ISSUE 4:
Effects of Harvesting on Biodiversity and Ecosystems

4.1 Overview and FRDC role

4.1.1 The issues

There is a widespread, growing concern about the effects of commercial and recreational fishing on ecosystems amongst the public and within the industries. A recent public survey of scope for a national oceans policy ("Waves" 1997) revealed that over 70% of respondents viewed the effects of commercial fisheries as their most important concern -- the second highest score after water quality - yet recreational fishing was a priority for only about 8%. Fisheries are also rapidly expanding into the deeper parts of the EEZ, usually ahead of any understanding of the habitat involved or its importance, and fishers are almost the only users of the resources there.

It is difficult to over-estimate the publicity generated by such fisheries as the orange roughy, gemfish, southern bluefin tuna and northern prawn. Bad public perceptions of imminent fisheries collapse, conflicts in resource sharing and environmental damage have become a major threat to fisheries. In the past few years the Biodiversity Unit of Environment Australia (formerly the Australian Nature Conservation Agency ANCA) has received nominations of oceanic longlining, prawn trawling and gillnetting for consideration as key threatening processes in management of endangered wildlife under the *Endangered Species Protection Act 1992*. Also, the failure of traditional yield-based management elsewhere has caused a push for adoption of the "precautionary approach" in fisheries management (Hilborn, 1996). This has been interpreted by some (eg. Dayton *et al.* 1995) to imply that the "burden of proof" (of low risk impacts) lies with the exploiter.

If nominations of prawn trawling and gillnetting succeed and a formal listing occurs, then these sectors of the industry are required to develop Threat Abatement Plans (TAPs) to mitigate threats to the survival of endangered species within three years of the listing date. Such nominations may spread to other fisheries as the conservation status of other

marine animals deteriorates. For example, nominations for grey nurse, great white and school sharks as “vulnerable species” under the *Endangered Species Protection Act 1992* are being considered.

Here we summarise the knowledge of effects of harvesting on Australian ecosystems -- but with only brief focus on the effects on target stocks. As a guide we have addressed all the issues identified in the global review of environmental effects of fishing by Dayton *et al.* (1995). We chose this particular review as a good starting point because it covers such a great variety of known and suspected impacts of harvesting. In contrast, the special volume (number 41, 1990) of the Australian Journal of Marine and Freshwater Research titled “Effects of Fishing” is somewhat of a misnomer, with a very narrow focus on issues associated with prawn trawling, particularly bycatch.

Some major Australian issues are outlined in Figure 4 (in Volume 1 of this review) and we have summarised R&D gaps and opportunities in Table 4.1.2.

The major concerns in Australia for effects of harvesting are :

- bycatch and wastage of fishes, elasmobranchs and crustaceans and incidental take of threatened, endangered or “charismatic” wildlife
- habitat damage by demersal trawls and scallop dredges
- indirect effects of reductions in target species and scavenging of discards
- generation of plastic debris and their environmental consequences
- changes in target species demography under fishing pressure (covered very briefly here).

These issues form an integral part of the FRDC core business and we conclude our coverage of them with sections reviewing current studies and knowledge on reducing and assessing the effects of harvesting. An informative overview of the policy and legislative framework behind some of these issues is given by Caton *et al.* (1997).

4.1.2 The literature

Australian literature on the effects of harvesting can be broadly broken down in Table 4.1.1 into three categories:

- bycatch documentation- by fishery type, depth, region and season; an entire issue of the Australian Journal of Marine and Freshwater Research (1990 Vol. 41 (1)) was concerned mainly with this issue: the first focus on effects of a particular fishery is documentation of bycatch composition and catch per unit of fishing effort. Informative

reviews of the bycatch in prawn trawl fisheries have been published by Andrew and Pepperell (1992) and Kennelly *et al.* (1992b).

- development and testing of bycatch reduction devices and practices to avoid habitat damage and make fishing gear more selective -- "monster" excluder-bars, square-mesh panels; semi-pelagic trawls; mesh-selectivity studies - cooperation of science and industry in R&D with high returns for investment. Informative reviews on R&D approaches and outcomes in reducing bycatch in the trawl industry have been presented by Brewer *et al.* (1997) and Kennelly (1997), and a full description of the various devices used in the prawn trawl fisheries has been published by Eayrs *et al.* (1997).
- studies that measure or infer effects of harvesting disturbances on benthic and fish communities, scavenger populations and populations of specific, non-target species -- includes studies of the mortality of megabenthos in trawl paths; fate of discards and scavenging routes; species shifts on fishing grounds; capture of juvenile stages of targets of other fisheries; changes in seabird populations. Reviews are not uncommon, as some major studies are still underway (eg. Blaber *et al*. 1994a, 1995a, and see FRDC#96/257) and the results of others are still being refined (eg. Moran *et al.* 1995). The broad results of the work done on the effects of fish trawling on the North West Shelf fisheries-megabenthos relationships has been reviewed by Sainsbury *et al.* (1997).

A somewhat neglected field of research in Australia has been sources of "unaccounted for" mortality of fish that have come into contact with fishing gear and escaped or otherwise been affected by fishing. A global review of these different sources of mortality has been presented by Chopin *et al*. (1997), with a focus mainly on trawling. In Australia, we found relatively few studies of short-term survival of turtles, fish and other organisms caught on hooks or in trawls, and only a single study of the possibilities of "ghost-fishing" (by snapper traps; Moran and Jenke 1989).

There is a growing body of literature that recognises the importance of assessing survival of animals that are caught and discarded (eg. turtles, Poiner *et al*. 1990, Ward 1996) or escape through bycatch reduction devices (see Brewer *et al*. 1997, Broadhurst *et al*. In Press a, Broadhurst *et al*. subm. c).

The survival of hooked fish released in recreational fisheries (eg. because they are undersize, unwanted species, or have been tagged) has been very poorly studied in Australia, despite a long history of overseas concern to improve such survival (see

Muoneke and Childress 1994 for review). The survival of fish caught on hooks in shallow water has been the subject of some recent study (coral reef fish, Diggles and Ernst 1997; yellowfin bream, Broadhurst *et al.* (subm. c); mulloway, Broadhurst and Barker (subm. e), and the results of telemetry of hooked and released billfish in north Queensland should be available soon (see FRDC#97/113).

A brief summary of the effects of harvesting is given for each Commonwealth fishery (where data exists) by Caton *et al.* (1997) and we have covered the same issues here in greater or lesser detail. However, their interpretation may be somewhat inconsistent as they acknowledge the possible impact of baitfish removals in pole-and-line tuna fisheries, but conclude that "the environmental effects of purse-seine fishing for jack mackerel are relatively small. Bycatch consists mainly of low catch rates (less than 5% by weight) of other commercial fish species". Jack mackerel are an important forage species for seals and other large predators in the fishing area.

The lack of literature on wider trophic effects of species removals may, therefore, reflect a lack of recognition of this effect of fishing. Bycatch issues and disturbance to benthic communities are of higher immediate priority and dominate the literature.

Table 4.1.1. Summary of Australian studies relevant to "Effects of Harvesting on Ecosystems and Biodiversity"

Fishery/Issue	Bycatch documentation	Bycatch reduction devices/practices	Substratum/benthos/ecosystem disturbance
Northern Prawn	Anon. (1993d), Eager and Campbell (1996), Harris and Poiner (1990), Hill and Wassenberg (1990), Limpus (1997), Marsh *et al.* (1997), Michaelis (1996), Pender *et al.* (1993a), Pender and Willing (1993a,b), Poiner *et al.* (1990), Ramm *et al.* (1990), Stevens (1993), Wassenberg *et al.* (1994), Ward (1996a)	Brewer (1994), Eayrs and Rawlinson (1995), Mounsey *et al.* (1995),	Harris and Poiner (1991), Hutchings (1990), Long *et al.* (1995), Poiner and Harris (1986, 1988)
West Coast/SA Prawn	Carrick (1997a), Laurenson *et al.* (1993)	Carrick (1997a), Broadhurst *et al.* (subm. f)	Carrick (1997a)
East Coast Prawn	Andrew and Pepperell (1992), Broadhurst *et al.* (1996a,b), Jones and Derbyshire (1988), Kennelly *et al*. (1992b, In Press b), Liggins *et al*. (1996),Robins (1995), Watson *et al.* (1990), Wassenberg and Hill (1989,1990)	Andrew *et al.* (1991), Andrew *et al.* (1993), Broadhurst (1995), Broadhurst and Kennelly (1996a, 1997), Broadhurst *et al.* (1996b, subm. b), Robins-Troeger (1994), Robins-Troeger *et al.* (1995),	Blaber *et al.* (1994a,1995a), Wassenberg and Hill (1987a,1990), Broadhurst (subm.d), Blaber *et al.* (1989), Pitcher (1997)
Estuarine Prawn	Andrew *et al.* (1995), Gray *et al.* (1990), Kennelly *et al.* (1992a), Liggins and Kennelly (1996)	Broadhurst and Kennelly (1994), Broadhurst and Kennelly (1995b, 1996b), Broadhurst *et al.* (1996a, 1997a, In Press c)	Gibbs *et al.* (1980)
Northern Fish	Moran *et al.* (1995), Ward (1996b)	Brewer *et al.* (In Press), Mounsey and Ramm (1991), Ramm *et al.* (1993),	Moran *et al.* (1995), Sainsbury (1982, 1987), Sainsbury *et al.* (1993, 1997), Thresher *et al.* (1986)
SE Fish Trawl	Tilzey *et al.* (1990), Tilzey (1994)	Broadhurst and Kennelly (1995a),	
Longline	Ross (1996), Stevens (1992)	Anon. (1991b), Chapman (1995), Dalziell and Poorter (1993)	
Scallop		Cover and Sterling (1994) , McLoughlin *et al.* (undated FRDC #91/49),	Black and Parry (1994), Currie and Parry (1994, 1995), Dredge (1989), Parry and Currie (1992),
Gillnet	Beumer *et al.* (1981), Grant (1993), Harwood and Hembree (1987), Marsh *et al.* (1995,1996), Marsh and Corkeron (1997), Paterson (1990), Russell (1988), Schaap and Green (1988), Williams and Schaap (1992),	Hembree and Harwood (1987)	

Fishery/Issue	Bycatch documentation	Bycatch reduction devices/practices	Substratum/benthos/ecosystem disturbance
Handline		Otway and Craig (1993)	Ayling *et al.* (1992)
Abalone/Rock Lobster			Andrew (1993a), Andrew and McDiarmid (1991)
Shoreline Harvesting/Angling	Kingsford *et al.* (1991a)	Winwood (1994)	Catterall and Poiner (1987), Forbes (1984), Keough *et al.* (1993), Luck (1990), Povey and Keough (1991), Quinn *et al.* (1996), Underwood (1993), Underwood and Kennelly (1990)

4.1.3 FRDC action

The FRDC plays the lead role in investing in R&D on the effects of harvesting on the environment and ways to reduce them. The outcome should be achieving sustainable fisheries, but there are not yet clear guidelines, goals and performance indicators for such an outcome in Australia - even for “biological reference points” in the fished stocks themselves (see Staples 1997).

The fundamental priority for the FRDC should be to help develop frameworks for defining and evaluating progress towards achieving this outcome. Staples (1997) recommends four key points:

- specifying what is to be achieved in terms of the resource, the environment, the economic and social benefits
- defining what is meant by “success” in meeting these objectives
- developing performance indicators against these objectives
- implementing a management system that has actions “triggered” by pre-defined changes in these indicators.

Priority R&D gaps and issues for the FRDC Ecosystem Protection Program will automatically arise from consideration of these needs by Management Advisory Committees, Fisheries Research Advisory Bodies and other organisations. The status reports for Commonwealth fisheries (see Caton *et al*. 1997) provide a good example of how environmental issues (and thus R&D needs) can be incorporated in State fishery reports - we found a general lack of reporting of the existing or potential effects of Australia’s many fisheries. There is a particular need for the FRDC to show initiative and responsibility in the prevailing climate of rapid expansion of fisheries into deeper waters of the EEZ, usually ahead of any understanding of the habitat involved or its importance, and fishers there are almost the only users of the resource.

In the meantime, there does exist a clear desire amongst both the public and industry to reduce the unpopular effects of fishing as an outcome in itself. This has been acknowledged in the July 1997 release of the draft Commonwealth Bycatch Policy, convened by the Australian Fisheries Management Authority. The primary goal is to develop “Bycatch Action Plans”.

In addressing this outcome our review has listed and described briefly the known and potential effects of harvesting from the Australian literature, and we suggest a general

range of R&D opportunities based on assessing and reducing these effects that may complement the existing FRDC "Effects of Trawling" sub-program.

We conclude that there have been very high returns on the investments being made by the FRDC in cooperative design and testing of more selective fishing gears, and that this should be expanded to a wider suite of fisheries. Kennelly (1997) has identified and demonstrated a very successful approach involving observer programs to first identify the bycatch issues and opportunities and then use close R&D partnerships with the commercial fleets to build, test and publicise the performance of bycatch reduction devices.

Less publicised is the need for development of R&D approaches to assess the short and long-term survival of bycatch or target species that escape, are discarded or pass through bycatch reduction devices.

There still remain large gaps in knowledge about just what the bycatch issues are in many sectors of the Australian fisheries. These gaps range from lack of knowledge of bycatch composition in specific fisheries (especially recreational fisheries) to need for spatial and temporal refinement of data on bycatch occurrence. Underlying the bycatch issue is a need for a "short-list" of species that should be avoided - a need for R&D on the "sustainability of bycatch" that is being piloted by FRDC #96/257 for the northern prawn fishery.

Studies of megabenthos destruction indicate that the North West Shelf may be an extreme example and that this threat needs to be assessed separately by close study of trawl paths in other fisheries, such as the SE Trawl fishery and the Arafura and Timor Seas. The key to understanding the effects of habitat damage in these fisheries is knowledge of the precise locations of trawling intensity, and of megabenthos growth, mortality and recruitment rates. Study of some of these factors is underway now in FRDC#97/205 and FRDC #96/257.

Ultimately this research will lead to consideration of untrawled megabenthos corridors that could serve both as harvest refugia and sources of replenishment as well as conserving benthic biodiversity. The evolution of differential GPS and vessel tracking technology (eg. Vessel Monitoring Systems VMS) offers great potential for collecting

precise information on the spatial nature of fishing, its bycatch and its potential for destruction of megabenthos.

There is a need for the FRDC to become more proactive in recognising the threats and opportunities posed by the current focus on implementation of a National System of Marine Protected Areas (NRSMPA) by the year 2000. The Interim Marine and Coastal Regionalisation of Australia (IMCRA) and other initiatives under "Ocean Rescue 2000" - a Dept of Environment, Sport and Territories responsibility -- form the basis for the planning of Marine Protected Areas (see Chapter 2).

If the appropriate knowledge of fisheries habitats is available (eg. inventories of fisheries habitat values, landings and effects of harvesting) and is part of the planning process, the NRSMPA could potentially provide a strong basis for a Fisheries Habitat Protection strategy. If the data are not included and the research not available, it will be difficult to optimise the fisheries value of marine park areas in cases where there is conflict with the goals of conservation of biological diversity.

Trawling is already covered under multiple-use provisions for management of the Great Barrier Reef Marine Park so the impact of NRSMPA may not be so severe in the north-east of Australia. In contrast, the biodiversity of the south has been vastly under-represented in the current Australian provision of Marine Protected Areas (Edyvane 1997) and such closures may not be part of normal fishing culture there.

Consequently, the greatest cause for concern may lie in the rock lobster, abalone and southern shark fisheries of the temperate reefs and the rocky-shore recreational fisheries. These fisheries lie in centres of biodiversity and "nests of endemicity" and their ecological effects have been hinted at (eg. Stoddart and Simpson 1996, Edyvane 1996a) - but not fully studied. Determination of the effects of rock lobster pot fishing on kelp, and abalone diving on species interactions, are amenable to powerful observation and experimental approaches.

"Baitfishes" such as jack mackerel, pilchards and anchovies are known to support populations of cetaceans, seals, sea lions, seabirds and predatory sportfish and gamefish. They are also widely fished for growing markets for human consumption, mariculture feed and angling bait. There is however no knowledge of the levels of competition for baitfish between these predators and the expanding commercial fisheries. The overseas

literature shows that extensive dietary analyses and construction of food webs are needed to predict the paths of such impacts (eg. Bax 1991). Further complexities are introduced by fishing of the predators themselves -- for example the populations of southern bluefin tuna reduced by fishing in the Great Australian Bight presumably ate much larger quantities of pilchards before both the tuna and pilchard fisheries began there.

There is a need to develop R&D techniques for studying such interactions. The larger predators (eg. dusky sharks in WA, seals) are also the major victims of entrapment in bait-box bands and other fishing debris. Development of “environmentally friendly” bait packaging (eg. biodegradable pilchard bags) could be a valuable expansion of the FRDC’s investments.

Finally, the deployment of artificial reefs (Branden *et al*. 1994) poses many R&D questions. They may be Australia’s earliest response to concerns about habitat destruction, but they could equally be viewed as mainly another fishing practice to aggregate fish and fishing effort (see McGlennon and Branden 1994). Their role as “sources” or “sinks” of fisheries production remains unknown and poorly studied (see Pickering and Whitmarsh 1997 for international review), but perceived benefits and demand for them is high (eg. Gorman 1995a,b). With a current focus on habitat restoration there may be a role for artificial reefs in areas where seagrass has been removed (eg. Cockburn Sound shell-sand mining), but basic questions about materials and design are not sufficiently known (Branden and Reimers 1994). Rubber tyres may exude sulphur-based compounds that actually discourage overgrowth by epifauna. Artificial reefs may, theoretically, comprise a habitat disturbance and pose a risk as a haven for introduced marine pests (see Chapter 5).

Table 4.1.2. Summary of Major Opportunities for FRDC investment in addressing R&D Gaps in knowledge of "Effects of Harvesting on Ecosystems and Biodiversity"

R&D Gaps	Main Habitats	Main Fisheries	Key Reference	Initiatives
understanding of the habitat and implications for ecosystem disturbances in the rapid expansion of new fisheries into deeper waters of the EEZ, and of existing fisheries on shelves where fishing is the major human impact	EEZ deeper than 20 m (national)	new seamount fisheries, demersal trawl, pelagic longline	Koslow (1997)	CSIRO FRDC#94/040, CTC/IMCRA
Lack of sufficiently comprehensive documentation of spatial fishing intensity, bycatch, and resilience of bycatch populations - what are the issues and which bycatch should be avoided?	Shelf, Gulfs, Bays (national)	Prawn Trawl, Finfish Trawl, Tropical Gillnet	Andrew and Pepperell (1992), Kennelly (1997), Pitcher *et al*. (1997), Robins (1995), Poiner and Harris (1996)	AFMA C'wlth Bycatch Taskforce
Untrawled Megabenthos corridors on trawl grounds - opportunities for fishery enhancement and biodiversity conservation - what are megabenthos recovery rates?	GBRMP, Moreton Bay	Prawn Trawl		FRDC "Effects of Trawling" sub-program, and FRDC#97/205
Need for further development and extension of "environmentally-friendly" fishing gear, techniques and codes of practice	Shelf, Gulfs and Bays (national) and estuaries (NSW)	Prawn Trawl, Finfish Trawl, sthn shark Gillnet; Tropical Gillnet	Brewer *et al*. (1997), Eayrs *et al*. (1997)	AFMA C'wlth Bycatch Taskforce
Effects of fishing on stocks, biodiversity, food chains and the substratum -- Insufficient knowledge-base to integrate fishing with plans for a National System of Marine Protected Areas?	Major gaps for rocky and coral reef fisheries (also shelves, see above)	Rock Lobster, Abalone, Recreational Line (esp. NSW) and Net (Tas.), GBR Line		CRC Reef "Effects of Line Fishing" experiment, CTC/IMCRA
Effects of Baitfish Removals on predators - how can it be assessed?	Shelf and Bays (WA, SA, Tas, Vic, Qld)	Pilchard, Jack Mackerel, Anchovy	Glaister and Diplock (1993)	
"Environmentally Friendly" Bait packaging - bait-box bands, plastic bait bags	Sub-tropical/Temperate inshore (WA, SA, Tas)	Rock Lobster, Recreational surf and rock-fishing	Wace *et al*. (1996)	
Artificial reefs -- sources or sinks of fisheries production?	Temperate inshore	Recreational Line	Pickering and Whitmarsh (1997)	

4.2 Bycatch and incidental take

The ESD Working Group on Fisheries (1991) defined bycatch as "*The part of the catch which has no commercial value and is returned to the sea, usually dead or dying*". The draft Commonwealth Policy on Fisheries Bycatch further defines by-product as the commercially valuable portion of the catch that was not the target, and bycatch as that portion of the catch that is discarded.

A review of the SOMER reports (Jones and Kaly 1996) and the bycatch literature in Table 4.1.1 (eg. Andrew and Pepperell 1992, Dayton *et al.* 1995, Limpus 1997, Hulsman *et al.* 1997a,b) shows that perhaps the most sensitive bycatch or target species are those with all, or combinations, of the following life-history traits:

- natural rarity - less than 10 breeding pairs of wandering albatrosses (Macquarie Island sub-species) are now present in Australian territories;
- restricted ranges - flatback turtles are endemic to NE Australia
- low populations, but with aggregative behaviour - small cetacean species
- low reproductive rates and live-bearing- - many sharks, sawfishes (*Pristis* spp) and rays; seasnakes; dugongs; (eg. loggerhead turtles average only 5 breeding seasons in a lifetime with 128 eggs per clutch, and 4 clutches, per breeding season)
- old age at first maturity and slow growth rates
- longevity -- adult turtles most vulnerable to fishing are several hundred times more valuable than juveniles in terms of population replacement potential; albatross pair to mate for life; North West Shelf sponges may be centuries old
- association and aggregation with target species -- juvenile mulloway (and perhaps loggerhead turtles) associate with prawns to prey on them; seabirds and dolphins associate with yellowfin tuna schools
- prolonged recruitment failure - ENSO events depress green turtle nesting and can cause starvation of penguin chicks; species at the edges of their range may have episodic recruitment
- large size, wide body shapes and/or slow movements - turtles and seals are entrapped or entangled in gears, ropes and litter; sawfishes and rays are herded by trawls
- poor survival when released - ram-jet ventilators (eg. queenfish, great white sharks) die very quickly in gillnets; air-breathers drown; soft-bodied species are crushed or embolised; species with swimbladders are embolised

These species may need decades (whales) to centuries (sponges) to recover from serious depletions of their populations. They include "charismatic megafauna", such as sea mammals, turtles, albatrosses and large sharks and rays. Less popular, but vulnerable nonetheless, are many benthic or deep-sea species of invertebrate and fish that share the characteristics of much delayed reproduction and low fecundity. Adult survivorship is extremely important to sustain populations of these two groups of organisms. Jones and Kaly (1996) have outlined some of these population concepts in the context of conservation. These patterns emphasise the importance of obtaining demographic data for bycatch as well as target species.

Apart from direct effects of depletion on the bycatch species, some popular ecological theories predict cascading effects on ecosystems of removals of "keystone" species. For example, Dayton *et al.* (1995) correlated a longline catch over 1 million large sharks with a rise in grey seal population from 3000 to 45 000, a rise in the infestation of cod with seal-worm parasites, and later stress and mortality in the high density seal population. Clear evidence of such indirect effects, not confounded by other factors, is lacking throughout the world - but "species-shifts" have been documented in Australia and elsewhere (see Section 4.5 below).

There have been a variety of responses to the bycatch issue in Australia, but the most thorough is perhaps demonstrated for the South East fishery (the Integrated Scientific Monitoring Program ISMP), the NSW prawn fisheries and the fisheries managed by the Commonwealth. These have involved:

- observer programs and monitoring of fleet dynamics, catch, bycatch and discards
- R&D response to nominations for particular fisheries as "key threatening processes" under the *Endangered Species Protection Act 1992*
- R&D response in developing "Threat Abatement Plans" (TAPs) in the case of successful nominations
- R&D in development of bycatch reduction devices and monitoring and extension of their performance.

4.2.1 Gillnetting - interactions with "charismatic megafauna" and bycatch issues

Australia lacks the pelagic drift-net fisheries notorious in other fishing zones for bycatch of cetaceans, seals and seabirds. Those effects have been reviewed by Dayton *et al.* (1995) and FAO. Taiwanese drift-netting for shark, tuna and mackerel became un-economical in

the northern AFZ after modifications to reduce dolphin bycatch failed (Hembree and Harwood 1987) and net lengths were restricted under license conditions downward from 10-20 km to 1.5 km.

However, inshore gillnetting north of the tropic of Capricorn for the purposes of both commercial fishing and government shark control is now known to have caused large bycatch of dugongs, dolphins, turtles, rays and sharks. Even Humpbacked whales have been captured occasionally in the anti-shark nets (McPherson 1997). With the exception of dugong declines (see Box 4.2.1 below) there has been assessment of only the effects of such gillnetting on shark catch rates.

For example, in the Queensland shark meshing program Paterson (1990) reported capture between 1962 and 1988 of 520 “dolphins”, 576 dugong, 3656 turtles and 13765 rays, aside from target sharks. For the target, “dangerous” sharks Simpfendorfer (1992) concluded that near Townsville Tiger Sharks had not been depleted, but populations of large Whaler sharks (*Carcharhinus* spp) had declined.

The issues surrounding inshore and estuarine gillnet fishing concern bycatch of threatened species and angling targets, waste through discarding practices and mesh selection on target species. These issues are important mainly in the tropics and fall into 4 categories :

- bycatch of dugong - and (very rarely) turtles, Irrawaddy and Indo-Pacific Humpbacked dolphins (see Marsh *et al.* 1997) and crocodiles
- bycatch and ethics of the anti-shark meshing program
- byproduct or bycatch of species popular with anglers - mainly Queenfish (*Scomberoides commersonianus*)
- discarding and/or poor quality of catch in times of large catch in hot climes
- mesh selection for large, female barramundi (eg. Russell 1988).
-

Voluntary cessation of indigenous hunting of dugong, and the recent ban on some forms of gillnetting, in a series of 9 (possibly extended to 12) large (>= 200 km) tracts of coastline in the Southern and Central GBR reflects the most pressing issue other than trawling - dugong bycatch -- and is summarised in Box 4.2.1 to show the overlap with other habitat issues.

In 1997 a nomination was received to list gillnetting in tropical and sub-tropical waters (Moreton Bay around to Shark Bay) as a key threatening process under the *Endangered Species Act 1992*.

BOX 4.2.1. THE DUGONG DECLINE

Dugongs are listed as vulnerable to extinction -- a contributing factor in listing of the GBRMP under World Heritage. Their life-history traits -- aggravated by seagrass loss -- make the "tolerance" for bycatch in fishing or shark meshing very low:

- an age at first maturity of 10-17 years
- an average calving interval of 3-7 years
- a single calf per calving
- a longevity of 70 years

A sustainable rate of harvest has been estimated at only about 1-2% of females every year. Given the known applications for indigenous harvest, the tolerance for incidental death by other causes has been estimated at only 1 per 200 females per year.

There has undoubtedly been a significant decline in the southern GBR region. Aerial surveys showed a dramatic decline between Cooktown and Bundaberg of

- 3479 +- 459 dugong in 1986/87
- 1857 +- 292 in 1992
- 1682 +- 236 in 1994

This compares to Northern GBR counts of 10,471 +- 1073 and Hervey Bay 1971 +- 359 in 1988.

The Reasons

1. *Gillnet Bycatch*. There was a known kill of 4 dugong in one month in Shoalwater Bay commercial operations, but logbook data is lacking. In Townsville the anti-shark meshing killed about 80 animals in its first year of operation and between 1963 and 1983 there were about 249 deaths. More recently 25 dugong were reported killed in the Townsville shark nets during 1988-92.
2. *Traditional Indigenous Hunting.* Data on CPUE or even Catch per permit is not collected -- but there has been an increase in the number of permit applications to take dugong
3. *Loss of seagrass*. Of the meadows known to support dugong 27% are within 5 km of a waste outlet. Seagrass loss was a huge problem in Hervey Bay. In 1988 there were about 200 dugong in the Bay. In 1992 two floods and a cyclone in quick succession killed about 1000 km^2 of seagrass (Preen *et al.* 1995). There were more than 100 dead dugong washed ashore. However, there has been inadequate monitoring of seagrass change in the GBRMP - a major flood in the Burdekin River had an unknown impact on seagrass and dugong in "pristine" bays near Townsville during the period of decline.

The calving rate has not risen in Hervey bay with subsequent seagrass recovery - the numbers have stabilised but the calves are not being born because the dugongs are still more or less starving. The calving rate has dropped from 22% to 1.5% in 1994. There has been a similar drop in Cleveland Bay calf sightings.

Some suggested Fisheries R&D was to urgently

- assess risk of dugong drowning in netting operations
- identify hot-spots where the activities of dugongs and gillnets overlap
- consult fishers to develop practices to avoid dugong capture and help rescue

Further Reading: Marsh *et al.* (1995, 1996, 1997), Marsh and Corkeron (1997)
Stop Press: Dugong Protection Areas (DPAs) declared, and arrangements in progress for buy-back of gillnet endorsements on licences by QFMA

Gillnetting on temperate reefs is conducted by both recreational and commercial fishermen in Tasmania - the latter for a growing live-fish trade in Banded Morwong (*Cheilodactylus spectabilis*) and Wrasses (*Pseudolabrus* sp). Fisheries-independent surveys by Schaap and Green (1988) showed significant differences between reefs subjected to different levels of fishing pressure in the relative abundances and the average size of some species, total fish abundance, and community diversity and species composition.

This result reflects the sensitivity of such reef faunas to disturbance predicted by a large number of New Zealand studies (eg. see Jones 1988b for review) that showed surprising longevities (odaciids live for up to 70 years p.c. J.H Choat; *C. spectabilis* for at least 50 years p.c. M. McCormick), high levels of site attachment (Barrett 1995) and complex sexual structures in populations (see Jones' papers in Appendix 5). The results of small-scale removals of individuals in these experimental studies have been characterised by significant effects on local populations.

4.2.2 Trawling and scallop dredging

Demersal trawling is the least selective of all fishing techniques in Australia, with the highest overall bycatch to target ratios in catch and possibly the highest public profile. It is also the largest producer of food fish for domestic markets (eg. SE trawl fishery, east coast otter trawl), a major source of high-value exports (northern prawn) and the single biggest commercial sector in Queensland.

There have been major reviews of this subject (eg. Andrew and Pepperell 1992, Kennelly 1995, 1996) and we will briefly cover here only the major points or new information. In general terms most studies show that bycatch is made up of small fish (<20 cm), and relatively few species predominate.

At the centre of concern for trawl bycatch is public perception of :

- turtle drownings
- killing of juvenile, commercially and recreationally important species
- destruction of megabenthos (see Section 4.3 below)
- wastage of fish

These concerns are present in one form or another wherever trawling occurs (eg. Hanley and Couriel 1992, Hanley 1996, Edyvane 1996a). Surprisingly, the sheer

inefficiency of prawn trawls in capture of most fish species (see Wassenberg *et al.* 1997) has not penetrated the public debate about the practise.

At the time of writing this review, prawn trawling (nominated in 1995) was being considered for listing as a key threatening process under the *Endangered Species Protection Act 1992* because of incidental catches of turtles, sea-snakes and two species of monacanthid leatherjackets (see Caton *et al.* 1997). It is ironic that the monacanthids were chosen. Apparently because they had declined the most, amongst only 18 taxa whose abundance had declined significantly, in a study of 82 species comparing survey results before and after 20 years of prawn trawling in the Gulf of Carpentaria (see Harris and Poiner 1991).

From an industry viewpoint bycatch is a problem (see Eayrs *et al*. 1997) because of:

- reduced gear efficiency - trawls spread less as the cod-end loads up
- crabs, megabenthos and "monsters" crush or scale and devalue prawns and fish
- "monsters" are dangerous to handle and bycatch raises handling and sorting times with heavier cod-ends
- dead fish (particularly in inshore banana prawn fishing on the east coast) wash up and cause public outrage
- sharks scavenge discards and may eat more prawns (see Section 4.4 below)
- retention of the blue swimmer crab bycatch is illegal in SA and they must be discarded.

Dayton *et al.* (1995) suggest that fisheries-related mortality may be the single biggest factor preventing recovery of sea turtle species - but this includes methods such as longlining and drift-netting as well as trawling.

Current and recent studies are addressing a significant gap in knowledge of the factors causing drowning and mortality of turtles in trawl fisheries. The green (*Chelonia mydas*), hawksbill (*Eretmochelys imbricata*), olive ridley (*Lepidochelys olivacea*), flatback (*Natator depressa*) and loggerhead (*Caretta caretta)* turtles are listed as being endangered, threatened or rare in the Commonwealth *Endangered Species Protection Act 1992* and the Queensland *Nature Conservation Act 1992*.

From several data sets collected between 1979 and 1988 in the northern prawn fishery, Poiner *et al.* (1990) estimated that an average of 5,730 (+- 1,907) turtles were caught

every year, of which an average of 344 (+-125). Though after the introduction in 1987 of management measures to reduce effort in the fishery, the number captured declined to about 4,114 (+-1369) turtles in 1988, of which an estimated 247 (+-90) turtles drowned. Notable factors were:

- turtle bycatch was restricted to depths< 43 m and the highest bycatch rates were from trawls of about 90 minutes in water <= 25 m
- flatbacks were the main turtle caught, but there were regional differences - loggerheads were caught in similar numbers to flatbacks in the SE Gulf
- no mortality recorded in trawls of ~ 90 minutes, rising to 7% in trawls of 180 minutes.

This study was then followed up, and refined, by Poiner and Harris (1996) who investigated the catch, mortality rates, size composition and injury rates for turtles at a species level in 1989 and 1990. Estimates were made of the sea turtles captured and killed in the fishery as well as the likely population sizes of turtles on the trawl ground.

From a monitoring program conducted by trained, volunteer fishermen and data analysis using elementary probability theory, Poiner and Harris (1996) found that:

- of the five species captured, three comprised 81% of the catch - the flatback (59%), the loggerhead (10%) and the olive ridley (12%). Green turtles (8%) and the hawksbill (5%) were captured only occasionally
- the highest catch rates were in depths between 10 and 40m (a 233,100 km^2 portion of the fishery), with few turtles captured below 40m (comprising 549, 900 km^2 of the area of the fishery)
- the highest catch rates were in the winter months of June and August, shortly before nesting commences in the early summer months
- mortality rates of the flatback, olive ridley and green turtles were relatively low (~11%) but the rates for loggerhead and hawksbill turtles were high (>20%) which may reflect the relative abilities of the species to resist drowning
- between 5,000 and 6,000 turtles are captured each year and about 14% drown in the trawl nets, with another 25% injured or comatose when brought aboard
- mortality estimates are <2% of the trawl-ground population size for all species except loggerhead (2.39%) and hawksbill (2.99%)
- the indigenous harvest of the green turtle in the Torres Strait is of the order of 5,200 to 6,300 turtles per year, and the Indonesian commercial fishery for turtles is estimated to take >70,000 adult green and hawksbill turtles per year.

Poiner *et al*. (1990) concluded that from the available data, however inadequate, the impact of trawl-induced drownings on the turtle populations was probably not of such proportions as to create immediate concern. Poiner and Harris (1996) concluded that the data were again inadequate, but also that trawler-induced mortality in the northern prawn fishery has less impact upon turtle populations than other hazards in northern Australia.

However, these contentions have not met general agreement. For example, Kennelly (1996), Marsh and Corkeron (1997), and Limpus (1997) ranked fishing as a primary threat to flatback, loggerhead, green and olive ridley turtles. There is general agreement amongst the fishing industry with the recommendations by Poiner *et al*. (1990) and Poiner and Harris (1996) that any measures that reduce drowning and delayed mortalities of turtles would be desirable.

Poiner and Harris (1996) indicated that options the fishery may have to reduce turtle mortality include:

- restrictions on fishing around seasonal nesting times (already done in the Gulf of Carpentaria)
- publicity on the importance of retaining comatose turtles until recovery
- shorter trawl tows (< 90 min)
- development of alternative trawl gear (see Section 4.8 below).

The numbers of turtles caught and killed in the Queensland east coast otter trawl fishery were estimated by Robins (1995) from a 2-year monitoring program using 50 volunteers from the commercial fleet. The results were:

- an average catch rate of 0.068 turtles *per day* fished - compared with the highest catch rates from Poiner and Harris (1996) of 0.098 turtles *per trawl* (we multiplied this by the usual 4 trawls per day to give a highest comparative estimate of 0.039 turtles *per day* fished in the northern prawn fishery)
- loggerhead (50.4%), green (30.1%) and flatback (10.9) turtles were the main species caught
- an estimated 5295 +- 1231 turtles were caught annually by the Queensland east coast otter trawl fishery, which had an annual fishing effort of 80,558 days
- about 1.1% of captured turtles were reported dead when landed. This mortality rate is lower than those reported for other trawl fisheries because in the Queensland east

coast otter trawl fishery tow durations are short (<80 min) in the areas where turtles are commonly caught.

Robins (1995) concluded that if all comatose turtles are assumed to die, the potential mortality rate of trawl caught turtles could be as high as 6.8%. However, the true mortality rate is probably somewhere between 1.1% and 6.8% of turtles landed, because some trawlermen resuscitate trawl-caught turtles.

Ward (1996a) compared the sea snake bycatch made by vessels that target different types of prawns in the northern prawn fishery:

- in 1989-90, 5203 sea snakes of 14 species were sampled. Hydrophines (11 species) represented 86.7% of the total catch. Aipysurines (3 species) represented 15%of specimens from vessels that targeted tiger prawns or endeavour prawns, but comprised only 1.1% of specimens from vessels that targeted banana prawns
- it was estimated that prawn trawlers operating between Koolan Island and Cape York during 1990 caught approximately 81,080 +- 13,670 sea snakes
- vessels that targeted tiger and endeavour prawns caught approximately 69 260 +- 8750 sea snakes
- vessels that targeted banana prawns *Penaeus merguiensis* caught 7200 +- 3250 sea snakes
- vessels that targeted red-legged banana prawns *P. indicus* caught 4620 +- 1120 seasnakes.

The results emphasised the advantages of interactions between fishers and scientists and the need to assess separately the impacts of the three fisheries that constitute the northern prawn fishery.

The turtle controversy and sea snake data illustrate our major gaps in knowledge of bycatch, its complexity and some solutions - bycatch is time, depth, area and gear specific, survival at release is species-specific (although most fish die), there are often other sources of fishing mortality and the "sustainability of bycatch" depends on the demographic parameters of the species in question. The units of effort used in reporting and estimating bycatch rates also cause problems when trying to make regional comparisons - emphasising again the need to improve the gathering of "logbook" information from fleets, using innovations such as Vessel Monitoring Systems.

In the absence of such data, public perception has been dominated by simple figures of prawn trawl bycatch : target ratios of 9 : 1 or even 20 : 1, yet in some fisheries the opposite trend is true -- eastern king prawns are fished down to 300m with 50-60% or less bycatch and discards and bycatch are usually much higher in water <30 m deep. Also overlooked is the rapid, growing trend to find markets for bycatch, that should best be classified now as "byproduct". In the deep-water , eastern king prawn fishery the cuttlefish, octopus, flounder, angel sharks (*Squatina* spp), goatfishes (*Upeneus*) and even shovelnose ray (*Aptychotrema rostrata*) tails are now sold for domestic consumption. Elsewhere on the east coast bugs (*Ibacus* and *Thenus*), scallops and sand crabs (*Portunus pelagicus*) are important byproduct.

In Southern Australia, too, the bycatch : target ratios are generally much lower than those publicised in the tropics. Carrick (1997a) recorded an average ratio of 3.5 : 1 for the Spencer Gulf prawn fishery, and Laurenson *et al.* (1993) reported that 130 tonnes was retained for sale of an estimated total catch of 354 tonnes of marine fauna off south-western Australia.

Allegations that prawn trawling destroys juveniles or competes for stocks of important species are widespread in Australia, but particularly so for:

- juvenile mulloway in NSW estuaries
- juvenile Spanish mackerels (*Scomberomorus commerson*) (eg. McPherson 1981) and "reds" (*Lutjanus sebae, L. erythropterus and L. malabaricus*) in localised regions of north Qld
- juvenile snapper (*Pagrus auratus*) in SA and parts of NSW and Qld
- adult King George whiting and juvenile squid (*Sepioteuthis australis*) in SA
- adult sand (blue swimmer) crabs (*Portunus pelagicus*) in WA, SA and sthn Qld
- adult school whiting *(Sillago bassensis*) in sthn WA.

The vulnerability of these animals to trawling is known to vary greatly with season and substratum type. For example, *Lutjanus erythropterus* and *L. malabaricus* move offshore from shallow nurseries through trawl grounds, but mainly in muddy channels, and Spanish mackerel are found on the trawl grounds inshore of their major spawning ground for only a short part of their life-history (p.c. #90 G. McPherson).

Carrick (1997a,b) showed significant bycatch of juvenile snapper only during good recruitment years when juveniles were caught outside their normal habitats in Spencer

Gulf. There was no significant influence of trawl bycatch-rates of King George whiting on the commercial catch rates for this species in a statistical analysis using 20 years of logbook data and lags in effect times of trawl effort. There have been claims (eg. Edyvane 1996a) of an interaction between trawling and declining catch rates of this species in south-eastern Spencer Gulf.

Trawl fisheries are by nature very complex in Australia, with marked variation in targets and gears on the basis of cross-shelf depth and sediment types (Watson *et al.* 1990, Gribble 1997), latitudinal region (see Williams 1997), season and market price (eg. Gribble 1997). For example, more than 80 species are exploited in the multispecies South East fishery, with 17 species managed under quotas (Caton *et al*. 1997). As a result there are very different bycatch issues and effects on the benthic habitats.

For example, a major issue in the SE Trawl has been a lack of gear and mesh selectivity studies and the large-scale (up to 50% on occasion) discarding of redfish (*Centroberyx* spp) and up to 20-30 % of tiger flathead because of size and price (p.c. #1000 D. Smith). Caton *et al*. (1997) list discard rates as 50% by weight for the total catch off NSW and eastern Victoria to 14-26% in the southern orange roughy fishery.

Assessing the selectivity of a range of gear types, including demersal trawls, in different habitats of the SE fishery is one of the objectives of a current project (FRDC#96/275 and FRDC#94/040).

Australian bycatch research, as a consequence, is active on three main fronts that vary in development or importance from region to region and fishery to fishery. These are summarised in Table 4.1.1 , under the headings:

- bycatch documentation - by fishery type, depth, region and season, and by partitioning into discards that float or sink, and are eaten by different types of scavengers; Volume 41(1) of the Australian Journal of Marine and Freshwater Research titled "Effects of Fishing" was concerned mainly with this issue. A broad, first focus of the Integrated Scientific Monitoring program (ISMP) in the SE Fishery was documentation of bycatch and discards through observer programs (see Caton *et al*. 1997)
- adaptation, design and testing of bycatch-reduction devices (BRDs) - "monster" excluder-bars, square-mesh panels; semi-pelagic trawls; mesh-selectivity studies - cooperation of science and industry in R&D with high returns for investment. Kennelly (1997) and Brewer *et al*. (1997) provide informative reviews on the state of

knowledge and R&D directions, while Eayrs *et al*. (1997) give technical descriptions of all devices used in Australian prawn trawl fisheries

- ecosystem effects of habitat damage, species removals and discard additions - includes studies of the fate of discards and scavenging routes; species shifts on fishing grounds and in seabird populations. Reviews on the topic are rare (eg Sainsbury *et al*. 1997) and a number of major studies are underway (see Section 4.8 below). For example, a new initiative (FRDC#96/257) aims to elucidate "sustainability" of bycatch groups by summarising their demography and vulnerability.

4.2.3 Bycatch in other fisheries -- estuarine angling, trawling and pocket-netting -- bycatch of juveniles of important species

West (1993) noted that a marked lack of juvenile mulloway in the Clarence River (NSW) in sampling during March and June was a result of the prawn trawling season there. In earlier months the biggest samples of mulloway had come from the main river channel where prawn catches were often the highest. Both Oyster Channel and the Broadwater on the Clarence River were deemed especially important as sub-tidal nursery habitats and these areas were subsequently closed to prawn trawling. This particular fishery has also received attention in fully documenting the bycatch issues (Liggins and Kennelly 1996) and developing devices to and net designs to reduce the bycatch (see eg. Broadhurst and Kennelly 1994, 1995b). Similar issues exist for mulloway bycatch in the Hawkesbury (Gray *et al*. 1990).

The angling media has been vocal in criticising the level of mortality of juvenile fish in the bycatch of commercial fishing operations, yet creel surveys in several States are uncovering large proportions of "under-size" fish being kept by anglers. These fisheries can be larger than their commercial counterparts. For example, West (1993) found that about half the mulloway and sand whiting, 28% of the yellowfin bream and 16% of the dusky flathead kept by anglers were undersize in NSW northern rivers. Similar surveys in Gulf St Vincent found large proportions of undersize King George Whiting retained by anglers in the nursery areas at the mouth of the Port River estuary. This problem is widespread, but poorly acknowledged, in Australia where there is a prevalence of overlap of angling areas with inshore nursery areas in bays and estuaries.

Other issues that have not been studied in Australian recreational fisheries concern:

- survival of hooked and released fish (sometimes embolised) with or without gear attached
- bycatch and discards in the non-selective gillnets, bait seines and cast-nets permitted for recreational use in various States.

There is generally a poor recognition of the effects of recreational fishing on the environment and fish stocks in Australia. The present R&D focus is aimed at first determining the magnitude and composition of the recreational catch (eg. see Hancock (ed.) 1995), and there are very few papers on the other effects of such activities (eg. Diggles and Ernst 1997). This is surprising, given the perceived value of individual sportfish such as great white sharks, billfish and barramundi, the interest in catching and releasing them and the overseas concern for hooking mortality (see Muoneke and Childress 1994 for review).

Estuaries are dynamic environments and both regular and irregular events could be expected to have major influence on bycatch composition - appropriate and extensive observer coverage will be needed to document bycatch issues properly. For example, Kennelly *et al*. (subm. a) showed effects of moon phase on catch composition and Andrew *et al.* (1995) showed that bycatch in an estuarine pocket-net fishery was both variable and driven largely by freshwater flow events:

- overall the bycatch to prawn catch ratio was 1:2 by weight in the Clarence River fishery, compared with commonly reported ratios of 20 : 1 in the trawl fisheries elsewhere. It is a *relatively* "clean" passive fishing method
- generally there was a small bycatch of about 35 kg per night per dig, however flood events saw great rises in bycatch up to about 125 kg per night
- fish (and prawns) moved downstream during high flow events and there is potential for much larger bycatches at these times. The whole fleet caught about 2 tonnes of bycatch per lunar month normally, but this went up to 7 tonnes after a flow event
- yellowfin bream, tailor, tarwhine, river garfish and snub-nosed garfish were species of angling/commercial importance in the bycatch. These were nearly all undersize, and only bream were considered to have much chance of survival after release
- over 96% of the bream observed were caught on just 7 out of 211 dig-nights. They were thought to be moving rapidly downstream to seek saltier water after a "fresh"
- best estimates of numbers caught are imprecise because of the flow influence. The "best" estimates for the entire fleet were :

	4 months (91/92)	8 months (92/93)
yellowfin bream	64, 079	3,152
tailor	24,777	13,307
tarwhine	13,085	298
river garfish	5,625	17,199
snub-nosed gar	5,070	11,775
non-commercial (mostly herring and perchlets)	1,864,331	784,182

- not all these fish would have reached "legal" size if they had not been caught. Estimating that number requires knowledge of natural mortality rates. Current knowledge does not enable any prediction of the ecological effects of removing these fish, or of returning their carcases to the food-chain
- NSW FRI have developed with industry the "Nordmore Grid" and other devices to reduce entry of bycatch, weed and logs into set-pocket and estuarine trawl nets (see papers by Broadhurst and Kennelly 1995b, 1996b, Broadhurst *et al*. 1996a, 1997a) .

4.2.4 Shoreline harvesting

Australian advances in development and application of ecological sampling designs and analysis (eg. Underwood 1991a, 1992, 1994) occurred with a foundation in studies of intertidal organisms. These studies have recently shifted from small-scale manipulative experiments to larger scales associated with shoreline harvesting.

Shoreline harvesting of intertidal animals for food and bait, and trampling of algal beds has been reviewed by Quinn *et al.* (1996). There are both direct and indirect effects of species removals that are measurable and may lead to "alternative stable states" where, for example, grazing snails become established and suppress recruitment of other molluscs (p.c. #970 M. Keough). In this regard poaching of abalone on reefs closed to fishing may aggravate the appearance of urchin "barrens" habitat by altering the level of interaction between sea urchins and abalone.

The effects of angling removals of key rocky reef fishes is much harder to study and virtually unknown - despite the significant effects of small-scale removals of such fishes in New Zealand experiments (see Appendix 5). Data on the recreational catch is lacking in Australia, but Kingsford *et al.* (1991a) found 37 species of fish in the catch along the NSW coast. Herbivorous luderick and black drummer, yellowfin bream (benthic macro-

carnivores) and tailor (pelagic piscivores), were the most important components -- but there was a diverse bycatch of reef-associated species including herbivores, wrasses and leatherjackets as well as significant removals of shellfish and crabs for bait.

Creel surveys in WA indicate that the proximity of limestone reefs to the "bread and butter" angling fishery for herring (*Arripis georgianus*) with small hooks means that a wide variety of "reef resident" wrasses and other unwanted species are caught too. This may result in localised depletion and reduced species diversity (p.c. #1410 S. Ayvazian).

4.2.5 Bycatch in other fisheries - longlining

In pelagic longlining the major issues have concerned the capture of albatross species and other seabirds (skuas, shearwaters) on the hooks as they sink during gear setting in southern longlining, the alleged "finning" and discards of blue sharks on the east coast and the bycatch of billfishes, especially black marlin in "Area E" off north Queensland. There are also some localised concerns with seals and turtles. Current research initiatives include observer programs to document the occurrence, composition and fate of bycatch in the pelagic longline fisheries, and use of sonic transmitters and archival tags to assess interactions between billfish and tuna on longlines (FRDC #97/113).

Oceanic longlining was listed under the *Endangered Species Protection Act 1992* as a key threatening process in 1995. A threat abatement plan for the effects of oceanic longlining on seabirds has now been drafted and can be downloaded at http://www.biodiversity.environment.gov.au/plants/threaten/longline/index.htm

There are also growing markets for some of the longline bycatch species, including Albacore, Rudderfish (*Lepidocybium flavobrunneum*), Ray's Bream (*Brama* spp) and shark.

Large sharks are becoming increasingly popular amongst the public and interactions between great white sharks (with shark nets and snapper longlines in SA) and grey nurse (with wobbegong set-lines in NSW) with commercial fishing gear have been the subject of recent inquiry (eg. Bruce 1992). The grey nurse shark is a protected species under the NSW Fisheries Act, and similar protection was being drafted for the great white shark in several States at the time of writing this review (see Caton *et al*. 1997 for review).

4.3 Habitat damage

From our review it is clear that the major anthropogenic threat to demersal fisheries habitats on the continental shelf is fishing - trawling in particular. Overall there is vast lack of knowledge of the macrobenthic communities on Australian shelves. In a review of the effects of trawling on macrobenthic epifaunal communities, Hutchings (1990) documented the neglect of study of these communities and their roles - in contrast especially to interspersed coral reefs in the tropics. In the intervening years, there have been some major initiatives to redress this imbalance on the North West Shelf (see Sainsbury *et al.* 1993, 1997, Moran *et al.* 1995); the Great Barrier Reef Marine Park (GBRMP) (Pitcher 1997, Pitcher *et al.* 1997); the Gulf of Carpentaria (Long *et al*. 1995); Torres Strait (Long *et al*. 1997b,c); and on the SE trawl grounds and southern sea-mounts (see FRDC#94/040, Koslow 1997).

In the Gulf of Carpentaria and North West Shelf the dominant macrobenthos are sponges, ascidians (colonial and solitary), alcyonarians, gorgonians, echinoderms molluscs and encrusting organisms such as bryozoans and serpulid worm tubes that settle on the larger organisms. Often these animals occur together in clumps, forming small patch reefs on otherwise bare muddy or sandy substrata. Hutchings (1990) suggested that there is an overlap in the species composition of macrobenthos in the North West Shelf, Gulf of Carpentaria and GBRMP. Long *et al*. (1997b) showed that seabed current stress determines distribution and abundance of sessile epibenthos in Torres Strait and that large areas are devoid of megabenthos cover.

Long *et al*. (1995) studied the distribution, biomass and community structure of megabenthos of the Gulf of Carpentaria, noting that this study was the first description of non-reefal megabenthos from tropical northern Australia and a rare opportunity to study intact benthic communities in the central Gulf that had been effectively closed to fishing for 14 years. Only the information on decapod crustaceans (Ward and Rainer 1988) has been published from the CSIRO studies in the North West Shelf megabenthos communities. Classification and ordination by Long *et al.* (1995) showed two main groups - a community of mainly suspension-feeders located in predominantly sandy sediments along the eastern and south-eastern margins and a community of predominantly deposit-feeders in the muddier sediments of the central and western Gulf. However, sessile suspension feeders (eg. sponges, zoantharians, pennatulaceans, bivalve molluscs and

ascidians) were also found in the muddy central Gulf wherever suitable substrata for attachment were found.

Recent video surveys by NTDPIF of the trawl grounds in the Arafura Sea found very sparse, small epibenthos with indications that they have rapid turnover. It is possible that the North West Shelf benthos is atypical of trawl grounds in Australia - being big and probably old -- whereas the Arafura and Timor ground benthos is evidently low density and very small in the areas surveyed. The epibenthos of the Torres Straits and Gulf of Carpentaria may have different resilience and regeneration time too, after disturbance by trawling, and this is presently under study by CSIRO Division of Marine Research (p.c. #20 D. Ramm, p.c. #1190 K. Sainsbury, also see Long *et al*. 1997c).

In regard to the potential for long-term disturbance by trawling on different regions of the Australian shelf, Long *et al.* (1995) indicated that the relationship between megabenthos abundance and species richness, and geographical location and environmental factors is complex - there may not be a simple link between species richness and latitudinal gradients in the subtidal marine environment. However, the link between substratum type and sessile megabenthos may be a general feature of our shelves, as Long *et al.* (1995) note that:

- sponges, alcyonarians and gorgonians were the dominant sessile megabenthos in the coarse sediments of the North West Shelf, but there was little sessile megabenthos in the pelagic carbonate muds on the nearby Scott Reef -Rowley Shoals platform
- sponges, ascidians, alcyonarians and hydroids were abundant in the coarse sediments of the deeper (50-70m) waters of the northern GBR, but there were few sessile megabenthos in the muddy inshore areas.

The association between shelf megabenthos and fisheries and other motile fauna has received scant direct attention relative to similar work on coral and rocky reefs, seagrasses and mangroves. The use of video cameras mounted on traps, trawls and fishery-independent sleds has been very useful in such study (eg. Sainsbury *et al.* 1993, Moran and Jenke 1989, Moran *et al*. 1995). Snappers (mostly *Lutjanus vitta*) and Emperors (*Lethrinus* spp.) associate with large epibenthos on the North West Shelf, whereas Butterfly-breams (*Nemipterus*) and Lizardfish (*Saurida*) occur in areas of open sand devoid of such assemblages (Sainsbury 1987). The distribution of decapod crustacea in that region is also associated with biomass of a large sedentary fauna (Ward and Rainer 1988).

Study of the epibenthos themselves is hampered mainly by the depths below the limits of safe SCUBA operation on trawl grounds and the taxonomic difficulties associated with these invertebrate groups. Studies of the biology and taxonomy of these groups, especially sponges, have been facilitated by the development of the bioprospecting industry in marine pharmaceuticals and fisheries R&D is now providing an additional impetus to research on their biodiversity (eg. FRDC #97/205).

A variety of innovative technologies has been developed to overcome the problems posed by depth, including side-scan sonar, video sleds, remotely-operated video and "ROXANN" software that interrogates "hardness" and "rugosity" from echosounder traces (se Pitcher *et al*. 1997).

One of the greatest challenges in assessing the effects of fishing on epibenthos is the lack of knowledge of potential for recovery, succession and resilience to trawling. There have been detailed studies on the community dynamics of pier-piling epifauna (see Keough *et al.* 1990 and Butler 1996), but it is unclear from the literature whether species in the same genus or family of epibenthos share the same reproductive modes, and even less is known of recruitment. There is also a lack of information on patch stability and turnover, on the need for pieces of hard substrata for attachment - and especially on growth rates and longevity. Currie and Parry (1995) suggest that studies of benthic "recovery" in experimental designs should have a duration at least as long as the longevity of component species - but frequently this is unknown. A new FRDC initiative (Pitcher *et al.* FRDC #97/205) will be addressing directly the dynamics of megabenthos patches and individuals, as well as determine the associations between shelter and diet of fishes inside and away from megabenthos patches.

The studies of depletion of tropical megabenthos by trawling have generally shown alarming rates of mortality of benthos >20 cm in maximum dimensions, especially after repeated trawls over the same track. Moran *et al.* (1995) used videos and trawls to estimate that a demersal trawl destroys about 16 % of such benthos in its path in a single pass, and they expressed concern that some previous studies of cod-end contents were under-estimating the effects of a trawl by not considering the damage by bridles and sweeps. Sainsbury *et al.* (1993) reported that the average catch per unit of trawl effort of sponges on the North West Shelf fell from 500kg hr^{-1} to only a few kg hr^{-1} as trawling developed. Video footage showed that as little as 10% of dislodged epibenthos ended up

in trawl cod-ends and the probability of destruction in the trawl path was 0.43-0.95 depending on best/worst scenarios for mortality after disturbance.

Recovery of megabenthos communities on the North West Shelf after cessation of trawling has occurred (rapidly for benthos < 20 cm; slowly for large megabenthos) after 10 years to a level that bears an unknown relationship to “untrawled” conditions, but *Lutjanus* and *Lethrinus* populations have also built up in these areas - so some fisheries function, at least, may be restored in such a time frame (Sainsbury *et al.* 1993).

Concern over the effects of fishing on benthic communities has a long history and has provided the impetus for a number of overseas research programs over the past 20-30 years. Collie *et al*. (1997) classify such disturbances as scraping or ploughing, sediment resuspension, physical destruction of bedforms and removal or scattering of non-target benthos. Most of these studies have detected significant effects on both infauna and epifauna (eg., Collie *et al*. 1997, Hall *et al.* 1993, Kaiser and Spencer 1996, Thrush *et al*. 1995). However, the persistence of these impacts depends on the rate of natural and fishing disturbance, the type of fishing gear, and sediment and epibenthos type.

For example, overseas studies of the scraping and ploughing associated with scallop dredging showed that dredges can crush scallops or push them into the sediment, as well as causing resuspension and loss of fine organic muds and silty sands and consequent coarsening of sediments to sandy gravel with shell hash. This turbidity was suspected to kill scallop larvae (Dayton *et al.* 1995)

Scallop dredging in Port Phillip Bay has been banned for political reasons, but a series of BACI studies there showed that interannual and inter-seasonal changes to community structure of epibenthos and infauna were greater than those due to the “grader-like” effect of the dredges (see Currie and Parry 1994,1995 for review). *Callianassa* mounds (but not the crustaceans themselves) were removed and there were significant effects on the dredging, but recovery took place within 14 months. However, the “recovered” community had an uncertain relationship to the “never dredged” community of 30 years previously and the flow-on effects of benthic changes were unknown. Analysis of spatial patterns of benthic bycatch back to 1963 showed consistency in landings of epibenthos in “rubbish bins” measures, and the direct effects of the dredges depend on substratum hardness. Higher, tine-induced mortalities occurred in “harder” sediment areas, whereas

the molluscan fauna and smaller scallops are pushed into softer sediments by the dredge tines.

Hauling of seine nets by hand, by hydraulic winch and by boat power (power-hauling in SA) occurs through seagrass beds in most States. Underwater video footage of haul-netting in SA Gulfs showed that the movement of the footrope flattens *Posidonia* ahead of it in a bow-wave effect and only removes some epiphytes and dead blades (p.c. #1560 K.Jones). Concern over the practice in Jervis Bay is under study by NSW FRI (FRDC #96/286). Live and dead blades will be tagged *in situ* and their presence in nets hauled over them will enable inferences to be made about the fate of live seagrass (*Posidonia* and *Zostera*) in hauling grounds.

There is also trawling in deeper north Qld seagrass beds and the implications are not yet clear. The rate of disturbance is most important, as many of the seagrass are naturally dynamic, and many meadows are avoided by trawlermen because of the nuisance algal load that is brought up (Lee Long and Coles 1997).

4.4 Secondary effects of discards

Crabs, fish, sharks, seabirds and mammals are known to aggregate to feed on discards (eg. Blaber and Wassenberg 1989, Wassenberg and Hill 1990). Some of these scavengers may change foraging behaviour from day to night (eg. seabirds, fish) and diet. In the Gulf of Carpentaria the crested and roseate terns and brown boobies are foraging on discards of floating, demersal, fish species and CSIRO are investigating the implications for nesting success (see Blaber *et al*. 1995 for review). Seabirds follow trawlers everywhere, and in South Australian Gulfs cormorants have learned to enter the seine nets of power-haulers in flocks of tens to hundreds to feed on the concentrated catch. In the case of some seabirds (cormorants, crested terns and others), nesting populations have increased as a result of foraging on trawl discards. This may, in turn, cause depletion of other bird species - the rapid increase (10-13% annually) in silver gull populations due to a variety of anthropogenic causes has caused competition for nesting sites (Ross 1996).

In the absence of any density-dependent effects of predation or competition the ability of any species to capitalise on discards introduced into the system will depend on its reproductive capacity.

Sharks are visibly associated with prawn trawling in the tropics and there are anecdotal suggestions that they have benefited from trawl discards. Stevens and McLoughlin (1991) recognised four broad reproductive strategies among tropical sharks that will determine their potential to increase in abundance. It is especially important to note that one group had an annual cycle but breeding was continuous throughout the year, these were mostly small bottom- associated sharks. It is likely that these small species should be the focus of early attention to the impacts of discards. Diets ranged from omnivorous to highly selective and fish was an important component of the diet in all but one species.

One of the highest R&D priorities for NORMAC is shark predation on prawns. A series of studies on prawn predators (eg. Salini *et al.* 1990,1992,1994) and rates of consumption has shown that sharks are major predators of prawns in the Gulf of Carpentaria. Studies of discards in Albatross Bay alone showed that about 10-20,000 tonnes of discards were being distributed per year -- to feed mainly sharks, which then possibly ate more prawns due to population expansion (p.c. #280 S.Blaber and D.Brewer).

4.5 Indirect effects of the reduction of target species and habitat damage

Overseas studies have shown that very heavy fishing can result in a rise in squid populations in the tropics, and by deposit feeders and invertebrates in the temperate zones. Indeed Dayton *et al.* (1995) report some observations that such fishing is “causing a rebirth of the Mesozoic-like system dominated by echinoderms and crustacea because overfishing has removed the evolutionarily-new teleost predators”. Release from predation, herbivory and interspecific competition are some of the mechanisms that could govern these interactions.

4.5.1 Species shifts on reefs

One of the most commonly predicted - but poorly documented -- problems with fishing concerns “cascading” effects on coral reefs of predator removals (Dayton *et al.* 1995) such as:

- an “undocumented increase” in herbivorous fish numbers by removal of large groupers and other serranids (eg. coral trout)
- a “release from predation” of sea urchins, crown-of-thorns (COT) starfish and corallivorous *Drupella* snails, with subsequent effects of grazing and corallivory on coral reef structures

Overseas studies of the urchin outbreaks on some reefs have shown support for these predictions, and many small-scale experiments have shown predation to be a major factor limiting community and population composition. However, studies at larger scales have repeatedly failed to find any effect of predator removals on other prey or non-target species, although there are usually differences in predator abundance between reefs "open" and "closed" to fishing (see Russ and Alcala 1989, Jennings and Polunin 1997 for review).

In the GBRMP surveys of gut contents of likely predators (*Lethrinus miniatus* and *L. atkinsoni*) and well controlled caging experiments inferred that line-fishing of such predators was unlikely to have had important influence of the outbreaks of COT starfish (see Mapstone *et al*. 1997 for review). Comprehensive studies of the effects of fishing in the GBRMP are underway now (see Box 4.9.1 below).

Marine herbivores, such as sea urchins, can have profound effects on the abundance and composition of algal assemblages on tropical, sub-tropical and temperate reefs. A series of papers by Andrew (1988, 1989, 1991, 1993b, 1994) has explored the experiments needed to test hypotheses concerning these effects - including the effects of fishing. For example, there has been an overseas debate over "urchin-lobster" interactions and the consequences of lobster fishing on urchin outbreaks. In our region, Andrew and McDiarmid (1991) studied the inter-relation between the sea urchin *Evechinus chloroticus* and rock lobster *Jasus edwardsii* in northern New Zealand. Both species were found in large numbers in the "Shallow Broken Rock" habitat - but rock lobsters were scarce in the "Barrens" habitat where urchins are mostly found, and urchins were largely absent from the kelp forests and deeper reef where rock lobsters were most abundant. During the day rock lobsters and sea urchins were spatially segregated on a small scale, but sea urchins were accessible to nocturnally foraging lobsters. Laboratory experiments demonstrated that large lobsters ate all sizes of sea urchins - with a preference for smaller urchins. The experimental removal of large brown algae or sea urchins and gastropods from areas of reef did not cause significant reductions in the daytime density of *J. edwardsi*. The authors argued that the changes in abundance of one species (for whatever reason) would not lead to changes in the local abundance of the other, mainly because of different microhabitat requirements.

Increases in abundance of sea urchins (*Prionocidaris*) have occurred (with seagrass dieback) in northern Torres Strait (see Long *et al*. 1997a), but the implications for the tropical spiny lobster fishery there are unknown (see Caton *et al.* 1997).

Small-scale manipulations and surveys at 7 mile beach and Dongara in WA (Joll and Phillips 1984, Jernakoff *et al.* 1994) have shown that western rock lobster (*Panulirus cygnus*) have a broad diet and high densities, and could be expected to have a predatory effect on molluscs such as the gastropod *Cantharides* spp. A corollary is that intensive rock lobster fishing could have effects on prey populations and indirectly on algal assemblages through herbivore removal. However, these findings have not been followed up with experiments at any scale.

There is an urgent need for studies on the effects of rock lobster fishing on sub-tropical and temperate reefs, as many of the southern fisheries are located in "nests of endemicity" that will probably feature highly in the NRSMPA. There have been suggestions that rock lobster fishing is a threatening process in some areas (Edyvane 1996a, Stoddart and Simpson 1996). The short-term effects of closure to fishing in such areas suggest that fishing (of all types) could have a measurable effect. For example, Edgar and Barrett (in press) found that densities of rock lobster *Jasus* and urchins, and the mean size of wrasse, leatherjackets, abalone and *Jasus*, all increased within the reserves relative to outside, over the first year of closure.

The authors conclude that large scale (1-2 km stretches of coastline), replicated, experimental closures to fishing are needed to define the effects of fishing on temperate reefs. These fisheries include angling, abalone diving, rock lobster potting and gillnetting (p.c. #1260 G. Edgar). At smaller scales reef fisheries within the limits of SCUBA diving are amenable to manipulations of prey, predator, shelter and algal assemblages and the clear waters would enable direct or video monitoring of the action of rock lobster pots to ascertain the damage they cause to the substrata (if any). Such work has been done for the Shark Bay trap fishery for snapper (Moran and Jenke 1989).

However, the Australian sea urchin studies have outlined a unique R&D opportunity to exploit urchin-abalone interactions and enhance both abalone yields and algal biodiversity by developing a small urchin fishery for *Centrostephanus rodgersii* (see Box 4.5.1 and FRDC #93/102).

BOX 4.5.1. MANIPULATION OF URCHIN-ABALONE INTERACTIONS - R&D OPPORTUNITIES FOR ABALONE ENHANCEMENT

The urchin *Centrostephanus rodgersii* creates and maintains "Barrens" habitat by herbivory. At the larger, among-habitat scale abalone are almost absent from the "Barrens" or "White Rock" habitat where sea urchins are most abundant. At a smaller within-habitat scale densities of urchins and abalone are negatively correlated at a scale of $10m^2$. At an even smaller, nearest-neighbour, scale within crevices both abalone and urchins are most likely to be found next to a conspecific (Andrew and Underwood 1992). It is also known that abalone eat drift algae and that coralline algae are critical for abalone spatfall and settlement, and it is suspected that there is a role for kelp in maintaining biofilms on these coralline algal surfaces - urchin grazing removes the kelp and possibly destroys abalone spat.

To increase the productivity of the southern NSW abalone fishery the study by NSW FRI involved :
- manipulating urchins by removal in pulse/press fishing
- abalone input by seeding with adults.

The results were that urchin removal caused an increase in abalone recruitment and numbers and NSW FRI will be developing a co-managed urchin roe fishery to supplement abalone harvesting in that area. Opportunities exist for seeding abalone brood stock into the algal habitats encouraged by urchin removal, and the ongoing experimental work will help define the mechanisms causing the interactions.

Contact: Dr Neil Andrew, NSW FRI see FRDC#93/102

4.5.2 Indirect effects of the reduction of target species and habitat damage -- species shifts on trawl grounds

The best-known Australian examples come from the CSIRO studies on the North West Shelf, reviewed by Sainsbury *et al.* (1993, 1997). Large fish with high domestic market value, especially Emperors and Snappers (*Lethrinus* and *Lutjanus*), were replaced by low value, small Lizardfish and Butterfly breams (*Saurida* and *Nemipterus*) after several eras of heavy trawling. The major mechanisms examined by CSIRO in experimental and modelling studies on the North West Shelf exemplify most of the routes by which species shifts can occur. They were:

- an intraspecific mechanism, under which the observed changes are regarded as independent single-species responses
- an interspecific mechanism in which there is a negative influence of *Lethrinus* and *Lutjanus* on the population growth rate of *Nemipterus* and *Saurida* so that *Nemipterus* and *Saurida* experience a competitive release as the abundance of *Lethrinus* and *Lutjanus* is reduced by fishing
- an interspecific mechanism in which there is a negative influence of *Saurida* and *Nemipterus* on the growth rate of *Lethrinus* and *Lethrinus* so that *Lethrinus* and *Lethrinus* are inhibited as the abundance of *Saurida* and *Nemipterus* increases for other reasons

- habitat determination of the carrying capacity of each genus separately, so that trawl-induced modification of the abundance of the habitat types alters the carrying capacity of the different genera.

In an analytic framework for evaluating adaptive management regimes the probability placed on the habitat limitation mechanism was about double that of the closest other contender after 5 years of experimental closures and surveys (see Sainsbury *et al.* 1997 and Section 4.9)

The need for life-history information in predicting species shifts and sustainability of bycatch species is best exemplified in the work by Thresher *et al.* (1986) on the four *Saurida* species that are found on the North West Shelf. One of the small-bodied species (*Saurida* sp. 2) lives for less than a year and has a very short generation time of only 60 days from settlement to sexual maturation. Its population had been doubling every year for over 5 years during the study and Thresher *et al.* (1986) suggest that the extremely short generation times would make *Saurida* sp. 2 an eminently pre-adapted "weed" species capable of rapid population expansion in the face of opportunities -- such as new sandy habitat or release from predation -- caused by trawling. They also warned that the *Saurida* are voracious predators of juvenile fishes and crustacea and that they may have long-term predatory and competitive effects on the community composition on the North West Shelf even if fishing pressure declines.

We also suggest that knowledge of the survival of discards is essential in understanding the effects of fishing -- as a further mechanism producing species shifts may be the differences amongst fish families in their ability to survive the rigours of being trawled, sorted and discarded. For example, Greenstreet and Hall (1996) found that the non-target species assemblage in the north-western North Sea had remained relatively unchanged despite a century of trawling - in stark contrast to the Georges bank where gadoid finfish have been replaced by dogfish (*Squalus* spp) and skates in an alternative stable state. These elasmobranchs are exploited in the North Sea, but not the Georges Bank, and this may have suppressed their rise, but the elasmobranchs discarded on the Georges Bank may also survive the capture by trawl better than other species, giving them a competitive advantage.

In this regard triggerfishes (Balistidae) may well have some advantage over other fishes in the tropics, as they have bony, carapace-like body armour and an ability to avoid

embolism of the swimbladder through the mouth. Anecdotal reports suggest that *Abalistes stellarus* is a feature in tropical Australia of grounds disturbed by trawling (p.c. S. Newman) but data on their biology and survival after discarding is not available. A "balistid rise" has been reported in overseas trawl grounds by Longhurst and Pauly (1987).

Tank studies of the survival of discards have generally shown low survival of fish in the tropics (20% after 8 hrs ; Wassenberg and Hill 1989), but Carrick (1997a) found "much higher" rates of survival amongst King George Whiting (no data supplied) and Snapper (50% after 2 hrs) in South Australia. There are a multitude of factors governing survival, including trawl duration and depth, bycatch composition and cod-end weight, air temperature and handling methods.

Blaber *et al.* (1994b) found a species composition in the Gulf of Carpentaria trawl grounds that may be related to intensive prawn trawling. The catch rates and biomass estimates were directly comparable to a study done with the same gear previously (Blaber *et al.* 1990a) that suggest some temporal stability in the patterns of fish abundance and shows no evidence of decline. In fact, the biomasses of the top 25 species were approximately double on the prawn trawl grounds compared to the rest of the Gulf, even though the commonest prawn ground species included some of the most abundant species in the Gulf as a whole. These included *Pomadasys, Upeneus*, *Pentaprion, Saurida* and various leiognathids, and these species form the bulk of prawn trawl discards (Harris and Poiner 1990, 1991, Ramm *et al.* 1990).

The distribution of larger, commercially important species of lutjanids and lethrinids was centred on a series of stations across the northern Gulf outside the areas of prawn trawling. However, further analyses of relationships between benthic structure, benthos and fish distributions are required before inferences can be made about the role of megabenthos disturbance cited by Sainsbury (1987) in species replacements.

On a longer time-scale Harris and Poiner (1991) compared catches and sediments in the Gulf of Carpentaria after 20 years of trawling to conclude that the abundance of 63% of 82 taxa had not changed, although there had been an overall decline in fish abundance. The declines were mostly with 18 benthic and offshore taxa (eg. *Paramonacanthus*, scorpionfish and soles) but increases occurred in 12 bentho-pelagic and nearshore taxa - including sharks, anchovies, sardines and trevallies. There was also an unexplained decrease in mud content of offshore sediments in the study area, which has been

associated overseas with both the ploughing effects of trawling and a lowering of fish diversity and production (Dayton *et al.* 1995). The results of Harris and Poiner (1991) emphasise the need to account for environmental variability in interpreting such long-term comparisons - including river outflow and temperature in shallow waters and sediments offshore.

The trawling practices by foreign fleets in the tropics may have intentionally removed megabenthos to "encourage" small fishes of high value on their domestic markets. For example, "butterfish" of the families Centrolophidae (*Psenopsis anomala*) and Ariommatidae (*Ariomma indica*) were the mostly highly-prized target of Taiwanese pair-trawlers in the Arafura sea and greatest catches were taken where the seabed had been damaged by trawling or over flattened substrata (Kailola *et al.* 1993).

Species shifts have been evident in the SE Fishery too, but interpretation of the data are difficult. In the early 1900s the gurnard *Pteridotrigla* (low now) and chinaman leatherjacket *Nelusetta ayraudi* (negligible now) were in the top 3-4 of species list in the SE Trawl (p.c. # 100 P.Last). Tiger flathead have been fished in Eastern Bass Strait since 1915 and are still a major species, but with lower catches. Current work by Bax *et al.* (FRDC #96/275 and FRDC#94/040) is designed to understand the use of different habitats by different species in the SE fishery as a first step to understanding the effects of fishing.

4.5.3 Indirect effects of the reduction of target species - competition with predators for food fishes

Aggregated prey such as schooling pilchards, squid and other "baitfish" are important as prey sources for the high food consumption of small cetaceans and seabirds, so dispersal of the aggregates by purse-seine fishing or other means is considered likely to be a problem by Dayton *et al.* (1995). Dispersal could cause predators to move elsewhere or to have difficulty in finding sufficient food. This issue has not been recognised or studied in Australia, yet it may be a significant problem at certain times and places because:

- our low nutrient shelf waters support relatively minor clupeid production
- our planktivorous, schooling jack mackerel and clupeids are known to undergo major shifts in recruitment, schooling behaviour and spatial location due to ENSO and other oceanographic factors
- there is a concentration of charismatic megafauna such as Tasmanian fur seals, cetaceans, seabirds and billfish in the areas where these "baitfish" predominate and it is known that some or all of these species rely heavily on these as a prey source

- there is widespread knowledge that baitfish form the major diet of other fished species such as Australian salmon, tunas, billfish, sharks, tropical mackerels and other sport and gamefish
- to feed, some seabirds need actively feeding predators to drive baitfish upward to the surface (eg. Blaber and Milton 1994).

In late winter/spring 1984 and 1985, adult little penguins in Port Phillip Bay died of starvation, apparently directly resulting from food deprivation (Harrigan 1992) and it was suggested at first that fishing had depleted their prey. Later study by Hoedt *et al.* (1995) indicated that baitfish (anchovies and pilchards) distributions may shift in Victoria during ENSO events, making foraging by adult penguins insufficient to meet demands of both body maintenance and chicks.

There are no well-defined protocols to study such effects of prey scatter and competition between fishing and predators, although it will be an issue of growing concern as a new pilchard fishery in SE Qld begins amidst much opposition from gamefishing and sportfishing interests. Studies of predator diets is a first step. Historical data on the diet of Australian salmon is available from factory sampling (p.c. # 1360 R.Lenanton) for periods before and after a major pilchard fishery began on the south coast of WA, but there has been no comparison of the pilchard composition in the diet.

4.6 Changes in demography under fishing pressure

Our focus here is on the environmental effects of fishing, but some mention should be made of the potential for changes within the fished stocks themselves because these, in turn, may affect Australian ecosystems. Genetic resources come under the definition of "biodiversity".

There have been some recorded incidences of changes in demography of fished species. For example, Cockrum and Jones (1992) studied the reproduction of King George whiting in the period 1980 to 1988, in comparison with studies undertaken in 1953 and 1966. The length at first maturity decreased for both sexes since 1953 -- from 36cm to 31cm for females and from 32cm to 27cm for males. This was attributed to heavy commercial and recreational fishing and "knife-edge recruitment" in the nursery areas. Similar changes have been mentioned for barramundi in Queensland (Williams 1997).

Abalone life-history makes them both easy to study and vulnerable to the genetic effects of local depletion. Shepherd (1990) has long-term, fishery independent data on demography for 3 sites spread throughout the South Australian fishery. All sites have shown subtle, slow declines in density and recruitment over 15 years. There has also been a decline in growth rate due to selection by divers for fast growing individuals and on the West Coast of SA (Elliston) the age-at-first-maturity has decreased by one year.

It has been proposed that the abalone there are putting more energy into egg production than somatic growth in response to size-selective harvest, and "slot" size limits are being tried to restore earlier demographic patterns (p.c.# 1540 S. Shepherd).

4.7 Generation of litter and the environmental consequences

The Australian problems of fishing debris, lost gear and litter is reviewed by Jones (1995), Coxon (1995) and Wace *et al.* (1996). Such debris includes scraps of netting, fibreglass strapping bands from bait boxes, tangles of monofilament fishing line and other plastics that concentrate along slicks and other hydrodynamic features before appearing on beaches and causing public alarm. The debris is often cast ashore far from their source (eg. Slip and Burton 1991), and studies have recently commenced to distinguish the foreign or domestic, commercial or recreational sources from one another in litter collections.

There are frequent reports of marine animals becoming entangled and suffering from the effects of net webbing, monofilament fishing line and fibreglass bait bands. The publicity and implications surrounding these events are particularly bad when the conservation status of the animal has been declared as "threatened" or "endangered" under the *Endangered Species Protection Act 1992*. Sea lions, southern fur seals, cetaceans, sea turtles, sea birds and sharks figure most prominently in these reports (eg. Slater 1991), and rates of seal entanglement as high as 1 - 2% have been reported by Caton *et al*. (1997). The wounds from bait bands are particularly alarming, and emaciated, "banded" whaler sharks have menaced spearfishermen in WA.

There have been no studies in Australia of the rate of loss of gear or occurrence of ghost-fishing by lost gill and trawl nets and rock lobster pots. Caton *et al.* (1997) suggest that the high levels of fishing debris found in litter surveys were partly because of the intense burst of orange roughy fishing prevailing at the time, and the littering and lost nets

that occurred in this period. Anecdotal reports suggest that rock lobster pots are lost in significant numbers in some areas when they become snagged or the buoy lines are dragged under by strong currents.

Recreational fishing is known to cause chronic littering - particularly at popular locations -- and this contributes to the debris documented by Wace *et al*. (1996). Brown's Beach in Innes National Park on Yorke Peninsular, SA, was temporarily closed to surf anglers for this reason, and similar problems have occurred on the rock-fishing platforms of Jervis Bay National Park, NSW. The use of 4 wheel drive vehicles has been found to cause egg destruction for some plovers and terns on beaches at surf-fishing locations (p.c. D. Paton, University of Adelaide) and destruction of terrestrial plants for firewood and vehicle access occurs in national parks throughout coastal Australia.

4.8 Reducing the effects of fishing

The term "environmentally friendly" fishing gear has been used recently in Australia to encompass a variety of attempts to reduce bycatch, to reduce contact of the gear with sessile benthic communities and to reduce littering with fishing debris (eg. see Brewer *et al*. 1997). The perspective of such a term has not been defined, and advances in "environmentally friendly" trawls that fly over benthic communities may actually increase effects of fishing on ecosystems by allowing fishing to occur in areas that previously could not be trawled without fear of gear loss. This again reinforces the lack of definition of objectives, outcomes and performance measures in pursuing ecologically sustainable development of fisheries in Australia (Staples 1997).

However, in pursuing an outcome of a reduction in bycatch, Australian fishermen have not lagged behind northern hemisphere adoption of appropriate technology. For example, Spencer Gulf prawn fishermen developed "crab bags" to prevent *Portunus* entering cod-ends and estuarine fishermen in NSW and Qld have used inclined panels or "blubber chutes" to avoid swarms of *Catostylus* jellyfish for over 20 years.

In the late 1980's there began an intense and rewarding R&D effort between industry and science in developing or adapting devices for Australian conditions and testing them (see Kennelly 1997, Eayrs *et al.* 1997 for reviews).

The major designs use inclined grids ("hard TEDs") or inclined mesh panels ("soft TEDs") to guide animals out of escape openings, or panels of mesh that allow fish to escape but not prawns. These rely on clever interpretation of water flow and pressure gradients and different behaviours of organisms in trawls. They have included:

- semi-pelagic fish trawls to avoid megabenthos and sea-bed dwellers (eg. Ramm *et al.* 1993)
- the AusTED, Super Shooter and Nordmore grid to exclude turtles, rays and other "monsters", jellyfish and megabenthos (eg. Mounsey *et al.* 1995, Broadhurst *et al*. 1997a)
- square mesh windows, fisheyes, square mesh cod-ends and radial escape sections to allow small fish to escape without loss of prawns (eg. Broadhurst *et al.* 1996b, Broadhurst and Kennelly 1996a, 1997)

The design and operation of all bycatch reduction devices for Australian prawn fisheries is reviewed by Eayrs *et al.* (1997) who recommend that a sound understanding of the bycatch issues at hand are necessary for selection and adaptation of devices which will vary amongst regions and fisheries. For example, Moran *et al.* (1995) do not believe that semi-pelagic trawls are a solution to megabenthos destruction on the North West Shelf as they are in the Arafura Sea where schools of large lutjanids occur. They argue that, even if such gear is legislated for use in the NW fishery, the fishermen will fish them hard on the bottom - as trials showed significantly smaller catches than a standard demersal trawl.

In 1995 prawn trawling was nominated as a key threatening process under the *Endangered Species Act 1992* and the nomination was still under consideration at the time of writing this review. If the formal listing goes ahead, then the industry will have to develop a threat abatement plan to mitigate threats to the survival of endangered species, such as turtles. Market forces may also hasten the voluntary adoption of bycatch reduction devices, as in May 1996 the USA placed bans on the import of any prawns caught in trawls not fitted with turtle-excluder devices.

The FRDC "Effects of Trawling" sub-program aims to set time frames and objectives for the adoption of bycatch reduction devices and to measure the performance of these measures, in terms of both bycatch reduction and achievement of "sustainability" in trawl fisheries. However, we could not find references to programs designed to measure the success of the reduction in bycatch and abatement of threat to endangered species.

The profit margin in the Queensland East Coast trawl fishery is much smaller than that in the Gulf of Carpentaria, and this will have implications for the voluntary or enforced use of TEDs. Targets given in the "Trawl Proposed Management Arrangements 1998-2005" by the QFMA are :

- compulsory use of Turtle Exclusion Devices in defined areas upon the implementation of the East-Coast-Moreton Bay Trawl Fishery Management Plan
- develop a process for minimising impacts upon threatened and endangered species which meets the requirements of conservation agencies including Environment Australia, by December 1998
- level of trawl-induced turtle kill to be negligible by (year) 2000 for the east coast and Moreton Bay.

Many other laws under State and Commonwealth Fisheries Acts have been designed to increase selectivity of fishing gear and reduce various effects of fishing -- such as discards of fishing debris (see Caton *et al.* 1997 for review), bycatch of threatened or endangered fauna, damage to benthic communities and mortality of "undersize" animals. They are too numerous to mention here, but notable examples from other fisheries are :

- development of semi-pelagic fish trawls is being pursued to reduce destruction and capture of megabenthos, improve catch quality and reduce bycatch of unwanted species (see Brewer *et al*. 1996,1997; this is now a requirement to participate in the Northern Fish Trawl)
- "Tori poles", night setting, bait thawing and bait-throwing devices have been successful in reducing hooking of albatross and other seabirds on longlines, and there is mandatory use of these devices south of 30° South
- spikes inside rock lobster pot entrances have been developed by SA fishermen to dissuade entry and bait stealing by sealions on Kangaroo Island
- selective mesh sizes and breaking strains, and attendance rules, have been implemented in the Queensland gillnet fisheries to reduce bycatch and entanglement of large marine animals
- funnels in Queensland eel traps have reduced freshwater tortoise bycatch
- the early efforts of the Australian National Sportfishing Association and gamefishing movement has instigated a shift of the angling culture toward catch-and-release and conservation (a code of practice for angling is being drafted as part of development of a National Policy on Recreational Fishing)

- the use of less harmful and more selective fishing gear (single hooks, barbless treble hooks, line classes) has been ruled or encouraged for certain locations and competitions in recreational fisheries.

The use of Marine Protected Areas to reduce effects of fishing is discussed in section 1.2.3.

4.9 Assessing the effects of fishing

Our review revealed that scientific assessment of the effects of fishing, particularly on shelf macrobenthos and habitats, is made difficult or confounded by the facts that:

- much of the mainland shelf <50 m deep has been trawled already - some heavily for very long periods - and differential GPS is enabling new areas to be trawled safely
- early data does not exist or the existing research and logbook data often are of little use in robust assessments due to lack of replication or standardisation, lack of metadata, bias and errors
- early fishery-independent surveys were not designed with statistical power in mind - failure to assess precision of old survey data may result in weak and uninformative test for change
- zoning of MEPAs are seldom designed with inherent models in mind for setting up contrasts in later assessments of effects of fishing
- trawling is a very low power way of sampling, because habitat patches are at the 10's of metres scale, and trawling integrates along a long path
- research surveys are much more reduced in time and space than the actual fishing effort - to obtain more replicates, reduce spatial variation of density estimates and evaluate patchiness. This may increase sampling power, but dilute the knowledge of actual, local impact on megabenthos and on bycatch species that aggregate
- short-term, low spatial scale work seldom shows any correlations between effects of fishing and habitat loss, and abundance of fished species
- there is little knowledge of the demography of non-target species
- changes in fishing gear efficiency, discarding and reporting practices and environmental forcing (eg. zonal winds, El Nino, river outflow) cannot be accounted for in historical comparisons
- a public backlash against manipulative science threatens future study in MEPAs where contrasts do exist for powerful experiments.

Sceptics suggest that ALL studies of effects of fishing are too late because there are few if any meaningful “controls” - most sensitive species have long been fished or removed (eg. Dayton *et al.* 1995). However, it should be argued that while such controls are desirable they are not necessary to understand the effects of fishing. Powerful experiments such as the CRC Reef “Effects of Line Fishing”, FRDC “Effects of Trawling” sub-program and the CSIRO North West Shelf studies have relied instead on maintenance of spatial and temporal contrast in effort and stock size.

Indeed, the question of sustainability on Australian fishing grounds should now remain centred on maintaining present, productive, fishing grounds in a manner to safeguard “representative” habitats - not winding back the clock to pristine, pre-fished habitats and assemblages everywhere (p.c. # 720 D. Staples). The appropriate design and implementation of marine protected areas under the NRSMPA, scheduled for implementation by the year 2000, could enable both fishing and maintenance or recovery of biodiversity.

Assessments of the effects of fishing have been conducted at increasingly larger spatial and temporal scales:

- long-term (>15 yr) zoning was used to produce large scale manipulations of trawling to infer effects on fisheries and recovery rates of fish communities and benthos (see Sainsbury *et al.* 1993 for review and Section 4.9)
- over 5 years the CSIRO/QDPI “Effects of Trawling” and CRC “Effects of Line Fishing” programs in the GBRMP are using depletions, comparisons of “open” and “closed” zones and other manipulated contrasts to achieve similar goals (eg. Ferreira and Russ 1995, and See Boxes 4.9.1 and 4.9.2)
- replicated pairs of fished and unfished grounds in Spencer Gulf have been trawled repeatedly to measure depletion rates of bycatch species and infer effects of prawn trawling (Carrick 1997a,b)
- repeated trawling of marked areas has allowed depletion rates of megabenthos and fish, and trawl selectivity for juveniles to be determined (eg. Moran *et al.* 1995)
- abalone and urchin densities have been manipulated at within-reef scales to infer mechanisms governing interactions (FRDC #93/102).

Study of the secondary effects of discards has been limited to video observations of underwater scavengers and stomach content analyses (eg. Wassenberg and Hill 1987), and to surveys of seabird nesting success and crop contents (eg. Blaber and Wassenberg

1989, Blaber *et al*. 1995). Use of dyed discards inside and outside of Gulf trawling seasons could aid gut content analyses of sharks to determine how much discards sharks are eating. Models could then be used to link consumption rates with size and age at first maturity and fecundity of sharks to estimate enhancement of shark populations. This work may be considered in a new project being conducted by CSIRO (p.c.# 280 S.Blaber; FRDC #96/257).

BOX 4.9.1. THE "EFFECTS OF LINE-FISHING" EXPERIMENT ON THE GBR -- STATE, PRESSURE AND RESPONSES IN THE FLEET, PREDATORS AND PREY POPULATIONS

The subject of a major multi-institutional experiment run through the Reef CRC in pursuit of a suite of harvest and management strategies with associated risks, for ultimate decisions on the Reef Line Fishery by QFMA/GBRMPA.

Background

Coral trout are valuable commercial, charterboat and recreational species with landings up to 1000 tonnes p.a. and the prospect of value-adding in the live-fish trade. They are also a top predator, whose removal may change other fish populations. An experiment was planned to refine both fisheries management and to test the way that multiple-use is zoned in the GBRMP. Coral Trout can be accurately and precisely counted independent of the fishery by Underwater Visual Survey.

Components

1) Document history of fishing and stocks (CPUE logs, oral history, fleet dynamics, prior research review)
2) Describe status of fishery and stocks from year to year (CPUE logs, catch and fishery-independent visual and biological surveys) and fisher attitudes and motivations
3) Measure directly the responses of fishery and stocks to changes in fishing pressure
- a) Monitoring before, during and after the Bramble reef (closed for 4 years) re-opening and
- b) pulse and press fishing in reefs zoned closed and open to detect response of coral trout and their prey

Design

24 reefs in the 4 major sectors of the GBRMP;
within each cluster of six reefs

- 2 control reefs that will remain closed for the duration of the experiment - to monitor and account for natural variation
- 2 "Green" experimental reefs - now protected, will be opened for line and spear fishing for **one year each**; will determine how effective seasonal or area closures are; will measure flow-on effects of fishing on prey and non-target fishes
- 2 "Blue" reefs - raising the level of fishing activity beyond present levels will enable study of response of stocks - closing them afterwards will provide information on recovery

Responses

Coral Trout are a high-level predator, therefore the experiment will be looking for response in abundance of prey species (such as Pomacentrids) and non-target species, as well as size/age and numbers of coral trout, through visual surveys. Close attention will be paid to the inverse relationships previously observed between adult coral trout abundance and juvenile (0+) abundance. This could be some evidence that fishing either
a) enhances recruitment from plankton, or
b) enhances survival of juveniles

Further Reading : Mapstone *et al.* (1997)

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BOX 4.9.2. THE CSIRO/QDPI "EFFECTS OF PRAWN TRAWLING" PROGRAM

This study in the northern Green Zone of the GBRMP focuses on Mid-Shelf Red-Spot King (*Penaeus longistylus*) trawl grounds, because the choice of "open" vs "closed" comparisons in the inshore part of the zone were confounded by illegal fishing. The sponge gardens in this area were found to exceed the area of hard coral reef.
The manipulations gained extreme accuracy (+- 5 m) using differential GPS. Prawn trawl effort is very aggregated -- 60% of the catch comes out of 10% of the area trawled in the Gulf of Carpentaria - so the experiment will incorporate much finer scale effects of aggregation of prawning effort.

- **year 1** most intensive set of inter-reefal benthos data for GBRMP
- **year 2** comparison of open/closed, bycatch, trawl gear comparisons
- **year 3 & 4** experimental simulations of impacts of prawn trawling on benthos, fish, prawns and bycatch
- **year 5** depletion experiment - different levels of trawl effort to assess rate of depletion of benthos by the trawl

1) Describe the area

- 10,000 square nautical miles inside the largest cross-shelf closure zone on the GBR
- at 100 random sites use fish trawl, prawn trawl, Church Dredge, video, diver and sediment grab samples.

One of the aims of this part was to find areas of commercial quantities of prawns that had never been trawled. Primarily red-spot kings, a very difficult task because with modern GPS trawlers can now shoot gear as little as 100 m away from reef.

2) Compare Blue and Green Zones (fish, prawns, megabenthos)

3) In areas found never to have been trawled, employ a BACI manipulation in 12 plots
- 6 controls + 6 treatment - 1nm by 2 nm, shallow and deep, by 2 seasons.
Used chaining or nets with differential GPS. Hit once in one season, repeated 6 months after, then 6 months after that, then 12 months after.

4) Monitoring, plus Depletion study

- *a) recovery of plots*.. depletion along one precisely defined track in 12 plots, repeated until significant decline in benthos; video before, monitor net catch during, then video after to monitor recovery
- *b) run video before/after*
- *c) use ROV over hard substrata*

Preliminary findings (March 1997):

- For many fish and sea bottom taxa the abundance is greater in the "closed" area than the adjacent "open" area, however the heterogeneity of species occurrence over the whole study area overshadows the detection of any major latitudinal patterns in species abundance
- the bycatch:marketed species ratio ranged from 9:1 to 12:1
- bycatch was dominated by small fish (50-70%), crustaceans and bivalves. The majority of fish are dead at the time of discarding and are taken by surface scavengers including some species of seabirds. Trawling has undoubtable, significant impact on bottom fish communities and potential flow on effects to scavenging populations
- a single pass of a trawl net can remove 5-20% of the sea bottom community and complete denuding of the sea bottom structure occurs after 10-13 trawl passes over the same area. In many areas of GBRMP where the frequency of trawling is at a relatively low frequency the 9mpacts of trawling may not be significant. However, there are many high intensity trawling areas where impacts would be extensive
- In prawn trawls, NO commercially or recreationally important species of reef fish were caught, which "confirms" previous work in the GBRMP

A new task has commenced to examine the rates and dynamics of sea bottom community recovery in an area where trawling had an effect but has now ceased.

Further Reading : Pitcher *et al.* (1997)