (1993). *Aquaculture: an Australian Environmental Review*. Total Environment Centre Inc., Sydney. 88 pp.

*MCFFA (1999). National Policy for the Translocation of Live Aquatic Organisms – Issues, Principles and Guidelines for Implementation. Ministerial Council on Forestry, Fisheries and Aquaculture, Canberra. ACT. 31 pp.

Merrick, J.R. and Schmida, G.E. (1984). *Australian Freshwater Fishes Biology and Management.* Griffin Press, South Australia. 409 pp.

Middleton, M.J., Bell, J.D., Burchmore, J.J., Pollard, D.A. and Pease, B.C. (1984). Structural differences in the fish communities of *Zostera capricorni* and *Posidonia australis* seagrass meadows in Botany Bay, New South Wales. *Aquatic Botany* **18**, 89-109.

Montgomery, S.S. (1990). Movements of juvenile eastern king prawns *Penaeus plebejus*, and identification of stock along the east coast of Australia. *Fisheries Research* **9**, 189-208.

*Montgomery, S.S. (2000). Status of eastern king and school prawn stocks. **In**: *Proceedings of Juvenile Prawn Summit June 26-27*. NSW Fisheries Publication. Sydney. pp. 28-47.

*Montgomery, S.S. and McDonall, V.C. (1988). A Summary of Research Conducted on Estuarine Prawn Trawl Fisheries in New South Wales and Recommendations for their Future Management. Fisheries Research Institute Internal Report, 46. 177 pp.

*Montgomery, S.S. and Reid, D.D. (1995). Assessment of Recreational Fishing of Prawn Stocks on the Commercial Fishery for Prawns off New South Wales. Final report to the Fisheries Research and Development Corporation. Project 91/88. NSW Fisheries, Sydney.

*Montgomery, S.S., Courtney, A.J., Andrew, N.L., Die, D.J., Cosgrove, M.G. and Blount, C. (1995). Patterns in the distribution and abundance of female eastern king prawns, *Penaeus plebejus,* spawning condition in waters off eastern Australia. **In**: *Proceedings of the Workshop on Spawning Stock-recruitment Relationships (SRRs) in Australian Crustacean Fisheries* (eds. Courtney, A.J. and Cosgrove, M.G.) pp. 93. Department of Primary Industries, Queensland.

*Moran, M.J., Jenke, J., Cassels, G. and Nowara, G. (1995). Research for Allocation of North-west Marine Finfish among Diverse User Groups. Fisheries Department of Western Australia, Draft Final Report to FRDC Project 91/28. 72 pp.

Morrisey, D.J. (1995). Saltmarshes. **In**: *Coastal Marine Ecology of Temperate Australia* (eds. Underwood, A.J. and Chapman, M.G.) pp. 205-220. UNSW Press.

Morrisey, D.J., Howitt, L, Underwood, A.J. and Stark, J.S. (1992a). Spatial variation in soft-sediment benthos. *Marine Ecology Progress Series* **81**, 197-204.

Morrisey, D.J., Underwood, A.J., Howitt, L. and Stark, J.S. (1992b). Temporal variation in soft-sediment benthos. *Journal of Experimental Marine Biology and Ecology* **164**, 233-245.

Morton, R.M., Pollock, B.R. and Beumer, J.P. (1987). The occurrence and diet of fishes in a tidal inlet to a saltmarsh in southern Moreton Bay, Queensland. *Australian Journal of Ecology* **12**, 217-237.

Murphy, G. I. (1980). Schooling and ecology and management of marine fish. **In**: *Fish Behaviour and its Use in the Capture and Culture of Fishes* (eds. Bardach, J.E., Magnusuon, J.E., May, .J.J. and Reinhart, R.C.J.M.) *ICLARM Conference Procedures* **5**, 400-414.

*NSW Department of Public Works and Services (1992). Draft Estuary Management Manual. NSW Government Printer. 194 pp.

*NSW Fisheries (1996). Licencing Policy. NSW Fisheries, Sydney. November, 1996.

*NSW Fisheries (1999a). Policy and Guidelines Aquatic Habitat Management and Fish Conservation 1999. (eds. Smith, A.K. and Pollard, D.A.) NSW Fisheries, Port Stephens Research Centre. 86 pp.

*NSW Fisheries (1999b). Policy and Guidelines for Bridges, Roads, Causeways, Culverts and Similar Structures 1999. (eds. Fairfull, S. and Carter, S.) NSW Fisheries, Sydney. 19 pp.

*NSW Fisheries (1999c). Fishery Profile: Estuary Prawn Trawl. NSW Fisheries, Sydney. 12 pp.

*NSW Fisheries (2000a). NSW Fisheries 2000 Research Report. Internal Report. Cronulla Fisheries Centre, Sydney. 499 pp.

*NSW Fisheries (2000b). North Coast Aquaculture Strategy. NSW Fisheries.

*NSW Fisheries (2000c). Indigenous Fisheries Strategy, Working Paper. NSW Fisheries, Sydney.

*NSW Fisheries (2001a). Status of Fisheries Resources 2000. Internal report. Cronulla Fisheries Centre, Sydney. 306 pp.

*NSW Fisheries (2001b). Consultation Paper - Selection Process for Candidate Aquatic Reserves for Rocky Shores and Estuaries (Batemans Shelf and Hawkesbury Shelf Bioregions). NSW Fisheries, Office of Conservation. 64 pp.

*NSW National Parks and Wildlife Service, (2000a). Recovery Plan for the Endangered Population of Little Penguins (*Eudyptula minor*) at Manly. NSW NPWS, Hurstville.

*NSW National Parks and Wildlife Service, (2000b). Little Tern (Sterna albifrons), draft recovery plan. NSW NPWS, Hurstville.

*O'Loughlin, E., Roberts, D. and Sainty, G. (1999). Guidelines to Management of Wetlands in Lower South Coast, NSW. Sainty and Associates Pty. Ltd. Sydney. 34 pp.

Ott, W.R. (1978). *Environmental Indices – Theory and Practice.* Ann Arbor Science, Ann Arbour, MI.

*Otway, N.M. and Macbeth, W.G. (1999). Physical Effects of Hauling on Seagrass Beds. FRDC Project Nos. 95/149 & 96/286. NSW Fisheries Final Report Series No. 15. Cronulla Fisheries Centre, Sydney. 86 pp.

*Paton, D.C., Ziembicki, M., Owen, P. and Heddle, C. (2000). Disturbance Distances for Waterbirds and the Management of Human Recreation with Special Reference to the Coorong Region of South Australia. Report prepared by The University of Adelaide, South Australia for the Migratory Waterbird component of the National Wetlands Program.

Patterson, K., Cook, R., Darby, C., Gavaris, S., Laurence, K., Lewy, P., Mesnil, B., Punt, A., Restrepo, V., Skagen, D.W. and Stefansson, G. (2001). Estimating uncertainty in fish stock assessment and forecasting. *Fish and Fisheries* **2**, 125-157.

Pauly, D. (1988). Fisheries research and the demersal fisheries of southeast Asia. **In**: *Fish Popoulation Dynamics*, 2nd edn. (ed. Gulland, J.A.) pp. 329-348. John Wiley and Sons, Chichester.

Pauly, D., Christensen, V., Dalsgaard, J., Froese, R. and Torres, F.Jr (1998). Fishing down marine food webs. *Science* **279**, 860-863.

*Pease, B.C. and Grinberg, A. (1995). New South Wales Commercial Fisheries Statistics 1940-1992. NSW Fisheries, Cronulla. 351 pp.

Peters, R.H. (1991). *A critque for ecology.* Cambridge University Press, Cambridge, United Kingdom.

Pilskaln, C.H., Churchill, J.H. and Mayer, L.M. (1998). Resuspension of sediment bottom trawling in the Gulf of Maine and potential geochemical consequences. *Conservation Biology* **12(6)**, 1223-1229.

Pizzey, G. and Doyle, R. (1984). *A Field Guide to the Birds of Australia.* Collins, Sydney. 460 pp.

*Pogonoski, J.J., Pollard, D.A. and Paxton, J.R. (in preparation). Conservation Overview and Action Plan for Australian Threatened and Potentially Threatened Marine and Estuarine Fishes. Report to Environment Australia Biodiversity Group by the NSW Fisheries Research Institute and the Australian Museum.

*Poiner, I.R. and Peterken, C. (1995). Seagrasses. **In**: *The State of the Marine Environment Report for Australia. Technical Annex 1: The Marine Environment* (eds. Zann, L.P. and Kailola, P.) pp. 107-117. Great Barrier Reef Marine Park Authority, Townsville.

Pollard, D.A. (1984). A review of ecological studies on seagrass-fish communities, with particular reference to Australia. *Aquatic Botany* **18**, 3-42.

Pollard, D.A. (1989). Artificial habitats for fisheries enhancement in the Australian region. *Marine Fisheries Review* **51(4)**, 11-26.

*Pollard, D. A. (1991). Spatial and temporal variability in the recruitment of a common esturaine fish, the yellowfin bream (*Acanthopagrus australis*, Sparidae), in south-eastern Australia. **In**: *Recruitment processes, Australian Society for Fish Biology Workshop Proceedings No. 16*, (ed. Hancock, D.A.) pp. 85-88. Australian Government Publishing Service.

Pollard, D.A. and Hutchings, P.A. (1990a). A review of exotic marine organisms introduced into the Australian region. I, Fishes. *Asian Fisheries Science* **3**, 205-221.

Pollard, D.A. and Hutchings, P.A. (1990b). A review of exotic marine organisms introduced into the Australian region. II, Invertebrates and Algae. *Asian Fisheries Science* **3**, 223-250.

Pollard, P.C. and Moriarty, D.J.W. (1991). Organic carbon decomposition, primary and bacterial productivity, and sulphate reduction in tropical seagrass beds of the Gulf of Carpentaria, Australia. *Marine Ecology Progress Series* **69**, 149-159.

*Pollard, D.A. and Growns, I.O. (1993). The Fish and Fisheries of the Hawkesbury-Nepean River System, with Particular Reference to the Environmental Effects of the Water Board's Activities on this System. Interim report to the Water Board – April 1993. NSW Fisheries, Fisheries Research Institute, Cronulla. 291 p. plus appendices.

Pollard, D.A. and Hannan, J.C. (1994). The ecological effects of structural flood mitigation works on fish habitats and fish communities in the lower Clarence River system of south-eastern Australia. *Estuaries* **17(2)**, 427-461.

*Powell, R.A., Jensen, R. and Horwood, L. (1989). The Effects of Policy Change on South-East Trawl Fishing Communities. Report to the Steering Committee on Long-Term Management of the South East Trawl Fishery. University of New England and Department of Primary Industries and Energy, Canberra.

Quigley, M.P. and Hall, J.A. (1999). Recovery of macrobenthic communities after maintenance dredging in the Blyth Estuary, north-east England. *Aquatic Conservation: Marine and Freshwater Ecosyst*ems **9**, 63-73.

*Racek, A.A., (1959). Prawn investigations in eastern Australia. *Research Bulletin State Fisheries, New South Wales* **6**, 1-57.

Rainer, S.F. (1982). Trophic structure and production in the macrobenthos of a temperate Australian estuary. *Estuarine, Coastal and Shelf Science* **15,** 423-441.

Roach, A.C. (1997). The effect of acid water inflow on estuarine benthic and fish communities in the Richmond River, NSW Australia. *Australian Journal of Ecotoxicology* **3**, 25-56.

*Robertson, A.I. and Alongi, D.M. (1995). Mangrove systems in Australia: structure, function and status. **In**: *The State of the Marine Environment Report for Australia, Technical Annex 1: The Marine Environment* (eds. Zann, L.P. and Kailola, P.) pp. 119-133. Great Barrier Reef Marine Park Authority, Townsville.

Robertson, A.I., Dixon, P.and Daniel, P.A. (1988). Zooplankton dynamics in mangrove and other nearshore habitats in tropical Australia. *Marine Biology* **96**, 193-206.

Rooker, J.R. and Dennis, G.D. (1991). Diel, lunar and seasonal changes in a mangrove fish assemblage of southwestern Puerto Rico. *Bulletin of Marine Science* **49**, 684-698.

*Ross, G.J.B. (1996). Status of Australia's seabirds. **In**: *SOMER Technical Papers: Status of Marine Biodiversity* (ed. Zann, L.P.). The State of the Marine Environment Report for Australia. Technical Summary, 17. GBRMPA.

Roughley, T.C. (1951). *Fish and Fisheries of Australia*. Angus and Robertson, Sydney.

*Roy, P.S. (1982). Evolution of estuaries in N.S.W. Water Research Foundation of Australia Symposium paper. 27 pp.

Roy, P.S. (1984). New South Wales estuaries: their origins and evolution. **In**: *Coastal Geomorphology in Australia* (ed. Thom, B.) pp. 99-121. Academic Press Australia.

Roy, P.S., Thom, B.G. and Wright, L.D. (1980). Holocene sequences on an embayed high-energy coast: an evolutionary model. *Sedimentary Geology* **26**, 1-19.

Roy, P.S, Williams, R.J., Jones, A.R., Yassini, I., Gibbs, P.J., Coates, B., West, R.J., Scanes, P.R., Hudson, J.P., and Nichol, S. (2001). Structure and function of southeast Australian estuaries. *Estuarine, Coastal and Shelf Science* **56**, (in press).

*Roy Morgan (1999). Recreational Fishing Licence Survey of 500 Persons in the Community. Confidential Document Prepared for NSW Fisheries, Roy Morgan Research, Sydney.

*Roy Morgan (2001a). Social Survey Results. Unpublished Research, Roy Morgan Research, Sydney.

*Roy Morgan (2001b). Economic Survey Results. Unpublished Research, Roy Morgan Research, Sydney.

*Ruello, N.V. (1969). Hunter region prawn fishery. *Fisherman* **3(5)**, 20-24.

*Ruello, N.V. (1971). Some Aspects of the Ecology of the School Prawn *Metapenaeus macleayi* in the Hunter region of New South Wales. MSc Thesis, University of Sydney. 145 pp.

Ruello, N.V. (1973a). Burrowing,feeding and spatial distribution of the school prawn *Metapenaeus macleayi* (Haswell) in the Hunter River region, Australia. *Journal of Experimental Marine Biology and Ecology* **13**, 189-206.

Ruello, N.V. (1973b). Influence of rainfall on the distribution and abundance of the school prawn *Metapenaeus macleayi* (Haswell) in the Hunter River region, Australia. *Marine Biology* **23**, 221-228.

*Ruello, N.V. (1975a). An historical review and annotated bibliography of prawns and the prawning industry in Australia. **In**: *First Australian National Prawn Seminar* (ed. Young, P.C.). Australian Government Printing Service, Canberra, Australia. 345 pp.

*Ruello, N.V. (1975b). Biological research and management of prawn fisheries in New South Wales. **In**: *First Australian National Prawn Seminar* (ed. Young, P.C.) pp. 222-233. Australian Government Printing Service, Canberra.

Ruello, N.V. (1975c). Geographic distribution, growth and breeding migration of the eastern Australian king prawn *Penaeus plebejus* Hess. *Australian Journal of Marine and Freshwater Research* **26**, 348-354.

Ruello, N.V. (1977). Migration and stock studies on the Australian school prawn *Metapenaeus macleayi. Marine Biology* **41**, 185-190.

*Ruello, N.V. (1996). A Study of the Demand and Importance of Seafood Sourced in NSW and Elsewhere to the Catering and Tourism Industries in NSW. FRDC, NSW. 157 pp.

*Ruello & Associates Pty. Ltd. (2000). Retail Sale and Consumption of Seafood. Report prepared for the Fisheries Research and Development Corporation. July 2000. 14 pp.

*Saila, S.B. (1983). Importance and Assessment of Discards in Commercial Fisheries. FAO Fisheries Circular, 765. 62 pp.

*Sainsbury, K.J., Campbell, R.A. and Whitelaw, A.W. (1993). Effects of trawling on the marine habitat on the north west shelf of Australia and implications for sustainable fisheries management. **In**: *Proceedings of Australian Society for Fish Biology Workshop "Sustainable Fisheries through Sustaining Fish Habitat"* (ed. Hancock, D.A.) pp. 137-145. Department of Primary Industries and Energy, Bureau of Resource Sciences, Australian Government Publishing Service, Canberra. August, 1992.

Sainsbury, K.J., Campbell, R.A., Lindholm, R. and Whitelaw, A.W. (1997). Experimental management of an Australian multi-species fishery: Examining the possibility of trawl induced habitat modification. **In**: *Global Trends: Fisheries Management.* pp. 107-112. John Wiley and Son.

Saintilan, N. and Williams, R.J. (1999). Mangrove transgression into saltmarsh environments in south-east Australia. *Global Ecology and Biogeography* **8**, 117-124.

Salini, J.P., Blaber, S.J.M. and Brewer, D.T. (1990). Diets of piscivorous fishes in a tropical Australian estuary, with special reference to predation on penaeid prawns. *Marine Biology* **105**, 363-374.

*Sammut, J., Callinan, R.B. and Fraser, G.C. (1993). The impact of acidified water on freshwater and estuarine fish populations in acid sulphate soil environments. **In**: *Proceedings of National Conference on Acid Sulphate Soils.* pp 26-36. Coolongatta, Australia.

Sammut, J., Melville, M.D., Callinan, R.B. and Fraser, G.C. (1995). Estuarine acidification: impacts on aquatic biota of draining acid sulphate soils. *Australian Geographical Studies* **33(1)**, 89-100.

Sammut, J., White, I. and Melville, M.D. (1996). Acidification of an estuarine tributary in eastern Australia due to drainage of acid sulphate soils. *Marine and Freshwater Research* **47**, 669-684.

*Scandol, J.P. and Forrest, R.E. (2001). Modelling Services for the NSW Estuary General Fishery. Draft Report for NSW Fisheries July 2001. Centre for Research on Ecological Impacts of Coastal Cities, University of Sydney, NSW. 114 pp.

*Scanes, P.R. (1988). The Impact of Eraring Power Station on the Fish and Fisheries of Lake Macquarie. Report prepared for the Electricity Commission of New South Wales. New South Wales Fisheries, Fisheries Research Institute, Sydney, Australia. 111 pp.

Scanes, P.R. and Scanes, K. (1995). Environmental problems due to disposal of wastes. **In**: *Coastal Marine Ecology of Temperate Australia.* (eds. Underwood, A.J. and Chapman, M.G.) pp. 297-310. UNSW Press.

Schwinghamer, P., Gordon Jr, D.C., Rowell, T.W., Prena, J., McKeown, D.L., Sonnichsen, G. and Guigne, J.Y. (1998). Effects of experimental otter trawling on surficial sediment properties of a sandy-bottom ecosystem on the Grand Banks of Newfoundland. *Conservation Biology* **12(6)**, 1215-1222.

Scoffin, T.P. (1970). The trapping and binding of subtidal carbonate sediments by marine vegetation in Bimini Lagoon, Bahamas. *Journal of Sedimentary Petroleum* **40**, 249-273.

*Shafer, D.J. and Lundin, J. (1999). Design and Construction of Docks to Minimise Seagrass Impacts. WRP Technical Notes Collection (TN WRP-VN-RS-3.1), U.S. Army Engineer Research and Development Center, Vicksburg, MS. 6 pp.

Shepherd, S.A., McComb, A.J., Bulthuis, D.A., Neverauskas, V., Steffensen, D.A. and West, R. (1989). Decline of seagrasses. **In**: *Biology of Seagrasses* (eds. Larkum, A.W.D., McComb, A,J, and Shepherd, S.A.) pp. 346-393. Elsevier, Amsterdam.

Sheridan, A.K. (1995). The genetic impacts of human activities on wild fish populations. *Reviews in Fisheries Science* **3(2)**, 91–108.

*Sherman, B. (2000). Scoping Options for Mitigating Cold Water Discharges from Dams. Report to: Agriculture, Fisheries and Forestry – Australia, NSW Fisheries, CRC for Freshwater Ecology, and NSW Department of Land and Water Conservation as part of the NHT Murray-Darling 2001 Fish Rehab Program. Consultancy Report 00/21. CSIRO Land and Water, Canberra. May 2000.

*Shotter, N., O'Donnell, M., Steetsel, P. and Birch, G.F. (1995). The environmental status of a large NSW estuary under threat - the Hawkesbury River System. **In**: *Proceedings of the 29th*

Newcastle Symposium on "Advances in the study of the Sydney Basin". pp. 59-65. Department of Geology, University of Newcastle.

Simenstad, C.A. and Thom, R.M. (1996). Functional equivalency trajectories of the restored Gog-Le-Hi-Te estuarine wetland. *Ecological Applications* **6(1)**, 38-56.

Simpson, K. and Day, N. (1996). *Field Guide to the Birds of Australia (5th ed).* Penguin Books, Australia. 440 pp.

Skilleter, G.A. (1995). Environmental disturbances. **In**: *Coastal Marine Ecology of Temperate Australia* (eds. Underwood, A.J. and Chapman, M.G.) pp. 263-276. UNSW Press.

*Smith, A., Pollard, D. and Gillanders, B. (1996). The Blue Groper in NSW. Fishnote DF/63. NSW Fisheries, Sydney. 2 pp.

*State Pollution Control Commission (SPCC) (1979). Effects of Dredging on Macrobenthic Infauna of Botany Bay. Environmental Control Study of Botany Bay. Sydney, Australia. Report No. BBS 10. 55 pp.

*State Pollution Control Commission (SPCC) (1981a). The Ecology of Fish in Botany Bay - Community Structure. Environmental Control Study of Botany Bay. SPCC, Sydney, Australia. Report No. BBS 23A. 127 pp.

*State Pollution Control Commission (SPCC) (1981b). The Ecology of Fish in Botany Bay - Biology of Commercially and Recreationally Valuable Species. Environmental Control Study of Botany Bay. Sydney, Australia. Report No. BBS 23B. 287 pp.

Stead, D.G. (1963). *Sharks and Rays if Australian Seas.* Angus and Robertson, Sydney. 211 pp.

*Steffe, A.S. and Chapman, D.J. (in review). A Survey of Daytime Recreational Fishing During the Annual Period, March 1999 to February 2000, in Lake Macquarie, New South Wales.

*Steffe, A.S., Murphy, J.J., Chapman, D.J., Tarlington, B.E., Gordon, G.N.G. and Grinberg, A. (1996a). An Assessment of the Impact of Offshore Recreational Fishing in New South Wales on the Management of Commercial Fisheries. FRDC Project No. 94/053.

*Steffe, A.S., Staines, J.F. and Murphy, J.J. (1996b). Recreational Use of Fisheries Resources in Northern New South Wales. Natural Resources Audit Council Project S7.

*Sullivan, M.E. (1982). Aboriginal Shell Middens in the Coastal Landscape of New South Wales. Thesis submitted for PhD, Australian National University.

Suter, G.W. (1993). A critique of ecosystem health concepts and indexes. *Environmental Toxicology and Chemistry* **12**, 1533-1539.

*Tamblyn, C. and Powell, R.A. (1988). Input and Output Study of the North Coast Agriculture and Fisheries Industries. NSW Department of Agriculture, Wollongbar.

*Tanner, M. and Liggins, G.W. (2000). New South Wales Commercial Fisheries Statistics 1998/99. Fisheries Centre Cronulla. 21 pp.

*Tanner, M. and Liggins, G.W. (2001). New South Wales Commercial Fisheries Statistics 1999/00 (draft). NSW Fisheries, Cronulla Fisheries Centre.

Thomas, B.E. and Connolly, R.M. (2001). Fish use of subtropical saltmarshes in Queensland, Australia. Relationships with vegetation, water depth and distance onto the marsh. *Marine Ecology Progress Series* **209**, 275-288.

*Thompson, G. and McEnally, J. (1985). Coastal Resource Atlas for Oil Spills in Port Jackson. State Pollution Control Commission, Sydney. 27 pp.

Thorhaug, A. (1990). Restoration of mangroves and seagrasses – economic benefits for fisheries and mariculture. **In**: *Environmental Restoration Science and Strategies for Restoring the Earth* (ed. Berger, J.J.). Island Press, Washington.

*Thorncraft, G. and Harris, J. (2000). Fish Passage and Fishways in New South Wales: A Status Report. Cooperative Research Centre for Freshwater Ecology Technical Report 1/2000.

Thresher, R.E., Sainsbury, K.J., Gunn, J.S. and Whitelaw, A.W. (1986). Life history strategies and recent changes in population structure in the lizardfish genus *Saurida,* on the Australian Northwest Shelf. *Copeia* **4**, 876-885.

Tuck, I.D., Hall, S.J., Robertson, M.R., Armstrong, E. and Basford, D.J. (1998). Effects of physical trawling disturbance in a previously unfished sheltered Scottish sea loch. *Marine Ecology Progress Series* **192**, 227-242.

Underwood, A.J. (1989). The analysis of stress in natural populations. *Biological Journal of the Linnean Society* **37**, 51-78.

Underwood, A.J. (1990). Experiments in ecology and management: their logics, functions and interpretations. *Australian Journal of Ecology* **15**, 365-389.

Underwood, A.J. (1995). Ecological research and (and research into) environmental management. *Ecological Applications* **5**, 232-247.

Underwood, A.J. (1998). Relationships between ecological research and environmental management. *Landscape and Urban Planning* **40**, 123-130.

Underwood, A. J. and Kennelly, S.J. (1990). Pilot studies for designs of surveys of human disturbance of intertidal habitats in New South Wales. *Australian Journal of Marine and Freshwater Research* **41**, 165-173.

Underwood, A.J., Chapman, M.G. and Connell, S.D. (2000). Observations in ecology: you can't make progress on processes without understanding the patterns. *Journal of Experimental Marine Biology and Ecology* **250**, 97-115.

*Virgona, J.L. (1983). Lake Macquarie Fish Study. Report prepared for the Electricity Commission of New South Wales. NSW Fisheries, Cronulla. 131pp.

*Virgona, J., Deguara, K., Sullings, D., Halliday, I. and Kelly, K. (1998). Assessment of the Stocks of Sea Mullet in New South Wales and Queensland Waters. FRDC Project No. 94/024, New South Wales Fisheries, Cronulla (Australia). 104 pp.

Wassenberg, T.J. and Hill, B.J. (1987). Feeding by the sand crab *Portunus pelagicus* on material discarded from prawn trawlers in Moreton Bay, Australia. *Marine Biology* **95**, 387-393.

Wassenberg, T.J. and Hill, B.J. (1989). The effect of trawling and subsequent handling on the survival rates of the by-catch of prawn trawlers in Moreton Bay, Australia. *Fisheries Research* **7**, 99-110.

Wassenburg, T.J. and Hill, B.J. (1990). Partitioning of material discarded from prawn trawlers in Moreton Bay. *Australian Journal of Marine and Freshwater Research* **41(1)**, 27-36.

Wassenberg, T.J. and Hill, B.J. (1993). Selection of the appropriate duration of experiments to measure the survival of animals discarded from trawlers. *Fisheries Research* **17**, 343-352.

*Watford, F.A. and Williams, R.J. (1998). Inventory of Estuarine Vegetation in Botany Bay, with Special Reference to Change in the Distribution of Seagrass. NSW Fisheries Final Report Series No.11, NSW Fisheries.

Watling, L. and Norse, E.A. (1998). Disturbance of the seabed by mobile fishing gear: a comparison to forest clearcutting. *Conservation Biology* **12(6)**, 1180-1197.

Watson, R.A., Dredge, M.L.C. and Mayer, D.G. (1990). Spatial and seasonal variation in demersal trawl fauna associated with a prawn fishery on the Great Barrier Reef, Australia. *Australian Journal of Marine and Freshwater Research* **41**, 65-78.

*West, R.J. (1985). Mangroves. Agfact F2.0.1. NSW Agriculture and Fisheries, Fisheries Research Institute, Cronulla. 15 pp.

*West, R.J. (1989). Seagrasses. Agfact F2.0.2. NSW Agriculture and Fisheries, Fisheries Research Institute, Cronulla. 8 pp.

West, R.J. and Gordon, G.N.G. (1994). Commercial and recreational harvest of fish from two Australian coastal rivers. *Australian Journal of Marine and Freshwater Research* **45(7)**, 1259-1279.

*West, R.J., Thorogood, C., Walford, T. and Williams, R.J. (1985). An estuarine inventory for New South Wales, Australia. Fisheries Bulletin 2. Department of Agriculture New South Wales, Division of Fisheries, Sydney. 140 pp.

Whitley, G.P. (1940). *The Fishes of Australia. Part 1: The Sharks, Rays, etc.* Royal Zoological Society of New South Wales, Sydney. 280 pp.

*Willett, I.R., Melville, M.D. and White, I. (1993). Acid drainwaters from potential acid sulphate soils and their impact on estuarine ecosystems. **In**: *Selected Papers from the Ho Chi Minh City Symposium on Acid Sulphate Soils* (eds. Dent, D.L. and van Mensvoort, M.E.F.) ILRI Pubn. No. 53. pp 419-425.

Williams, R.J. and Watford, F.A. (1996). An inventory of impediments to tidal flow in NSW estuarine fisheries habitat. *Wetlands (Australia)* **15(2)**, 44-54.

*Williams, R.J., Henry, G.W., Murphy, J.J., Smith, A.K., Grima, D.M. and Harvey, J.R. (1993). Jervis Bay Marine Ecology Study. Project 9: Commercial and Recreational Fishing and Diving in Jervis Bay. NSW Fisheries, Cronulla NSW.

*Williams, R.J., Hannan, J. and Balashov, V. (1995). Kooragang Wetland Rehabilitation Project: Fish, Decapod Crustaceans and their Habitats. First Interim Report, Summer 1993/94. NSW Fisheries, Fisheries Research Institute, Cronulla. 106 pp.

Williams, R.J., Watford, F.A., Taylor, M.A. and Button, M.L. (1998). New South Wales coastal aquatic estate. *Wetlands (Australia)* **18**, 25-48.

*Williams, R.J., Watford, F.A. and Balashov, V. (2000). Kooragang Wetland Rehabilitation Project: History of Changes to Estuarine Wetlands of the Lower Hunter River. NSW Fisheries Final Report Series, No.22. NSW Fisheries. 82 pp.

Wilson, S.P. and Hyne, R.V. (1997). Toxicity of acid-sulphate soil leachate and aluminium to embryos of the Sydney rock oyster. *Ecotoxicology and Environmental Safety* **37**, 30-36.

Yearsley, G.K., Last, P.R. and Ward, R.D. (1999). *Australian Seafood Handbook: An Identification Guide to Domestic Species*. CSIRO Marine Research, Australia.

Young, P.C. (1981). Temporal changes in the vagile epibenthic fauna of two seagrass meadows (*Zostera capricorni* and *Posidonia australis*). *Marine Ecology Progress Series* **5**, 91-102.

Young, P.C. and Carpenter, S.M. (1977). Recruitment of postlarval Penaeid prawns to nursery areas in Moreton Bay, Queensland. *Australian Journal of Marine and Freshwater Research* **28,** 754-773.

*Zann, L.P. (1995). Our Sea, Our Future. Major findings of the State of the Marine Environment Report for Australia. Great Barrier Reef Marine Park Authority for the Department of the Environment, Sport and Territories, Ocean Rescue 2000 program. Commonwealth of Australia. 112 pp.

*Zann, L.P. (1996). State of the Marine Environment Report for Australia: Technical Summary. Great Barrier Reef Marine Park Authority for the Department of the Environment, Sport and Territories, Ocean Rescue 2000 program. Commonwealth of Australia. 531 pp.