Ecological Sustainability of Bycatch and Biodiversity in Prawn Trawl Fisheries

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OBJECTIVES:

1. To undertake a literature review of prawn trawl bycatch and methods of estimating and monitoring bycatch of prawn trawl fisheries from published information to add to the already substantial literature database on bycatch reduction devices.
2. To compile a detailed description of the bycatch in the NPF and Torres Straits tiger and banana prawn fisheries and Queensland East Coast banana prawn fisheries to provide a reference against which future assessment can be made.
3. To measure the impact of prawn trawling on the sustainability of important vertebrate bycatch species, particularly those that may be vulnerable or endangered, and for those bycatch species for which no significant reductions can be achieved.
4. To assess the effects of prawn trawling on the biodiversity of key fish and other vertebrate communities.
5. To develop cost-effective, accurate and feasible methods of describing and monitoring prawn trawl bycatch that would be acceptable to all stakeholders.

1. NON-TECHNICAL SUMMARY

Prawn trawl fisheries are under increasing public and legislative pressure to manage their bycatch sustainably. Although this is now explicit in the fisheries management acts and the new *Environment Protection and Biodiversity Conservation Act*, there is little information on which to base sound management decisions. Bycatch cannot be managed without knowing what and how much is caught. This information is critical to determining the impact of trawling on the sustainability of bycatch species and its potential impact on biodiversity. Monitoring bycatch is also important as it provides vital baseline information for assessing changes in the catch rates of bycatch. This project focused on these issues in the Northern Prawn Fishery (NPF), the Torres Strait Prawn Fishery (TSPF) and the Queensland Banana Prawn Fishery. The study had four major aims:

- To describe the bycatch of the NPF, TSPF and Queensland East Coast banana prawn fishery
- To assess the impact of trawling on the sustainability of vertebrate bycatch species
- To assess the effects of prawn trawling on the biodiversity of vertebrate bycatch communities, and
- To develop cost-effective, accurate and feasible methods of describing and monitoring bycatch

1) To describe the bycatch of the NPF, TSPF and Queensland East Coast banana prawn fisheries
The NPF and TSPF cover a large area, but most fishing occurs in 10 areas of high effort. These areas were sampled by scientific surveys and by an observer on commercial boats to describe the bycatch. The bycatch was very diverse; 390 species of fish, 47 species of elasmobranchs (sharks, rays and sawfishes) and 234 invertebrate taxa were recorded. Fish species made up about 73% of the bycatch weight. This means that most bycatch does not survive trawling because most fish die. Three families, Bathysauridae (lizard fish or grinners), Leiognathidae (pony fishes) and Nemipteridae (monacled bream), made up 41% of the weight. However, most of the fish species were rare. The bycatch differed across the areas of the fisheries and with time of year. The bycatch composition of the TSPF differed from the NPF and within the NPF, the fishing areas formed two groups with different bycatch. These two regions were dominated by different species of prawn. Hence, future monitoring programs should monitor at least two regions in the NPF, one from each group and restrict comparisons to the same time of year.

The Queensland banana prawn fishery is not large, but there is concern over bycatch washing up on beaches. The bycatch was sampled with an observer on commercial boats. A total of 316 taxa of bycatch were identified. The dominant species were the black-tipped ponyfish *Leiognathus splendens*, (9.1% of all individuals), the little jewfish *Johnius borneensis* (7.6%) and a small portunid crab *Charybdis callianassa* (7.2%). Penaeid prawns, other than banana prawns, accounted for about 12% of the bycatch. The bycatch composition varied with latitude, differing in the grounds off each major fishing port. About 10% of the species contribute to other recreational or commercial fisheries in Queensland. A comparison of bycatch from nets with and without Bycatch Reduction Devices (BRDs) shows that the ratio of bycatch : prawn may be reduced by 55% by using BRDs.

2) To assess the impact of trawling on the sustainability of vertebrate bycatch species
Stock assessments for bycatch species are a challenge because bycatch is very diverse and little is known about the biology of most species. Hence, we developed an approach to examine the likely impact of trawling on vertebrate bycatch species and applied this to the NPF. Two overriding characteristics determine the sustainability of bycatch species: the susceptibility of a species to capture and mortality in a prawn trawl (susceptibility) and the capacity of a species to recover once depleted (recovery). A number of biological criteria were assessed for each characteristic. Species were ranked on each characteristic and the ranking reflects their ability to resist fishing pressure and therefore their priority for management, monitoring and research. The fishes, elasmobranchs (sharks, rays and sawfishes) and sea snakes were dealt with separately due to taxonomic and biological differences.

Since the 1980's, 411 fish species have been recorded in NPF bycatch. The species that are ranked as least likely to be sustainable and therefore the priority for management, monitoring, and research were highly susceptible to trawls. They are benthic or demersal, their main habitat is soft sediments and their diet may include prawns. Their recovery capacity is low. In applying this process we have highlighted important gaps in current knowledge of bycatch species but the ranking must be used with caution. Future research should be aimed at developing a greater understanding of the biology of species and their distribution in the region of the fishery.

The biology of elasmobranchs makes them more susceptible to overfishing than bony fishes because they are long lived, slow growing, reach maturity at a later age and have few young. Fifty-six species of elasmobranchs have been recorded in the bycatch of the NPF. Most are dead when landed on deck (56%) and survival is lower for smaller individuals. The species that were the least likely to be sustainable were the sawfishes (Pristidae) and some stingrays (Dasyatidae). They are all bottom dwellers which increases their susceptibility to capture. Research focusing on these high priority species is vital to ensure their long term sustainability. We need to know more about the basic biology, distribution, movement patterns and stock structure of these species. The introduction of compulsory Turtle Excluder Devices (TEDs) and BRDs in 2000 will result in the exclusion of only large elasmobranchs. Most elasmobranchs caught by trawlers are small and would fit through TEDs.

The biology of sea snakes also makes them more susceptible to overfishing than bony fishes. The total fishing mortality of the 13 species of snakes in the NPF bycatch is about 49%. Most snakes caught are mature. Our estimates of sea snake catch and biomass of each species indicate that fishing mortality could be 5-6% per year, which appears sustainable for all but 2 species, *Hydrophis pacificus* (Large headed sea snake) and *Disteira kingii* (spectacled sea snake). In the Gulf of Carpentaria, these two species are a high priority for further study on the effects of trawling. TEDs and BRDs appear effective at reducing sea snake catch.

3) To assess the effects of prawn trawling on the biodiversity of vertebrate bycatch communities
The vertebrate bycatch community was compared between areas open to trawling and areas that have been protected for 15 years, in the western Gulf of Carpentaria. If trawling had a large impact on biodiversity we would expect to see fewer species, lower catch rates and smaller individuals in the open areas. This was not the case; there was no consistent difference in the number of species between open and closed areas or in catch rates between open and closed areas. In general, the mean size of species was greater in the open areas. Although the results were equivocal with respect to the impact of trawling on biodiversity, this does not imply that trawling has no impact. Any differences between open and closed areas may be reduced by the low commercial effort in the open area, aggregated trawling, potential trawling in the closure, and the mobility of species. This combined with high natural variation may obscure any impacts of trawling.

4) To develop cost-effective, accurate and feasible methods of describing and monitoring bycatch.
The complex nature of NPF bycatch necessitated studies of sampling and monitoring methods to guide management. As most species are rare, a sample of 10% of the total catch contains about half of the species in the catch and has an 80% sampling error for the rare species. This sample size is the minimum recommended for monitoring. The results suggest that it is probably not feasible to monitor to detect a 50% change in catch rate for the very rare species. However, it may be possible to monitor more common species in one or two regions. This variability in bycatch is affected by factors such as moon phase and these should be taken into account when developing monitoring programs.

We compared the three possible methods for monitoring NPF bycatch: crew-member observers; trained observer collections; and scientific surveys. The fishery-dependent strategies are the least costly and have a potential advantage provided by the large number of vessels that can collect information. However, crew-member observers cannot collect data on all bycatch without affecting fishing operations. Trained observer costs are higher than crew-member observers, but they can collect more accurate and reliable information on a wider range of species, with less imposition on the fishing operation. Scientific surveys are the most costly method, but provide reliable, accurate and immediately available data. They are also the only method of collecting data on bycatch in unfished areas. The design of a monitoring program will depend on the specific objectives. However, any monitoring program should aim to collect information on a suite of bycatch species and detect changes in populations that may be at unsustainable levels. Other features of a monitoring program are also defined in this report. A monitoring program will be critical to assess whether the bycatch is sustainable or not.

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Conclusions
The high diversity of the bycatch of these tropical prawn fisheries and the fact that most species are rare means that managing the sustainability of the bycatch is a significant challenge. There are clearly some species that are more susceptible to trawling and are unlikely to recover if they are depleted; these species are the least likely to be sustainable. Future research and management should concentrate on these species. The development of a monitoring program for bycatch is not straightforward; the available methods differ in aspects such as data accuracy, reliability and cost. This project provides guidelines that can be used in the development of a monitoring program.

2. BACKGROUND

The continental shelf sea floor is one of the richest parts of the marine environment. It supports a wide diversity of animals that live in or on the substrate or in the waters immediately above the substrate. Many of these animals (e.g. fish and prawns) are valued as seafood and most of the world's fisheries exploit this zone - 95% of marine fish catches come from continental shelves (Pauly and Christiensen, 1995). However, few modern fishing methods catch solely their target species. Many fishing methods have a low selectivity, resulting in the catch of non-target species, or bycatch. Some bycatch is retained for marketing (often termed byproduct) but the extent of this varies among countries and is dependent on the relative values of the bycatch and the target species. Alverson *et al.* (1994) estimated 27 million tonnes of bycatch were discarded globally each year. This high volume of discards and the increasing awareness of the potential impacts on the environment has resulted in bycatch becoming an issue of global importance.

Prawn trawling is one of the least selective fishing methods, in most prawn trawl fisheries the weight of bycatch is greater than the weight of the commercially important prawns (Saila, 1983; Andrew and Pepperell, 1992). Worldwide it is estimated that prawn trawling produces a third of all discards (Alverson *et al.*, 1994). Globally, therefore, there has been increasing concern regarding the high levels of bycatch in prawn trawl fisheries and the impact of this on the bycatch species (Pascoe, 1997; Hall, 1999). This concern is often focused primarily on species that are the target of other commercial or recreational fisheries (e.g. Gutherz and Pellegrin, 1988; Broadhurst and Kennelly, 1994; Graham, 1995; Nance & Scott-Denton, 1996) or species which are listed as endangered or vulnerable, e.g. turtles (Anon., 1990; Poiner *et al*, 1990; Nance and Scott-Denton, 1996). However, there are significant numbers of other species caught as bycatch and for most the impact of prawn trawling is unknown.

Prawn trawl fisheries are among Australia's most valuable, however there is increasing public pressure regarding the issue of prawn trawl bycatch. In Australian prawn trawl fisheries the majority of the bycatch is discarded (Pender and Willing, 1989). The large volumes of bycatch, wash-ups of discarded bycatch on the Queensland east coast, the capture of species that are the target of commercial and recreational fisheries and the deaths of vulnerable or charismatic animals such as turtles, have increased public awareness and concern regarding the impact of prawn trawling on bycatch. These issues have led to a strong negative public perception regarding the damage and waste caused by prawn trawling bycatch.

The legislation under which Australian prawn trawl fisheries are managed is also explicit in its concern about bycatch. Australian fisheries are required to be managed in a manner consistent with the principal of ecologically sustainable development and the impacts on non-target species are expected to be taken into account. For Commonwealth fisheries, this is set out in the *Fisheries Management Act 1991*, and state fisheries legislation has similar principles. Fishery managers are, therefore, expected to deal with broader issues, rather than just the sustainability of the target species. Exactly how they are expected to manage the impacts of fisheries on the non-target species is unclear. This aspect of fisheries science and management is relatively new and there is limited information on which managers can base decisions (Harris and Ward, 1999).

Environmental legislation has also increased pressure on fisheries to manage the impacts of fishing on non-target species. The Commonwealth *Endangered Species Protection Act 1992* protects vulnerable or endangered species from man-made processes. Under this act, trawling can be nominated as a threatening process if it contributes to the destruction of a vulnerable or endangered species. Successful nominations under this act result in threat abatement plans which can modify the operations of the fishery. To date prawn trawling has been nominated as a threatening process for sea turtles and some fish species (*Paramonacanthus japonicus* and *P. filicauda*) but the nomination of prawn trawling as a threat to turtles has been deferred and the nomination with respect to the fish species was unsuccessful. The deferral in the case of the turtles is dependent on the fisheries developing effective measures to reduce or eliminate the capture of turtles.

The new *Environment Protection and Biodiversity Conservation Act,* will come into place in July 2000. It replaces five pieces of legislation, including the *Endangered Species Protection Act 1992*. This new Act will affect all fisheries which export their product. Under this Act fisheries will be assessed against guidelines which examine their management with respect to target species, bycatch species and the impacts on the environment. In order to continue exporting their product, fisheries will be required to demonstrate that their current management and research priorities include managing the impacts of fishing on bycatch species in a sustainable manner.

One, of the most obvious method for managing bycatch is by reduction of the amounts captured. Many trawl fisheries throughout the world are required to use Bycatch Reduction Devices (BRDs) or Turtle Exclusion Devices (TEDs) to achieve this. In the last decade there has been substantial research into the development of TEDs and BRDs for prawn trawls. TEDs successfully exclude turtles and large animals (Brewer *et al.*, 1998), while other BRDs can reduce the total amount of bycatch (Broadhurst *et al.,* 1996). Substantial resources have been invested in BRD and TED research worldwide (e.g. Watson and Taylor, 1988; Watson *et al.,* 1993) and within Australia (Broadhurst and Kennelly, 1995; Mounsey *et al.,* 1995, Robins-Troeger *et al.*, 1995; Broadhurst *et al.*, 1996, 1997; Brewer *et al.,* 1998). However, it is unlikely that the bycatch from prawn trawlers will be completely by present designs. These are achieving up to about 30% reductions in bycatch in night time fisheries (Broadhurst *et al.*, 1996). The managers of some Australian prawn fisheries, have therefore, introduced compulsory use of BRDs and TEDs either in the whole fishery or in selected areas. This introduction has the potential to make a significant impact on bycatch populations. However a significant bycatch will continue to be taken by trawlers. We need to know whether species in this bycatch are sustainable under the remaining trawling impact.

Current knowledge of bycatch in prawn trawl fisheries in Australia varies substantially (Section 4). Some fisheries, such as the NSW prawn trawl fishery, have been the focus of intensive surveys to describe bycatch (Kennelly, 1992), while others lack even a basic description of the species composition of bycatch. A recently completed study focused on the broader environmental effects of prawn trawling in the far northern GBR. This study examined the differences between areas open and closed to trawling, the fate of discarded species and the effects of repeated trawling over the same area and the impacts of trawl discards on seabird populations (Poiner *et al.*, 1998)

Fisheries managers cannot address the effects of fishing on bycatch without first knowing what and how much is taken by the fishery. This information is critical to determining the impact of the prawn trawling on the sustainability of the bycatch species and the potential impact on biodiversity. Monitoring of bycatch is vital to producing baseline information and also determining whether changes in bycatch species catch rates occur. This is important for the long term management of bycatch and to determine whether management interventions have been successful. The most appropriate method for monitoring will vary among fisheries and depend on the specific questions being addressed.

This project focused on three tropical prawn trawl fisheries, for which the above questions needed to be addressed. These fisheries were the Northern Prawn Fishery (NPF), the Torres Strait Prawn Fishery (TSPF) and the Queensland Banana Prawn Fishery (Figure 2.1).

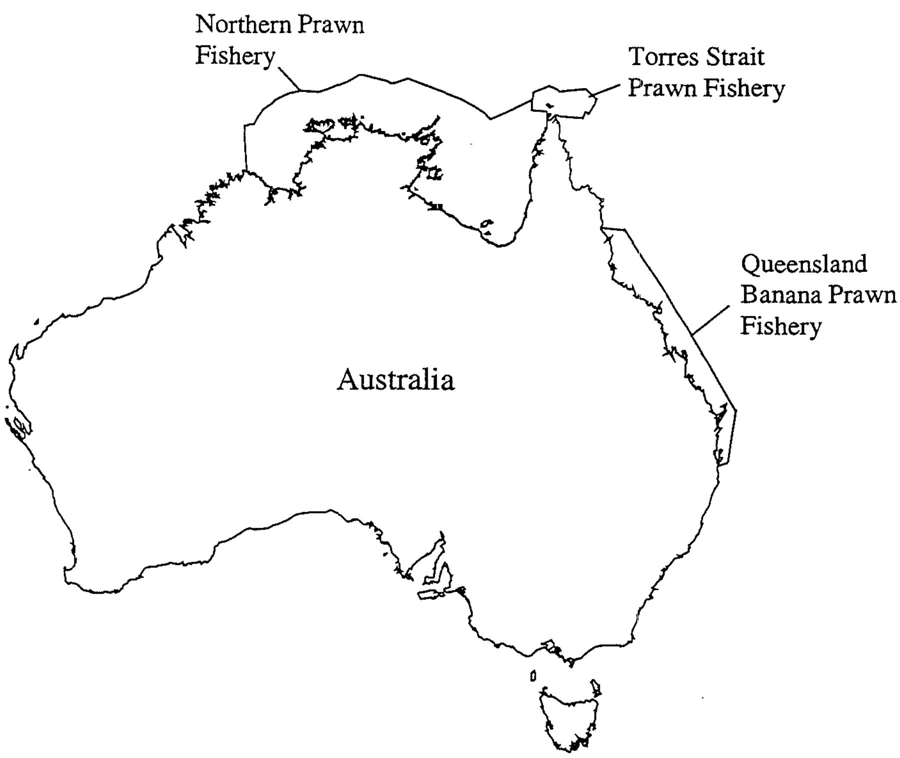

Figure 2.1 The location of the Northern Prawn Fishery, the Torres Strait Prawn Fishery and the Queensland Banana Prawn Fishery.

Description of the fisheries

Northern Prawn Fishery

The NPF is one of Australia's three most valuable fisheries, with 130 vessels capturing 8,265 tones of prawns in 1998 (Sharp *et al.*, 1999). This is a Commonwealth managed fishery which started in the 1960's. The current managed area covers over 6,000 km of coastline and over 1,000,000 km^2 of ocean (Figure 2.1). The vessels tow a twin gear configuration, generally with Florida Flyer type nets. The fishery is currently open for about 6 months of the year, from April to June and then September to November (AFMA).

The fishery has two components; a short 'banana prawn season' (approximately 3 weeks in April) when banana prawns (primarily *Penaeus merguiensis*) are caught during the day and night, and a longer 'tiger prawn season' (approximately 25 weeks) when tiger (*P. semisulcatus* and *P. esculentus*) and endeavour (*Metapenaeus endeavouri, M. ensis*) prawns are caught during night time trawling (McLoughlin *et al.*, 1997). When fishing for banana prawns, trawlers tend to target large, visible schools of prawns (Robins and Sachse, 1994) using short duration trawls (<1 h). This pattern of trawling results in trawls which are often 100% prawns and so there is not a strong concern about bycatch during the short banana prawn season. In contrast, the night-time tiger prawn fishery targets more dispersed prawns using much longer duration trawls (3 – 4 h). As the prawns are less aggregated and the trawls longer than the banana prawn season, higher levels of bycatch are likely to be taken. There is consequently more concern regarding the bycatch of the tiger prawn fishery.

The bycatch of the western regions of the NPF (off the NT coast) was described, from collections on commercial fishing boats during the 1980s (Ramm *et al.*, 1990; Pender *et al.*, 1992). The spatial and seasonal coverage of the study was governed by where the commercial fishery was operating and the observers movements. The demersal fish community in one region of the NPF was examined at a finer scale in the 1960's, prior to the start of the commercial fishery (Rainer and Munro, 1982; Rainer, 1984). This was replicated in the 1980's to examine whether impacts of 20 years of fishing could be detected (Harris and Poiner, 1991). Skippers are currently required to record the catches of turtles in bycatch and in addition a 3 year program is currently underway using trained crew members to log turtle capture and collect biological information on turtles. In this program records are also kept of seasnake and sawfish captures (FRDC 98/202 *Monitoring the catch of turtles in the NPF*).

The management committee of the NPF (NORMAC) has been highly proactive with respect to bycatch. The issue of bycatch has been identified as a research priority for many years. Bycatch research has been supported since the early 1990's and the Northern Prawn Fishery Management Advisory Committee (NORMAC) has produced the first bycatch action plan for an Australian fishery. The NPF Bycatch Action Plan (1998), includes the compulsory introduction of BRDs and TEDs in 2000. The identification of bycatch sustainability indicators and the requirement to monitor bycatch and the impact of BRDs are also part of the Bycatch Action Plan.

Torres Strait Prawn Fishery

The TSPF is a much smaller fishery that started in the mid 1970's. Currently there are 83 vessels taking 2000 tonnes of prawns (Jackson *et al.*, 1999). The catch is dominated by endeavour prawns, but also includes tiger prawns (Jackson *et al.* 1999) with trawling occurring only at night (McLoughlin *et al.*, 1997). The TSPF is between the NPF (Figure 1.1) and the Queensland East Coast Trawl Fishery (QECTF). All vessels in the TSPF, except 3 Torres Strait Islander licenses, are required to hold QECTF endorsements and 17 vessels also hold licenses for the NPF. Currently the fishing effort is controlled by allocating fishing days to each vessel. The bycatch of the TSPF was examined with scientific trawls in the 1980's (Harris and Poiner, 1990), but abundances of bycatch species were presented at the family level.

Queensland Banana Prawn Fishery

The Queensland banana prawn fishery is part of the Queensland East Coast Trawl Fishery (QECTF). About 600 tonnes (valued at about $6 million) of banana prawns annually. Most of the catch is taken by otter-board trawlers, with beam trawlers operating in rivers and estuaries land about 15% of the catch. The majority of catch and effort occur in two general areas; a northern area between Cairns and Mackay, and a southern area from Rockhampton to Bundaberg. The fishery is highly seasonal, mainly from January to June. Catches are generally positively correlated with
rainfall. Yankee doodle or Florida Flyer type nets are used by fishers in a quad gear configuration, although some use triple gear or trouser net configurations. Although the fishery contributes only about 10% of the total catch and effort in the QECTF, bycatch from the banana prawn sector attracts a disproportionately high level of community concern. This is because trawling for banana prawns takes place during daylight hours in nearshore shallow coastal waters that are generally in the vicinity of coastal towns, cities and ports where fishing operations are highly visible. Bycatch from the fishery sometimes washes up onto local beaches where it is readily encountered by, and causes concern among, the general public, recreational fishers, conservationists, tourist operators and others.

References

Alverson, D.L., Freeber, M.H., Murawski, S.A., Pope, J.G., 1994. A global assessment of fisheries bycatch and discards. FAO Fish. Tech. Paper 339, 233pp.

Andrew, N.L., Pepperell, J.G., 1992. The by-catch of shrimp trawl fisheries. Oceanogr. Mar. Biol. Ann. Rev. 30, 527-565.

Anon., 1990 Decline of the sea turtles: Causes and prevention. Committee on Sea Turtle Conservation, National Research Council, National Academy Press, Washington D.C.

Brewer, D.T., Rawlinson, N., Eayrs, S., Burridge, C., 1998. An assessment of bycatch reduction devices in a tropical Australian prawn trawl fishery. Fish. Res. 36, 195-215.

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

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

Broadhurst, M.K., Kennelly, S.J., O'Doherty, G., 1996. Effects of square-mesh panels in codends and of haulback delay on by-catch reduction in the oceanic prawn-trawl fishery of New South Wales, Australia. Fish. Bull. 94, 412-422.

Broadhurst, M.K., Kennelly, S.J., Barker, D.T., 1997. Simulated escape of juvenile sand whiting (*Sillago ciliata*, Cuvier) through square-meshes: Effects on scale-loss and survival, Fish. Res. 31, 51-60.

Graham, G.L., 1995. Finfish bycatch from the southeaster shrimp fishery. In Solving bycatch: considerations for today and tomorrow. Alaska Sea Grant College Program Report No 96-03, University of Alaska Fairbanks. pp. 115-120.

Gutherz, E.J., Pellegrin, G.J., 1988. Estimate of the catch of red snapper, *Lutjanus campechanus*, by shrimp trawlers in the U.S. Gulf of Mexico. Mar. Fish. Rev., 50, 17-25.

Hall, S.J., 1999. The Effects of Fishing on Marine Ecosystems and Communities. Blackwell Science Ltd, Great Britain.

Greer, A. E., 1997. The Biology and Evolution of Australian Snakes. Surrey Beatty & Sons, Sydney.

Harris, A.N., Poiner, I.R., 1990. By catch of the prawn fishery of Torres Strait: Composition and partitioning of the discards into components that float or sink. Aust. J. Mar. Freshwat. Res. 41, 37-52

Harris, A.N., Poiner, I.R., 1991. Changes in species composition of demersal fish fauna of southeast Gulf of Carpentaria, Australia, after 20 years of fishing. Mar. Biol. 111, 503-519.

Harris, A.N., Ward, P., 1999. Non-target species in Australia's Commonwealth Fisheries. A critical review. Bureau of Rural Sciences, Canberra. 152pp.

Jackson, S., Gaffney, P., Turnbull, C., 1999. Torres prawn handbook 1999. Australian Fisheries Management Authority, Canberra, Australia.

Jennings, S., Kaiser, M.J., 1998. The effects of fishing on marine ecosystems. Adv. Mar. Bio. 34, 203-354.

Kennelly, S.J., 1992. Study of the by-catch of the NSW East Coast Trawl Fishery. Final report to the Fisheries Research and Development Corporation. No 88/108

McLoughlin, K., Wallner, B., Staples, D., 1997. Fishery status reports 1996. Bureau of Resource Sciences, Kingston, Australia.

Mounsey, R.P., Baulch, G.A., Buckworth, R.C., 1995. Development of a trawl efficiency device (TED) for Australian prawn fisheries. I. The AusTED design. Fish. Res. 22, 99-105.

Nance J.M., Scott-Denton, E., 1996. Bycatch in the Gulf of Mexico Shrimp Fishery. In Hancock, D.A., Smith D.C., Grant, A., Beumer, J.P. (Eds.) Developing and sustaining world fisheries resources: the state of science and management, 2nd World Fisheries Congress proceedings, CSIRO Publishing, Australia. pp. 98-102.

Pascoe, S., 1997. Bycatch management and the economics of discarding. FAC Fish. Tech. Paper 370, 137pp.

Pauly, D., Christensen, V., 1995. Primary production required to sustain global fisheries. Nature 374, 255-257.

Pender, P.J., Willing, R.S., 1989. Trash or treasure? Aust. Fish. 48, 35-36.

Pender, P.J., Willing, R.S., Ramm, D.C., 1992. Northern Prawn Fishery bycatch study: distribution, abundance, size and use of bycatch from the missed species fishery., Fishery Report No. 26 (Northern Territory Department of Primary Industry and Fisheries), 70pp.

Poiner, I.R., Buckworth, R.C., Harris, A.N.M., 1990. Incidental capture and mortality of sea turtles in Australia's northern prawn fishery. Aust. J. Mar. Freshwat. Res. 41, 97-110.

Poiner, I., Glaister, J., Pitcher, R., Burridge, C., Wassenberg, T., Gribble, N., Hill, B., Blaber, S., Milton, D., Brewer, D., Ellis, N., 1998. Final report on effects of trawling in the Far Northern Section of the Great Barrier Reef. CSIRO Division of Marine Research, Cleveland, Australia.

Rainer, S.F., 1984. Temporal changes in a demersal fish and cephalopod community of an unexploited coastal area in northern Australia. Aust. J. Mar. Freshwat. Res. 53, 747-768.

Rainer, S.F., Munro, I.S.R., 1982. Demersal fish and cephalopod communities of an unexploited coastal environment. Aust. J. Mar. Freshwat. Res. 33, 1039-1055.

Ramm, D.C., Pender, P.J., Willing, R.S., Buckworth, R.C., 1990. Large-scale spatial patterns of abundance within the assemblage of fish caught by prawn trawlers in northern Australia.

Robins, C., Sachse, M., 1994. A creep called technology: evolution of the fleet. In: Pownall, P.C. (Ed.), Australia's Northern Prawn Fishery. NPF25, Cleveland, Australia, pp.23-34.

Robins-Troeger, J.B., Buckworth, R.C., Dredge, M.C.L., 1995. Development of a trawl efficiency device (TED) for Australian prawn fisheries. II. Field evaluations of the AusTED. Fish. Res. 22: 107-117.

Saila, S.A., 1983. Importance and assessment of discards in commercial fisheries. FAO Fish. Circ. No. 765, 62pp.

Sharp, A., Bishop, J., Harris, D., 1999. Northern Prawn Fishery and Kimberley Prawn Fishery data summary 1998. Australian Fisheries Management Authority, Canberra.

Watson, J.W., Taylor, C.W., 1988. Research on selective shrimp trawl designs for penaeid shrimp in the United States; A review of selective shrimp trawl research in the United States since 1973. FAO expert consultation on selective shrimp trawl development, Mazatlan, Mexico, 24-28 November 1986. FAO Rome, 1986.

Watson, J., Workman, I., Foster, D., Taylor, C., Shah, A., Barbour, J., Hataway, D., 1993. Status report on the development of gear modifications to reduce finfish bycatch in shrimp trawls in the Southeastern United States 1990-1992. NOAA Tech. Mem. NMFS – SEFSC – 327, 131pp.

3. NEED

In order for prawn trawl fisheries to manage the direct impact of trawling on the bycatch species there is a need to i) establish cost-effective, reliable and widely-accepted methods to describe and monitor bycatch, ii) obtain detailed descriptions of bycatch composition, iii) identify the bycatch species which are not sustainable and iv) to understand the impact of trawling on biodiversity.

The current scarcity of data on the effects of prawn trawling on bycatch species and marine communities leaves fisheries managers unable to either counter arguments about the threat trawling poses to bycatch species and biodiversity, or to develop strategies to minimize the possible effects of trawling. This project addresses the needs of the NPF and TSPF, as well as the QEC banana prawn fishery by examining monitoring methods, describing bycatch and how it varies, and evaluating the sustainability of species and examining the impacts on biodiversity. The information provided will enable fisheries managers to evaluate and manage the impact of prawn trawling on bycatch species. This will allow them to maintain their proactive approach to bycatch.

4. OBJECTIVES

- To undertake a literature review of prawn trawl bycatch and methods of estimating and monitoring bycatch of prawn trawl fisheries from published information to add to the already substantial literature database on bycatch reduction devices (Section 5).
- To compile a detailed description of the bycatch in the NPF and Torres Straits tiger and banana prawn fisheries and Queensland East Coast banana prawn fisheries to provide a reference against which future assessment can be made (Section 6).
- To measure the impact of prawn trawling on the sustainability of important vertebrate bycatch species, particularly those that may be vulnerable or endangered, and for those bycatch species for which no significant reductions can be achieved (Section 7).
- To assess the effects of prawn trawling on the biodiversity of key fish and other vertebrate communities (Section 8).
- To develop cost-effective, accurate and feasible methods of describing and monitoring prawn trawl bycatch that would be acceptable to all stakeholders (Section 9.).

5. REVIEW OF THE STATUS OF BYCATCH IN AUSTRALIA AND S. E. ASIA AND OF METHODS OF ESTIMATING AND MONITORING BYCATCH OF PRAWN TRAWL FISHERIES.

To undertake a literature review of prawn trawl bycatch and methods of estimating and monitoring bycatch of prawn trawl fisheries from published information to add to the already substantial literature database on bycatch reduction devices.

5.1 Introduction

The issue of bycatch has been subject to numerous reviews. These have focussed on broad level global issues or on specific gears including seining, gill nets, trawling and dredging. As these reviews have been extensive, the focus of this section is confined to bycatch of prawn trawls in Australia. The specific issues examined are:

- The geographical areas covered by Australian studies on prawn trawler bycatch;
- The content and type of bycatch data available in the Australasian region;
- Information on endangered, threatened or protected species affected by prawn trawling;
- Survival and damage to discarded bycatch species;
- Scavenging on discarded bycatch from prawn trawling;
- Bycatch reduction devices (BRDs);
- Estimating and monitoring bycatch.

5.2 The geographic areas covered by Australian studies on bycatch

Prawns are caught along most of the western, northern and eastern coastline of Australia as well as from parts of the south. The fisheries extend across a range of habitats from tropical to sub-tropical to temperate waters. The bycatch composition of Australian prawn trawl catches is highly diverse. For example, Pender *et al.*,(1992) recorded 218 fish taxa from the western half of the NPF; Rainer (1984) sampled 359 fish taxa and Poiner and Harris (1985, Harris and Poiner 1991) recorded 245 fish species from the south east Gulf of Carpentaria region of the NPF. The bycatch from the Torres Strait region has been described by Harris and Poiner (1990) and they record 111 families of fish. Jones and Derbyshire (1988) identified 183 fish taxa from the Queensland East Coast Trawl Fishery, 353 fish species were identified in New South Wales prawn grounds (Graham *et al.*, 1993) and 150 species of fish were identified from south Western Australia (Laurenson *et al.*, 1993). In addition, many hundreds of species of invertebrates are reported from northern prawn trawls. This high diversity does not extend to southern areas. Only six fish species and two invertebrate species have been reported for the South Australian prawn fishery (McShane *et al.*, 1999). No reports have been found on the composition of the prawn trawler bycatch from the Victorian prawn trawler regions. The composition of the bycatch from the banana prawn fisheries of the Northern Prawn Fishery has not been described. The composition of the bycatch from the banana prawn fisheries of the Queensland East Coast Trawl Fishery is described in Section 6.1 of this report.

The list of published reports on bycatch in the Australian region (Table 5.2.1) indicates that the studies have been restricted to specific fisheries or regions, often localised within State fisheries. That is logical and expected. However, the different methods of measurement of abundance and the different taxonomic levels used make comparisons across and between fisheries very difficult. A standardisation of methods of abundance analysis and at the same taxonomic level would enable comparisons to be made at bio-regional levels. There are few comparable data on the composition of the bycatch from each of the fisheries and there are no published descriptions of bycatch of banana prawn fisheries. There is also no continuous long-term monitoring of the bycatch composition over time or of any impacts on vulnerable or endangered species other than turtles. The development of a standardised approach to monitoring bycatch from prawn trawl fisheries is an objective of this report (see Section 9).

5.3 Endangered, threatened or protected species

The International Union for the Conservation of Nature (IUCN) has defined the status of a species or population for conservation. "*A species is considered endangered when it is in immediate danger of going extinct, if the current threats to that species persist. A threatened species is one that is under threat of becoming extinct if the current threats to that species persist*".

Sea turtles

Marine turtle species are listed in the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) as either endangered or threatened. Turtles, due mainly to their longevity and low fecundity (giving birth to few young) and lack of any parental care and thus having a low capacity to recover from exploitation, are listed as endangered or potentially vulnerable to the impacts of trawling. In Australia Loggerheads (*Caretta caretta*) and Olive Ridleys (*Lepidochelys olivacea*)) are listed as endangered and Flatbacks (*Natator depressus*) as potentially threatened species under the *Endangered Species Act* 1992.

While trawling is not the major cause of mortality on turtle populations (Poiner and Harris, 1996) it is contributing to the decline in their populations. The catch of turtles by prawn trawlers in northern Australia has been the focus of several studies (Poiner *et al.*, 1990; Poiner and Harris, 1994,1996; Robins,1995). In the NPF, Flatback turtles (*Natator depressus*) are the main species caught (45%), with Loggerheads (*Caretta caretta*) (19%), Olive Ridleys (*Lepidochelys olivacea*) (15%) and Green turtles (*Chelonia mydas*) (4%) all contributions to the catch (Poiner *et al.*, 1990). Mortalities, due to drowning, vary between 10 and 18% in the NPF. The rates of mortality vary with depth and duration of the trawls and between fisheries (Poiner and Harris, 1996). In the QECTF, Loggerhead turtles are the most common turtle caught by trawlers (50.4%). Mortality rates are between 1.1% and 6.8%, much lower than for the NPF (Robins, 1995). The lower death rates on the east-coast may be a result of shorter trawls (< 80 mins) compared to the 3 h trawls normally used in the NPF.

Guidelines on procedures for handling captured turtles supplied to fishers by the Australian Nature Conservation Agency (ANCA), the Queensland Commercial Fishermen's Organisation, (QCFO) and Australian Fisheries Management Authority (AFMA). These are helping to reduce the effects of salt water inhalation and fewer deaths of turtles have subsequently been reported in NPF log books. The use of Turtle Excluder Devices (TED's)

Table 5.2.1 Summary of bycatch research in Australasian prawn trawling areas. Taxon are labelled F = fish, I = invertebrates, B = both, level refers to the level of taxonomic identification F = family, S = species, O = other. (* = identified to species where possible)

Authors	**Taxon**	**Level**	**Measure of abundance**	**Geographic location**	**Frequency of sampling**
Bejie, (1980).	F	F	% weight	Malaysia (Sarawak)	21 trawls during one month.
Cannon, *et al.,* (1987).	B	S	Presence/ absence	Qld east coast	Seven cruise (3y) different areas.
Dredge (1989 a, b).	B	S	Numerical	Qld east coast (Townsville)	Monthly sampling at 24 sites (2y)
Gray *et al.,* (1990).	B	S	Numerical	Hawksbury River NSW	Monthly (~2y)
Harris and Poiner, (1990).	B	F	CPUE	Torres Strait	Three monthly sampling (2y)
Jones and Derbyshire, (1987).	B	S*	Numerical	Qld east coast (Townsville)	Monthly (2y)
Kennelly, (1993).	B	S	CPUE	NSW rivers and oceanic	Three monthly sampling (2y)
Kennelly *et al.*, (1998)	B	S*	Weight% Number%	NSW rivers and oceanic	Three monthly sampling (2y)
Kulbicki and Wantiez, (1990).	F	S	Frequency of occurrence and weight	New Caledonia	8 trawls over one month
Laurenson, *et al.*, (1993)	B	S	CPUE	South Western Australia	9 sites sampled over four seasons (1y)
Pender and Willing, (1990).	B	S	CPUE	Northern Territory	5 grounds during 1988 fishing season
Pender *et al.*, (1992).	B	S*	CPUE	Northern Territory	5 grounds during fishing season (2y)
Poiner and Harris, (1985).	B	S	Number/area swept	South-eastern Gulf of Carpentaria	181 samples over 10 months
Rainer, (1984).	B	S	CPUE	South-eastern Gulf of Carpentaria	1293 samples over 5 seasons (2y).
Rainer and Munro, (1982)	B	S	Presence/ absence	South-eastern Gulf of Carpentaria	341 samples over 3 months
Ramm *et al.*, (1992)	F	S	CPUE	Northern Territory	5 grounds during fishing seasons (2y)
Wassenberg *et al.,* (1997).	F	S	CPUE	Shelburne Bay Qld east coast	122 samples over 2 y
Wassenberg *et al.,* (1998).	F	S	CPUE	Shelburne Bay Qld east coast	40 samples from 2 sites
Watson, (1984).	F	F	CPUE	Gulf of Papua	71 samples over 8 boat weeks
Watson and Goeden, (1989).	B	S*	Numerical	Qld east coast (Townsville)	Monthly (2y)
Watson *et al.,* (1990).	B	S*	Numerical	Qld east coast (Townsville)	Monthly (2y)

will be compulsory in the entire NPF from the 15 April 2000 as well as on some areas of the Qld east coast. These devices allow turtles to escape from the nets (see Section 5.5 on bycatch reduction devices). The NPF has been monitoring turtle catches for the last 2 years and has put in place a further one year monitoring of turtle catches and their fate after being caught for the year 2000 in order to assess the effectiveness of the compulsory use of Turtle Exclusion Devices (TEDs). NORMAC has also set a target of reducing the catch of turtles to 5% of the number caught in 1989 and 1990.

Sea snakes

Sea snakes are not considered an endangered species and are not listed in CITES (ANCA. 1994) however, they are listed as protected animals (Schedule 1 of the National Parks and Wildlife Regulations, 1994). Other than a few papers using data collected from different areas during the 1970s and 1980s (see Section 7.4.1) there are few comparable data (particularly due to changes in fishing patterns and effort over time (see Buckworth, 1987, Robins *et al.*, 1998)) on their distribution, catch rates by species or ecological data on which to determine their long term sustainability. Sea snakes, like turtles, are caught in northern prawn trawls (Kimberleys, NPF, TSPTF and the QECTF). Sea snake species may have a low capacity to recover from fishing and are potentially threatened by the impacts of trawling (Marsh *et al.*, 1993), due mainly to their low fecundity (giving birth to few young) and longevity (~5 to 10 y).

About 30 species of sea snake are known to live in the waters off northern Australia and about 50% of these are endemic (Marsh *et al.*,1993). These animals live in coastal waters to a depth of about 50 metres. They occur over a variety of habitats from coastal reefs to offshore muddy-sand substrates. Many sea snake habitats overlap with the NPF and the QECTF. Wassenberg *et al.*, (1994) established that during 1991 between 100 000 and 150 000 sea snakes were caught by prawn trawlers in the Gulf of Carpentaria and that 33% of these died as a result of trawling. Heatwhole and Burns, (1987) estimated that between 10 to 42% of sea snakes caught in prawn trawls die.

Most studies of sea snakes in Australia have focussed on distribution patterns (Shuntov, 1971; Heatwole, 1975; Redfield *et al.*, 1978; Dunson, 1975; Wassenberg *et al.*, 1994; Ward, 1996 a). Consequently, there is insufficient biological information available on which to evaluate the long-term sustainability of sea snake populations on trawl grounds. The little data available on the life history characteristics of many Australian species of seasnake is summarised in Greer (1997), but no detailed life history data have been published for the Australian species caught by trawlers.

Elasmobranchs

Elasmobranchs (sharks, rays and sawfish) , are potentially vulnerable to the impacts of trawling, due mainly to their low fecundity (giving birth to few young),. Unlike species that spawn very large numbers of eggs, elasmobranchs have a more direct relationship between fishing mortality and potential recruitment.

Sawfish (Pristidae) of northern Australia have recently been nominated as endangered under the *Endangered Species Act* 1992, particularly as they readily become entangled in nets. One estimate of total catch for sawfish for the western NPF is that of Pender *et al.*, 1992 but this is based on a catch of 10 sawfish from 278 commercial prawn trawls. This study was limited to waters adjacent to the Northern Territory. The species were not identified. The fate of sawfish caught in nets is partially dependent on their size and whether the crew remove the saw and fins. Often a saw has to be removed from the animal to remove the animal from the nets, particularly if they are very large (>2.5 m) and dangerous to the crew. Fins attract high prices and in recent years finning has been a standard practice in the NPF. Fins if kept by the crew are sometimes recorded as byproduct (Sharp *et al.*, 1998).

Sharks (Carcharinidae) represented 12% of the bycatch in the western NPF in 1988 (Pender *et al.*, 1992) with an estimated catch of 305 tonnes in NT waters. Pender *et al.* (1992) also present CPUE (kg h^{-1}), weight of individuals and catch for three shark species by region within NT waters. No such detailed data exist for sharks caught as bycatch in the rest of the NPF, the Torres Strait or other Australian prawn trawl fisheries. Sharks collectively are listed in NPF logbooks as by-product (kg) but species identification is not practical within logbooks. As not all sharks are kept or recorded, the logbook data under-represent the total bycatch in the fishery. Currently, the log books on byproduct are not validated and do not give accurate estimates of catchrates for sharks.

Pender *et al.*, (1992) recorded at least five species of rays in the western NPF. They estimated a catch of 294 tonnes of rays in 278 trawls during the two year study period. Catch rates of Dasyatidae of 1 kg h^{-1} have been recorded from the Torres Strait (Harris and Poiner, 1990). Dasyatidae have been recorded from research trawls in the Queensland east-coast fishery (Dredge, 1989 a, b) but there is no detailed information about the species or the amounts caught by the fishing industry. Dasyatidae appear common in the NSW prawn trawl grounds (Graham *et al.*, 1993), but again the impact of the fishery on this group is not known. No published details on sharks and rays caught by prawn fishers in the other southern states were found.

The compulsory introduction of TED's in prawn trawl nets in the NPF and areas of the QECTF (see Section 5.5 on bycatch reduction devices) may also reduce elasmobranch catch rates. These devices may enable some sharks and rays to escape. It is unlikely that sawfish will benefit from these devices as their saws often become entangled in the net.

5.4 Survival and damage of discarded species

Knowledge of survival rates of bycatch species is important as it enables estimates of mortality rates to be made. This provides a greater understanding of the impact of trawling on the bycatch species. A number of studies have shown that nearly all fish (80 to 90%) are dead when discarded from prawn trawls (Hill and Wassenberg, 1990; Laurenson *et al.*, 1993; Wassenberg and Hill, 1989, 1993). Amongst invertebrates, nearly all bivalves and gastropods, robust echinoderms such as asteroids and holothurians, crabs and scyllarid lobsters survive capture in trawls. More delicate crustaceans, most echinoids, crinoids and soft corals do not survive. The fate of discarded sessile animals previously attached to the seabed (eg sponges and gorgonians and alcyonarians) is not known, but there is probably a high mortality rate in these groups.

Many animals are damaged by the physical impacts of the trawl and while not necessarily dead may not survive. Some are crushed or pierced by spines and some have limbs and appendages broken off. In one study, external damage to crustaceans was extensive (Wassenberg and Hill, 1989) with 51% of 484 crabs suffering damage. Softer shelled crustaceans suffered more damage to their cephalothorax than did the crabs, but no correlation was found between body size and damage. Trawls also affect animals that pass through the net during trawling, but there is hardly any information on this. Fish may lose of scales. We do not know if there is an impact on these animals.

The entry of discards into different ecological pathways begins with the discarding process. Bycatch discarded from prawn trawlers divides into three categories: floating material, sinking material that is alive and sinking material that is dead. Many discarded species float, particularly fish (50 to 80%) and do so for at least 10 h (Wassenberg and Hill, 1990). The species composition and the depth from which they are hauled are significant contributors to whether or not a species floats (Harris and Poiner, 1990). Floating fish may still be alive, but their extended swim bladders prevent them from returning to the seabed. This renders them vulnerable to scavengers (birds, sharks and dolphins) and these fish may eventually die. Sinking material makes up the largest component of discards, consisting of crustaceans, echinoderms, molluscs and about half of the fish. Animals that return to the seabed alive may survive unless they are fatally damaged. Dead animals that reach the seabed are eaten by scavengers such as fish, crabs and sharks (Hill and Wassenberg, 1990, 1992; Wassenberg and Hill, 1987).

The introduction of Bycatch Reduction Devices (BRDs) may improve survival of fish (Blaber *et al.*, 1997). Experiments conducted to test the survival of fish recaptured after they passed through square mesh codends (treatment) compared with fish passed through a standard codend (control) (Farmer *et al.*, 1998) showed that after 8 days, 21% of treatment fish and 15% of control fish were still alive. Survival varied between taxa and ranged from 0% for *Cynoglossus* sp. to 100% for *Terapon puta*. Loss of scales seemed to be the main injury sustained by fish escaping through the codend of prawn trawls (Farmer *et al.*, 1998), but there was not much visible damage to fish escaping from standard codends. This is the only study of survival of trawl escapees in any Australian or tropical Indo-Pacific trawl fishery. Studies in the North Sea have shown that fish may suffer internal damage such as stress induced haemorrhage (Wardle, 1981). Animals that are damaged or weakened in these ways may be more vulnerable to predators but there is no information presently available on these effects in Australian trawl fisheries. Wassenberg and Hill (1993) showed that mortality from trawling continues for up to four days after trawling and then becomes negligible. This suggests that internal damage is important and assessment of the condition of discards must take this time factor into account.
A major gap exists in the case of large animals as no survival studies have been done on any of the larger animals such as sharks or rays

5.5 Scavenging on discards

One major effect of discarding practices and differential damage and survival of bycatch species is the alteration of trophic dynamics through the provision of food (as discards) in quantities that are not naturally available to scavengers (Blaber *et al.,* 1998; Hill and Wassenberg, 1992). The provision of this food may increase the population sizes of marine scavengers such as sharks, some crab and fish species. This process may change community structures (Jennings and Kaiser, 1998).

Direct and indirect observations of scavengers of discards have identified sharks, dolphins, fish and crabs as the main scavenger species (Blaber and Wassenberg, 1989;Hill and Wassenberg, 1990; Wassenberg and Hill, 1987, 1990). In Moreton Bay, the far northern Great Barrier Reef and the Torres Strait, dolphins and sharks scavenge at the surface and portunid crabs (eg *Portunus pelagicus*) and fish (mostly nemipterids, lethrinids and lutjanids) are the main scavengers on the sea bed (Hill and Wassenberg, 1990; Wassenberg and Hill, 1987, 1990). There are no published data on scavengers of discards other than birds in the NPF (Blaber and Milton, 1994). However, unpublished data collected by CSIRO suggests that the situation is similar to the east coast of Queensland and the Torres Strait with dolphins and sharks being the main near- surface scavengers of sinking material. No data are available on scavenging on the seabed in the NPF.

Seabirds are one of the major scavengers on trawler discards and extensive work in the Northern hemisphere has shown significant changes in seabird populations as a consequence of the availability of this food (Furness *et al.,* 1988). The few studies in Australia suggest that feeding on prawn trawler discards may affect seabird populations Blaber and Wassenberg (1989) found three species of birds (*Phalacrocorax varius, P. melanoleucos* and *Sterna bergii*) feeding on trawler discards in Moreton Bay. These birds ate about 14% of discarded fish, by weight. They were normally diurnal feeders that learned to scavenge at night. The results of that study suggest that the feeding habits and diets of these birds have been modified to take advantage of a substantial source of food. Crested terns (*Sterna bergii),* frigate birds (*Frigata ariel, F. minor*) and brown boobies (*Sula leucogaster*) were observed to feed on discards in the Gulf of Carpentaria (Blaber and Milton, 1994), Torres Strait (Hill and Wassenberg 1990) and the far northern Great Barrier Reef (Blaber and Milton, 1994). Populations of crested terns in the northern Great Barrier Reef were found to increase after the commencement of prawn trawling possibly as a response to the availability of discards (Blaber *et al.*, 1998). It is possible that an increase in crested tern populations may have adverse effects on other seabird populations through competition for nesting sites or for food at times when trawling is not taking place.

5.6 Bycatch reduction devices (BRDs)

Australian researchers have recently developed and tested devices that reduce bycatch in prawn trawls - Bycatch Reduction Devices (BRDs). A subset of BRD's that assist the escape of turtles and other large animals (TEDs) have also been introduced. Exclusion of bycatch fish and invertebrates from prawn trawls in order to minimise the impact on demersal fish communities is an objective of management agencies. This is in accord with the principles of economically sustainable development, the Precautionary Principle and the long term sustainability of the marine environment.

Exclusion of large animals is generally desirable in prawn trawl catches for two reasons. Firstly, some large animals such as turtles are vulnerable or endangered, and secondly, large animals can damage and therefore devalue prawns by crushing them in the codend. Other reasons to exclude large animals from catches are to avoid the difficulties, dangers and time delays associated with handling them on the deck, to decrease the damage they cause to fishing gear and to minimise impacts on the marine community (Brewer *et al.* 1995, Rawlinson and Brewer 1995). Some large animals such as sharks are valuable for their fins and therefore exclusion is not always welcomed by the crew of trawlers.

Scientists from the New South Wales Fisheries Research Institute have been studying bycatch reduction techniques in New South Wales offshore and inshore prawn trawl fisheries since 1989. These studies have included description of the interaction between prawn trawling and other commercial and recreational fisheries (Kennelly *et al.* 1992, 1993), and the development and testing of several BRDs. They include square-mesh panels (Broadhurst and Kennelly 1994 and 1996 and Broadhurst *et al* 1996b), Nordmøre grids and separator panels (Andrew *et al.* 1993, Broadhurst *et al.* 1997). These projects have reported significant reduction in unwanted bycatch without significant loss of prawns. They have tested these devices in close collaboration with the industry, which has resulted in some voluntary adoption of BRDs in these fisheries (Broadhurst *et al.* 1996).

Fishing Technologists and Scientists from the Northern Territory Department of Primary Industry and Fisheries (NTDPIF) and Queensland Department of Primary Industries have developed and tested a device, known as the AusTED (Australian trawl efficiency device), aboard commercial trawlers in sub-tropical Australian prawn fisheries. This device has a flexible grid to exclude large animals such as turtles, and escape openings and meshes to exclude smaller bycatch (Mounsey *et al.* 1995). Research trials showed no differences in prawn catches between the control and AusTED equipped nets, but sea turtles and large sting rays were excluded from the AusTED equipped net and non-commercial bycatch was significantly reduced at most sites trawled (Robins-Troeger *et al.* 1995).

Scientists from the CSIRO/AMC/NTDPIF after consultation with industry members, tested a total of 17 different BRDs, or combinations of BRDs, in the NPF (Blaber *et al.*, 1997). All nets fitted with inclined grids excluded most large sharks and turtles. No sea turtles were caught in any of the codends with BRDs containing excluder grids (125 trawls), whereas the two codends without these grids (51 trawls) caught 11 sea turtles (1 every 4.6 trawls). Fish were also excluded, but this varied with the device or combination of devices (Brewer *et al.*, 1998). Highest exclusion was achieved by the Nordmøre grid + square-mesh window (~35%), but the Nordmøre grid + fisheye and the AusTED, all excluded more than 26% of small fish bycatch. Square-mesh codends (45 mm mesh) were able to reduce the amount of unwanted bycatch by about one-third while maintaining catches of commercially valuable prawns. The amount of prawn that was lost varied with the device or combination of devices (Brewer *et al.*, 1998).

Australian researchers have applied and modified BRD technology from overseas work into local prawn trawl fisheries. The studies in the NPF and on the Queensland east coast have shown that several grid devices can virtually eliminate catches of turtles and other large animals. The performance of these devices is expected to improve as they are adopted on commercial boats, providing industry with a larger range of effective BRDs for use in the NPF and other Australian prawn trawl fisheries. A guide to bycatch reduction devices for Australian prawn trawl fisheries based on the above research efforts has been published by the Australian Maritime College (AMC) (Eayrs *et al.*, 1997) and a video (produced by QDPI) explaining the current state of knowledge of TEDs and BRDs is available to all prawn trawl fishers in northern Australia. Strategies for further commercialisation and implementation of bycatch reduction devices have recently been developed in the northern Prawn Trawl Fishery (FRDC 96/254).

While these devices will enable some bycatch reductions they are unlikely to eliminate unwanted bycatch entirely. The efficiency of these devices will improve with time, but the levels of exclusion that are achievable will be limited. Further work will be required to set achievable target levels required for management. Monitoring will be required to see that these target levels are maintained. Despite the use of these devices in reducing bycatch, the impacts of trawling on demersal fish may still be significant for vulnerable species.

5.7 Estimating and monitoring bycatch in prawn trawl fisheries

Estimation of amounts of discards in Australian prawn fisheries have generally been based on scientific surveys (Jones and Derbyshire, 1988; Pender *et al.*, 1992; Ramm *et al.*,1990;) or from observer programs (Kennelly, 1992). The catch rates of bycatch or the ratio of bycatch to catch are extrapolated to total effort or total catches of the fleet by area to obtain estimates of total discards (Kennelly, 1992) or bycatch per unit of fishing effort (CPUE) (Andrew and Pepperell, 1992).

Because of the enormous amount of resources required to measure bycatch from every boat in each region of a fishery, several assumptions have been used to estimate amounts of bycatch caught (Andrew and Pepperell, 1992). One common assumption is that ratios of bycatch to prawns range from 5:1 in temperate regions to 10:1 in tropical regions (Juhl and Drummond, 1977; Allsopp, 1982; Caddy, 1982; Harris and Poiner, 1990). The literature indicates a large range in the ratios for Australia. For example, in the western NPF the ratios ranged from 8:1 to 21:1 (Pender *et al.*, 1992), but were as low as 3.3:1 for trawls in the Torres Strait fishery (Harris and Poiner 1990). While this data is used to estimate the total amount of bycatch it gives no information on bycatch composition.

The composition of bycatch may vary within a fishery. Ramm *et al.*, (1990) found that the composition of commercial bycatch samples varied along geographic and bathymetric gradients in the western NPF. In a study of bycatch from a riverine prawn fishery, Gray *et al.*, (1990) found a reduction in the number of species with distance upstream. Kennelly *et al.*, (1998) found latitudinal changes in amounts of bycatch discarded along the NSW coast and significant species specific variations in abundance at all spatial and temporal scales sampled. The range of ratios in the literature, further complicated by the potential changes in composition within and between fisheries, makes such use of ratios a rather tentative and unreliable method for estimating the amounts of bycatch caught in a fishery.

Estimates of bycatch in prawn fisheries have also been made by observers on vessels in the fleet (Harris and Poiner, 1990; Kennelly *et al.*, 1992, 1998; Ramm *et al.*, 1990). The observers collected information of the CPUE and composition of the bycatch from a number of boats and regions within the fishery. These data have been extrapolated to estimate the total bycatch for the fleet and region. Observers are not always able to weigh the bycatch and the estimates they make are probably subject to error. Large animals are difficult to weigh and estimates of their weight will contribute to errors in total weight. Bias may be introduced by a number of methods (Andrew and Pepperell, 1992), (1) subsampling may produce errors, (2) recapture of dead discards will lead to overestimates of bycatch and (3) the loss of discards from the net before the codend is brought onto the boat underestimates bycatch. Other sources of potential error include the logbooks used by the fishers. If there are errors in the amount of effort recorded then there could be errors in the estimated amounts of bycatch caught.

Both the ratio and CPUE methods for estimating quantities of bycatch have large degrees of uncertainty that confound direct comparisons of the methods (see Andrew and Pepperell, 1992). Whenever the bycatch contains juveniles of other important fisheries, the CPUE method is probably more appropriate (see Andrew and Pepperell, 1992; Allsopp, 1982). There is need for a statistically robust comparison of these and other methods to improve estimates of quantities of bycatch in Australian fisheries.

Other than a program monitoring turtles (FRDC 98/202) currently under way in the NPF to repeat the earlier study by Poiner *et al.,* (1990), there is no comprehensive long-term monitoring of bycatch in Australian prawn trawl fisheries. The logbook program monitoring effort in the NPF and TSPTF has a provision for reporting other species in the catch, (shark, squid, bugs etc). These categories are classified as retained byproduct and may vary from day to day and boat to boat. There is currently no validation of this data. The lack of a comprehensive bycatch monitoring program is a major impediment to our understanding of the impact on bycatch species and communities.

Monitoring all bycatch species in all fisheries is potentially expensive and time consuming (Alverson *et al.,* 1994). However, despite the cost, pressures are mounting for better information. Design of cost effective monitoring will be essential and will need to take into account the numerous variables (eg lunar, tidal and biological cycles) that affect bycatch composition and quantity.

References

Allsopp, W.H.L., 1982. Use of fish by-catch from shrimp trawling: future development. In *Fish By-catch – Bonus from the Sea: Report of a Technical Consultation on Shrimp By-catch Utilization held in Georgetown, Guyuana,* 27-30 *October 1981,* IDRC, Ottawa (IDRC-198e), pp 29-41.

Alverson, D.L., Freeberg, M.H., Murawski, S.A., Pope, J.G., 1994. A global assessment of fisheries bycatch and discards. FAO Fisheries Technical Paper 339.

Andrew, N L, Kennelly, S J., Broadhurst, M K, 1993. An application of the Morrison Soft TED to the offshore prawn fishery in NSW, Australia. Fish. Res. 16: 101-11.

Andrew, N L, Pepperell, J.G., 1992. The bycatch of shrimp trawl fisheries. Oceanography Marine Biology Annual Reviews, 30 527-565.

Bejie, B., 1980. Observations on the trash fish from catches of a prawn trawler in coastal waters of Sarawak. In Report of the workshop on the biology and resources of Penaeid shrimps in the South China Sea area – Part 1. Held at Kota Kinabalu, Sabah Malaysia, 30 June – 5 July 1980. SCS/GEN/80/26. pp 70-77.

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

Blaber, S.J.M., Milton, D.A., 1994. Distribution of seabirds at sea in the Gulf of Carpentaria, Australia. Aust. J. Mar. Freshwater Res., 45, 445-454.

Blaber, S., Brewer, D., Buckworth, R, Burridge, C., Farmer, M., Milton, D., Salini, J., Wang, Y., Wassenberg, T., Buxton, C., Cartwright, I., Eayrs, S., Rawlinson, N., Gill, N., Mounsey, R., Ramm, D., MacCartie., 1997. Effects of trawl design on bycatch and benthos in prawn and finfish fisheries. Final report to the Fisheries Research & Development Corporation. 93/179., pp 1-199.

Blaber, S.J.M., Milton, D.A., Smith, G.C., Farmer, M.J., 1998. The importance of trawl discards in the diets of tropical seabirds of the northern Great Barrier Reef, Australia. Mar. Ecol. Prog. Ser., 127, 1-13.

Brewer, D T, Eayrs, S, Rawlinson, N. J. F., 1995. Bycatch reduction devices show promise in the NPF. Aust. Fish., 54, 24-6

Brewer, D., Rawlinson, N., Eayrs, S., Burridge, C., 1998. An assessment of bycatch reduction devices in a tropical Australian prawn trawl fishery. Fish., 720, 1-21.

Broadhurst, M. K., Kennelly, S. J., 1994. Reducing the by-catch of juvenile fish (mulloway) in the Hawkesbury River prawn-trawl fishery using square-mesh panels in codends. Fish.Res., 19, 321-31

Broadhurst, M. K., Kennelly, S.J. 1996. Effects of square-mesh panel in codends and of haulback delay on bycatch reduction in the oceanic prawn-trawl fishery of New South Wales, Australia. Fish. Bull., 94, 312-422.

Broadhurst, M K, Kennelly, S J, O'Doherty, G., 1996b. Effects of square-mesh panels in codends and of haulback delay on bycatch reduction in the oceanic prawn-trawl fishery of New South Wales, Australia. Fish, Bull., 94, 412-22.

Broadhurst, M K, Kennelly, S. J., Watson, J.W., Workman, I.K., 1997. Evaluations of the Nordmore grid and secondary bycatch-reducing devices (BRD's) in the Hunter River prawn–trawl fishery, Australia. Fish. Bull., 95, 209-219

Buckworth, R., 1987. Changes in fishing effort and catching power in the DMZ tiger prawn fishery. Northern Prawn Fishery Information Notes, CSIRO No, 10, 2-3.

Caddy, J.F., 1982. Management of shrimp fisheries. In Fish By-catch – Bonus from the Sea: Report of a Technical Consultation on Shrimp By-catch Utilization held in Georgetown, Guyuana, 27-30 October 1981, IDRC, Ottawa (IDRC-198e), 120-124.

Cannon, L.R.G., Goeden, G.B., Campbell, P., 1987. Community patterns revealed by trawling in the inter-reef regions of the Great Barrier Reef. Mem. Queensl. Mus., 25, 45-70.

Dredge, M.L.C., 1989a. Bycatch from the central Queensland prawn fisheries: Part 1. The prawn fisheries, species composition and site associations from the bycatch. Fisheries Research Branch, Queensland Department of Primary Industries, Technical Report FRB 88/04.

Dredge, M.L.C., 1989b. Bycatch from the central Queensland prawn fisheries: Part 2. Spatial and temporal changes in by-catch composition and community assemblages. Fisheries Research Branch, Queensland Department of Primary Industries, Technical Report FRB 88/04.

Eayrs, S., Buxton, C., McDonald, B., 1997. A guide to bycatch reduction in Australian Prawn Trawl Fisheries. pp1-54. Australian Maritime College, Launceston, Australia.

Farmer, M.J., Brewer, D.T., Blaber, S.J.M., 1998. Damage to selected fish species escaping from prawn trawl codends: a comparison between square-mesh and diamond-mesh. Fish. Res., 38, 73-81.

Furness, R.W., Ensor, K., Hudson, A.V., 1988. Interactions between scavenging seabirds and commercial fisheries around the British Ilses. In Burger, J. (Ed) Seabirds and other marine vertebrates. Competition, predation and other interactions. Columbia Univ Press, New York, pp 240-268.

Graham, K.J., Liggins, G.W., Wildforter, J., Kennelly, S.J., 1993. Kapala Cruise Report No. 110. Fisheries Research Institute, NSW Fisheries, 69 pp.

Gray, C.A., McDonall, V.C., Reid, D.D., 1990. By-catch from prawn trawling in the Hawksbury River, New South Wales: species composition, distribution and abundance. Aust. J.Mar. Freshwater Res., 41, 13-26.

Harris, A.N., Poiner, I.R., 1990. Bycatch of the prawn fishery of Torres Strait; composition and partitioning of the discards into components that float or sink. Aust. J. Mar. Freshwater Res., 41, 37-52.

Harris, A.N., Poiner, I.R., 1991. Changes in species composition of demersal fish fauna of southeast Gulf of Carpentaria, Australia, after *20* years of fishing. Mar. Biol., 111, 503- 519.

Hill, B.J., Wassenberg, T.J., 1990. Fate of discards from prawn trawlers in Torres Strait. Aust. J. Mar. Freshwater Res., 41, 53.64.

Hill, B.J., Wassenberg, T.J., 1992. The fate of material discarded from shrimp trawlers. International Conference on shrimp bycatch. Held at Lake Buena Vista, Florida May 24-27, 1992. 115-123.

Jennings, S., Kaiser, M., 1998. The effects of fishing on marine ecosystems. Adv. Mar. Biol., 34, (in press)

Jones, C.M., Derbyshire, K., 1988. Sampling the demersal fauna from a commercial penaeid prawn fishery off the central Queensland coast. Mem. Queensl. Mus., 25(2),403-415.

Juhl, R. Drummond, S.B., 1977. Shrimp bycatch investigation in the United States of America. A status report. In :Symposium on progress in Marine Research in the Caribbean and adjacent regions, 12-16 July 1976, Caracus. FAO Fish Rep., No. 200 FIR/k2000, pp 213-220.

Kennelly, S.J., 1992. The effect of shrimp trawling bycatch on other commercial and recreational fisheries – an Australian perspective. International Conference on shrimp bycatch. Held at Lake Buena Vista, Florida May 24-27, 1992. 97-113.

Kennelly, S.J., 1993. Study of the by-catch of the NSW east coast trawl fishery. Final Report to the Fisheries research & Development Corporation. 88/108,

Kennelly, S.J., Liggins, G.W., Broadhurst, M.K., 1998. Retained and discarded by-catch from oceanic prawn trawling in New South Wales, Australia. Fish. Res., 36, 217-236.

Kulbicki, M., Wantiez, L., 1990. Variations in the fish catch composition in the Bay of St Vincent, New Caledonia, as determined by experimental trawling. Aust. J. Mar. Freshwater Res., 41, 121-144.

Laurenson, L.J.B.; Unsworth, P. Penn, J.W., Lenanton, R.C.J., 1993. The impact of trawling for saucer scallops and western king prawns on the benthic communities in coastal waters off south-western Australia. Fisheries Research Report Fisheries Department Western Australia 100, 1-93.

Marsh, H., Corkeron, P.J., Limpus, C.J., Shaughnessy, P.D., Ward. T.M., 1993. Conserving marine mammals and reptiles in Australia and Oceania. In C. Moritz and J. Kikkawa (Eds.) Conservation Biology in Australia and Oceania. Surrey Beatty and Sons: Chipping Norton. pp. 225-44.

Mounsey, R.P., Baulch, G.A., Buckworth, R.C., 1995. Development of a trawl efficiency device (TED) for Australian prawn fisheries. The Austed design. Fish. Res., 22, 99-105.

McShane, P.E., Hall, S.J., Carrick, N.A. (1999). Trophic consequences of prawn trawling: linking bycatch to benthos. Pp 106-12. In C. Buxton and S.Eayrs (Eds). Establishing meaningful targets for bycatch reduction in Australian fisheries. Australian Society for Fish Biology Workshop Proceedings, Hobart, September 1998. Australian Society for Fish Biology, Sydney.

Poiner, I.R. Harris, A.N.M., 1985. The effect of commercial prawn trawling on the demersal fish community of the south eastern Gulf of Carpentaria. In A.K. Haines, G.C. Williams, D. Coates (Eds). Torres Strait Fisheries Seminar, Port Moresby, 11-14 February 1985. AGPS Canberra. pp 239-261

Poiner, I.R. Harris, A.N.M., 1994. Incidental capture and mortality of sea turtles in Australia's Northern Prawn Fishery. In R. James (Ed.). Proceedings of Australian Marine Turtle Conservation Workshop. (Held at Seaworld Nara Resort, 14-17 November 1990) Australian Nature Conservation Agency, Canberra, ACT. pp 127-135

Poiner, I.R., Buckworth, R.C. Harris, A.N.M, 1990. Incidental capture, and mortality of sea turtles in Australia's Northern Prawn Fishery. Aust. J. Mar. Freshwater Res., 41, 97-110.

Poiner, I.R. Harris, A.N.M,. 1996. Incidental capture, direct mortality and delayed mortality of sea turtles in Australia's Northern Prawn Fishery. Mar. Biol., 125, 813-825.

Pender, P.J. Willing, R.S., 1990. Northern prawn fishery bycatch with market potential. *pp, 1-52.* Northern Territory, Department of Primary Industry and Fisheries, Fishery Report *20.*

Pender, P.J., Willing, R.S., Ramm, D.C., 1992. Northern prawn fishery bycatch study: Distribution, abundance, size and use of bycatch from the mixed species fishery. Northern Territory, Department of Primary Industry and Fisheries, Fishery Report *26.* pp 1-70.

Rainer, S.F., 1984. Temporal changes in a demersal fish and cephalopod community of an unexploited coastal area in northern Australia. Aust. J. Mar. Freshwater Res., 35, 747-68.

Rainer, S.F., Munro, I.S., 1982. Demersal fish and cephalopod communities of an unexploited coastal environment in northern Australia. Aust. J. Mar. Freshwater Res., 33, 1039-55.

Ramm, D.C., Pender, P.J., Willing, R.S., Buckworth, R.C., 1990. Large-scale spatial patterns of abundance within the assemblages of fish caught by prawn trawlers in northern Australian waters. Aust. J. Mar. Freshwater Res., 41, 79-95.

Rawlinson, N., Brewer, D.T., 1995. 'Monsters', 'blubber' and other bycatch. Aust. Fish., 27-28.

Robins, J.B., 1995. Estimated catch and mortality of sea turtles from the east coast otter trawl fishery of Queensland, Australia. Biol. Conserv., 74, 157-167.

Robins, C.M., Wang, Y., Die, D., 1998. The impact of global positioning systems and plotters on fishing power in the northern prawn fishery, Australia. Can. J. Fish. Aquat. Sci., 55, 1645-1651.

Robins-Troeger, J.B., Buckworth, R.C. Dredge, M.C.L., 1995. Development of a trawl efficiency device (TED) for Australian prawn fisheries. II. Field evaluations of the AusTED. Fish. Res., 22, 107-17

Sharp, A., Bishop, J. Harris, D., 1998. Northern Prawn Fishery and Kimberley Prawn Fishery Data Summary. Australian Fisheries Management Authority, Canberra. 1-41.

Ward, T.M., 1996a. Sea snake bycatch of prawn trawlers on the northern Australian continental shelf. Mar. Freshwater Res., 47, 631-635.

Wardle, C.S., 1981. Physiological stress in captive fish. pp 403-414 in 'Aquarium Systems' (ed A.D. Hawkins) Academic Press, London U.K.

Wassenberg, T.J., Hill, B.J., 1987. Feeding by the sand crab *Portunus pelagicus* on material discarded from prawn trawlers in Moreton Bay. Mar. Biol., 95, 387-393.

Wassenberg, T.J., Hill, B.J., 1989. The effect of trawling and subsequent handling on the survival rates of the bycatch of prawn trawlers in Moreton bay, Australia. Fish. Res., 7, 99-110.

Wassenberg, T.J., and Hill, B.J., 1990. Partitioning of material discarded from prawn trawlers in Moreton Bay. Aust. J. Mar. Freshwater Res., 41, 27-36.

Wassenberg, T.J., Hill, B.J., 1993. Selection of the appropriate duration of experiments to measure the survival of animals discarded from trawlers. Fish. Res., 17, 343-352.

Wassenberg, T.J., Salini, J.P. Heatwole, H. and Kerr, J.D., 1994. Incidental capture of sea-snakes (Hydrophiidae) by prawn trawlers in the Gulf of Carpentaria, Australia. Aust. J. Mar. Freshwater Res.,. 45, 429-43.

Wassenberg, T.J., S.J.M. Blaber, Burridge, C.Y., D.T. Brewer, J.P.Salini and Gribble, N.A., 1997 The effectiveness of fish and shrimp trawls for sampling fish communities in tropical Australia. Fish. Res., 30, 241-251.

Wassenberg, T.J., Burridge, C.Y., Connell, M., Gribble, N., 1998. A validation of short duration scientific tows as a representation of long commercial length tows: comparing the catch rates, size composition and species composition of prawn trawler bycatch in the far northern Great Barrier Reef, Australia. Fish. Res.,36, 35-46.

Watson, R.A., 1984. Trawl fish composition and harvest estimates for the Gulf of Papua. pp25, Report No 84-01. Fisheries Research & Surveys Branch, Dept Primary Industry, Port Moresby, Papua New Guinea, Watson, R.A., Goeden, G., 1989. Temporal and spatial zonation of the demersal trawl fauna of the central Great Barrier Reef. Mem. Queensl. Mus., 27(2), 61-620.

Watson, R.A., Dredge, M.L.C., Mayer, D.G., 1990. Spatial and seasonal variation in demersal trawl fauna associated with a prawn fishery on the central Great Barrier Reef, Australia. Aust. J. Mar. Freshwater Res.,41, 65-77.

6. BYCATCH DESCRIPTION

To compile a detailed description of the bycatch in the NPF and Torres Straits tiger and banana prawn fisheries and Queensland East Coast banana prawn fisheries to provide a reference against which future assessment can be made.

6.1 Description of bycatch in the Queensland Banana Prawn Fishery

6.1.1 Introduction

Tropical prawn trawl fisheries generate a higher proportion of bycatch-to-catch than any other form of fishing (Alverson et. al.,1994). With approximately 800 otter-board trawl endorsements, and a further 210 beam-trawl endorsements, the Queensland trawl fishery has the largest number of trawlers of any Australian prawn fishery. As such, production of bycatch by the fishery seems likely to be comparatively high.

Several sectors can be distinguished within the fishery, including those for banana prawns, tiger and endeavour prawns, king prawns and scallops (Robins and Courtney, 1999). Although the banana prawn fishery produces about 10% of Queensland's total prawn catch and trawl fishing effort, bycatch from this particular sector attracts a disproportionately high level of public concern. This is because most trawling for banana prawns takes place during daylight in very shallow waters that are often close to the coast and highly visible to coastal residents. Bycatch regularly washes onto beaches causing concern among locals, conservationists, tourism operators, recreational fishers, and others. While much greater levels of fishing effort are directed at tiger and endeavour prawns, scallops, and king prawns, the public generally do not encounter bycatch from these sectors because they occur at night and further offshore, reducing the incidence of beach wash-ups.

Banana prawns are a common species in rivers, estuaries and shallow coastal waters throughout Queensland. They display a typical type 2 penaeid prawn life cycle (Dall et al., 1990). Postlarvae settle in mangrove-lined muddy estuaries and may ascend several kilometres upstream. At about half the adult length, individuals leave the estuary to grow, mature and spawn offshore. On the Queensland coast some adults appear to remain in rivers over winter and may contribute to two generations each year (Dredge, 1985). Trawling generally takes place in waters less than 20 m deep, adjacent to coastal mangrove stands. The compulsory logbook database system (CFISH) indicates that from 1988-98 about 630 tonnes of banana prawns were landed by beam and otter-board trawlers in Queensland annually, with the majority caught by otter-board trawlers. Catch and effort are highly seasonal, with the majority of the catch taken from January to June (Figure 6.1.1).

Catches are strongly influenced by, and generally increase with rainfall, similar to the banana prawn fishery in the south eastern Gulf of Carpentaria (Staples, 1985). The fishery can be stratified into two broad regions, based on the spatial distribution of the catch (Table 6.1.1); a northern region north of 22°S mainly between Cairns and Mackay and a southern region south of 22°S mainly between Rockhampton and Bundaberg. A recreational cast net fishery for banana prawns has developed in recent years, mainly in estuaries flowing into Moreton Bay, in the state's southeast. While landings from the recreational sector have not been quantified, bycatch from this sector is negligible compared with the trawl sector.

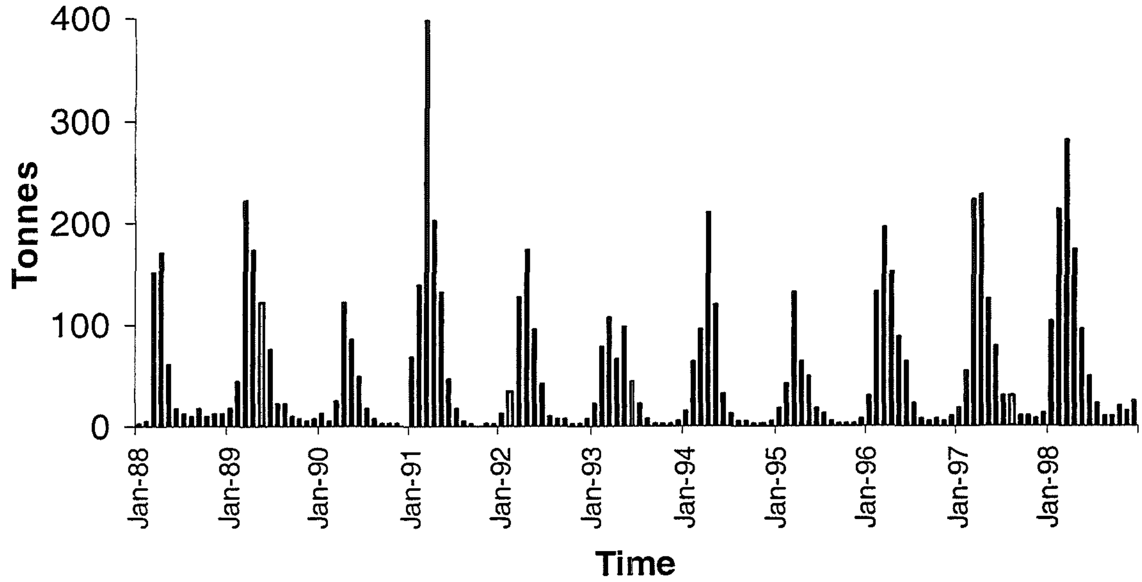

Figure 6.1.1 Annual landings of banana prawns in Queensland. Catches from beam trawl and otter-board trawls are combined. Data were extracted from CFISH compulsory logbook database for species code 701901 (banana prawns) only.

There is community concern over the impact of trawling banana prawns on:

a) populations of fin fish species that are of value to other recreational and commercial fisheries,
b) populations of a large number of other fish and invertebrate species that are caught incidentally in the fishery and which have no direct value to fisheries,
c) populations of sea turtles, and other species of high conservation status,
d) seabed habitats, the structure of benthic communities and marine ecosystems, and
e) visible and physical pollution of beaches.

Current knowledge of the fishery's bycatch composition and quantity is scant. There is a need to determine its composition and the impact on the populations of non-target species. There is also a need to quantify the amount of bycatch presently produced by the fishery so that progress of bycatch reduction initiatives can be gauged. Finally, there is a need to examine the impact of Bycatch Reduction Devices (BRDs) in the fishery and promote their adoption.

Table 6.1.1 Annual landings of banana prawns from Queensland's trawl fishery. The fishery can be stratified spatially into two broad regions, a northern and a southern region. Data were obtained from the compulsory CFISH logbook database. The logbook retrieval was undertaken for banana prawns only (species code 701901). Logbook records that did not provide a latitudinal reference are omitted.

Year	Northern region (Latitudes < 22°S) Tonnes	Southern Region (Latitudes > 22°S) tonnes	Total tonnes
1988	339.1	128.8	468.0
1989	368.4	342.7	711.1
1990	236.5	91.2	327.7
1991	788.5	226.5	1014.9
1992	103.2	408.2	511.4
1993	232.8	214.3	447.0
1994	306.7	255.5	562.2
1995	156.3	188.3	344.6
1996	328.6	378.4	707.0
1997	564.8	206.0	770.8
1998	316.0	237.8	553.8

This was a collaborative study between CSIRO, QDPI and the AMC. QDPI addressed one part of objective 3 in the proposal :

> "To compile a detailed description of the bycatch in the NPF and Torres Strait tiger and banana prawn fisheries and the Queensland East Coast banana prawn (*Penaeus merguiensis*) fisheries to provide a reference against which future assessment can be made."

To this end, QDPI has provided a detailed description of bycatch in the Queensland banana prawn fishery, and an estimate of the tonnage of bycatch with associated confidence intervals. Additional information is provided on the impact of fish species that contribute to other fisheries in Queensland, and on the effect of BRDs.

6.1.2 Methods

Sampling

Catch details and samples of bycatch were obtained by a scientific observer on board commercial otter-board trawlers operating in the fishery. QDPI Fisheries contacted skippers/owners of vessels operating throughout the fishery to discuss the project's background and objectives. If they were agreeable, the observer would then arrange to board the vessel for the duration of a cruise, which generally ranged from 3-10 days. The objectives of the fieldwork were to obtain samples of bycatch and weight measures of the total catch (prawns plus bycatch), targeted prawn catch, and bycatch, from representative trawls throughout the fishery.

All commercial fishing and research sampling were undertaken during hours of daylight as banana prawns are active and more catchable during daytime. Fishers targeting banana prawns on the Queensland coast generally deploy quad gear (four nets, each with a headrope length of 4-5 fathoms) although some use twin, triple gear or trouser net configurations. Yankee doodle or Florida flyer type nets are commonly used. The data-gathering procedure was to obtain measurements and one bycatch sub-sample from one net from each trawl. Where industrial scales could be secured to the trawl gantry without adversely affecting fishing operations, the total weight of the net was measured (to the nearest 0.1 kg) immediately upon being brought to the surface. (The weight of the empty net was subtracted from the total weight.) Otherwise, the weight of the catch was obtained after emptying the net onto the sorting tray and summing the weights of individual basket-loads measured with smaller scales. Large animals (turtles, rays and sharks) were removed from the catch and returned to the water after having their species, length and weight recorded. Individual turtle weights were not measured because no practical method of weighing such large individuals on board was available. The banana prawn catch was then weighed, recorded to the nearest 0.1 kg and retained by the fishers, leaving the remaining bycatch which was then sub-sampled. The duration, location, prevailing weather conditions and vessel details associated with each trawl were recorded. An average estimate of the depth of each trawl was obtained by measuring depth at the beginning and end of each trawl.

Sub-sampling was carried out for every trawl by randomly selecting a volume of the bycatch from the sorting tray that could be stored and frozen on board in a standard-sized (60 x 30 x 20 cm) seafood storage box. The weight of a filled box varied, but was in the order of 10 kg. At the completion of each cruise, samples were transported to the QDPI Southern Fisheries Centre by refrigerated truck or rail, where the contents were sorted to species level, counted, weighed and recorded in a database. Length measurements (total length or fork length) were recorded for 20 individuals of each fish species in each sample to obtain information on the size.

Statistical methods

Generalized linear modelling was used (Genstat statistical software) to examine variation in the number of bycatch species caught in the trawls and factors affecting the bycatch : prawn weight ratios.

Cluster analysis

Cluster analysis was undertaken because it is commonly used to examine variation in the structure of aquatic faunal communities (Clarke and Green, 1988; Watson and Goeden, 1989; Gray et al., 1990; Watson et al., 1990; Clarke, 1993; Clarke and Ainsworth, 1993) and is particularly suited for databases that contain a large number of species – characteristic of benthic trawl bycatch. A hierarchical agglomerative clustering analysis was carried out using PRIMER (Plymouth Routines in Multivariate Ecological Research) software developed by Clarke and Warwick (1994). The program calculates a Bray-Curtis similarity index (Bray-Curtis, 1957) for each pair of samples and uses the unweighted pair-group arithmetic averages to produce cluster groups. Similarity indices were based on catch rates of individual species in the trawls using the formula:

$$\hat{N}_{st}\ hour^{-1} = N_{st} \times \left({TBW_t}/{WSS_t} \right) /\ duration\ of\ trawl_t\ (hours)$$

where $\hat{N}_{st}$ is the estimate the number of individuals of species s caught per hour in trawl t, N_{st} is the number of individuals of species s in the sub-sample of trawl t, TBW_t is the total bycatch weight of trawl t, WSS_t is the weight of the sub-sample of bycatch taken from the trawl t. Although large individuals were not included in the sub-sampling procedure, the incidence of their capture was recorded and converted to an hourly catch rate. In this way, a common unit of catch rate (i.e., number trawled hour^{-1}) was used for both the sub-sampled species and those large individuals not included in the sub-samples.

Input of the data was by way of a two-dimensional matrix of the catch rate of each species by sample. Catch rates were log-transformed [$\log_e$ (number caught hour^{-1} + 1)] prior to the cluster analysis. Because most species do not occur in every sample, the matrix is characterised by a large number of zero catch rates. To reduce the number of zero observations used in the analysis, the frequency of occurrence of each species was calculated and those present in fewer than 5% of samples omitted. Preliminary cluster results were difficult to interpret because of the large number of samples. To overcome this, samples were grouped by day, and similarity indices re-calculated based on average daily catch rates. It was assumed that pooling and averaging in this way was likely to have little effect on the overall results, as samples obtained on the same day were in relatively close geographic proximity to one another and could, therefore, be considered as replicates.

Estimating total bycatch

Because there is no practical means of directly measuring the total weight of bycatch in the fishery, estimates were derived. For any particular year, the total weight of bycatch can be estimated by multiplying the bycatch : prawn catch weight ratio by the total weight of prawns caught for that year. This type of approach results in a single deterministic estimate that is without confidence intervals. In the present study, we sought to obtain more robust estimates of total annual bycatch weight using stochastic methods that consider the variability in both the ratios and annual landings. We also considered the spatial variation in bycatch estimates by stratifying the fishery, based on catches from the two general regions - a northern sector and a southern sector – and estimated bycatch from each sector separately. Average annual total weight of bycatch produced by the fishery was obtained using the following procedure:

1. A frequency distribution of mean bycatch weight : prawn weight ratios was estimated by applying bootstrapping methods to the raw ratios obtained with standard trawl gear. This distribution was based on 1,000 bootstrap estimates of the mean.
2. A distribution of mean annual landings was obtained for each sector (north and south) by applying the same bootstrapping technique to the 11 years (1988-98) of annual landings for each sector. Obviously, no clear frequency distribution can be detected from only the raw 11 annual records, however, the distribution of mean landings derived from bootstrapping conformed to a normal distribution.
3. A frequency distribution of average total annual bycatch weight estimates was derived by repeatedly multiplying randomly selected mean ratios (derived in step 1) by mean annual landings (derived in step 2). Monte Carlo methods were used to randomly select values from each distribution and multiply them together. 10,000 estimates were made, providing a distribution of total estimated annual bycatch, with a mean and standard deviation for each sector.
4. The procedure was then repeated, changing step 1 and replacing the standard gear ratio measures with ratios obtained from nets with BRDs. In this way, estimates of total bycatch obtained with standard gear could be compared with those obtained with BRDs.

For certain bycatch species that contribute to other fisheries, the number of individuals caught in the bycatch in an average year was estimated using a similar approach. That is, ratios of the number of individuals : weight of prawns were obtained from field observations. A distribution of mean ratios was then derived using bootstrapping and finally, Monte Carlo methods were used to repeatedly estimate the total number of individuals for the particular species in the bycatch for an average year, based on the product of the mean ratio and mean annual landings.

6.1.3 Results

Ten sampling cruises were undertaken on five commercial trawlers throughout the fishery from 25/11/96 to 24/3/98 (Table 6.1.2). Weight measures and bycatch samples were obtained from a total of 287 trawls (Figure 6.1.2) over 63 days at sea (average 4.5 trawls sampled per day).

Of these, 184 were from standard nets, while 58 samples were from vessels with BRDs and 45 from a single vessel with a grid fitted to reduce turtle catches (Table 6.1.2). Samples from standard trawl nets were obtained from vessels operating in the Cairns, Townsville, Mackay and Gladstone regions, while those from the Bundaberg region were obtained from a single vessel with a bycatch reduction grid fitted. In the Townsville region, samples were obtained from standard trawl nets as well as those fitted with a BRD, facilitating a comparison of bycatch weight : prawn weight ratios from the two gear types within a single area.

Table 6.1.2 Cruise and bycatch sample collection details.

Cruise number	Region/Port	Date	Number of samples from trawls with standard net	Number of samples from trawls with BRD	Number of samples from trawls with grid	Total number of samples
1	Bundaberg	25-28/11/96			17	17
2	Townsville	22-28/2/97		28		28
3	Townsville	1-8/3/97	28			28
4	Gladstone	16-18/3/97	16			16
5	Bundaberg	22-26/3/97			28	28
6	Mackay	16-20/4/97	22			22
7	Mackay	21-30/4/97	33			33
8	Cairns	13-19/7/97	27			27
9	Cairns	23-29/7/97	28			28
10	Townsville	10-24/3/98	30	30		60
		Total	184	58	45	287

Detailed description of bycatch

Only samples from the 184 standard fishing net trawls were used to describe the bycatch. When sampling was undertaken, the majority of vessels in the fishery did not deploy BRDs, and therefore samples from nets with BRDs or grids were considered to be unrepresentative of the fishery's bycatch, and therefore excluded from the description.

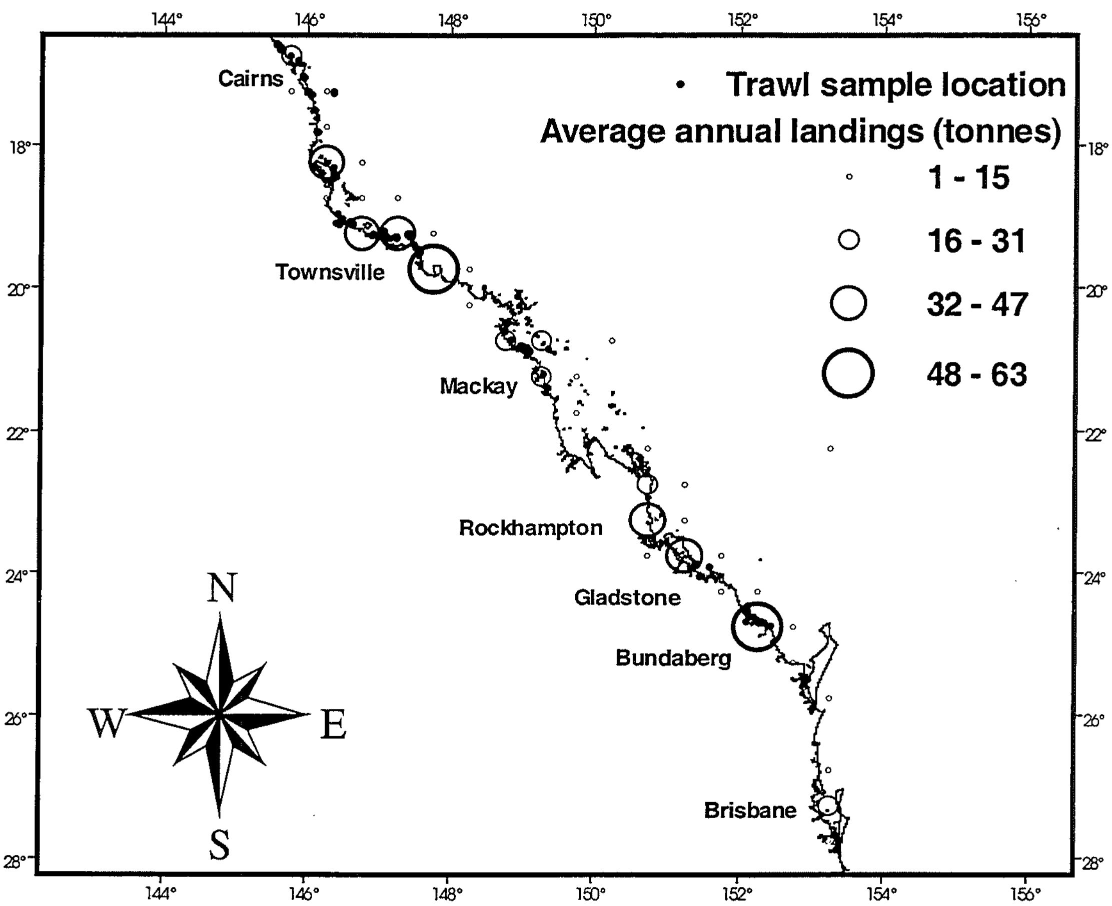

Figure 6.1.2 Spatial distribution of average annual landings of banana prawns on the Queensland east coast and the location of the 287 trawls where bycatch was sampled. Compulsory CFISH logbook data used were yearly totals in each 30'x30' logbook grid for the period 1988-98. Average annual landings of less than 1 tonne have been omitted for clarity.

A total of 316 taxa were collected representing eight phyla [Chordata, Arthropoda (comprised entirely of Sub-Phylum Crustacea), Echinodermata, Mollusca, Cnidaria, Porifera, Annelida, Bryozoa] (Appendix 3A). Additional species were caught in samples obtained from the non-standard nets with BRDs and grids. While the majority of fish, crustacean, echinoderm and molluscan species were identified, it was not possible, within the scope of the study, to identify all members of the Porifera, Cnidaria, Annelida and Bryozoa to species level. Ninety-three percent of species were relatively uncommon, each contributing less than 1% to the total number of individuals sampled. Forty-four percent were represented by fewer than 10 individuals, while 20% were represented by a single individual. The bycatch was characterised by small demersal and pelagic fish, portunid crabs and penaeid prawns. Nine families comprised 80% of all individuals collected; Leiognathidae, Penaeidae (other than *P. merguiensis*), Sciaenidae, Portunidae, Haemulidae, Carangidae, Teraponidae, Clupeidae and Engraulididae (in decreasing order of abundance). Leiognathids accounted for 24% of all individuals and were twice as abundant as the second most common family (Penaeidae). Twenty-five species, or species groups represented 80% of all individuals (Figure 6.1.3). The most common was the black-tipped ponyfish *Leiognathus* *splendens*, accounting for 9.1% of all individuals, followed by the little jewfish *Johnius borneensis* (7.6%), a small portunid crab *Charybdis callianassa* (7.2%), the orange ponyfish *Leiognathus bindus* (7.0%) and the blotched javelin-fish *Pomadasys maculatus* (5.0%) (Appendix 3A). Penaeid prawns (*Metapenaeus sp.*, *Trachypenaeus sp.* and *Metapenaeopsis sp.*) collectively accounted for about 12% of all individuals.

While only two green turtles, *Chelonia mydas* were included in the bycatch, sea snakes were more common. *Lapemis hardwickii* was the most common sea snake (141 individuals), followed by *Hydrophis elegans* (43), then by *Disteira major* (6) and *Disteira kingii* (4). Sea snake catch rates averaged 1.05 individuals per net per trawl.

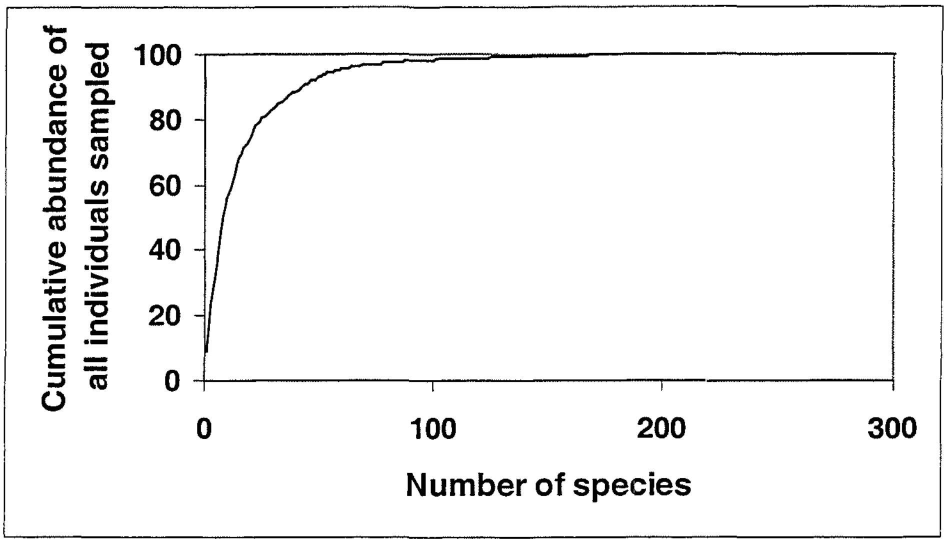

Figure 6.1.3 Relationship between the cumulative abundance of all individuals sampled and the number of species in 184 samples of bycatch obtained in the Queensland banana prawn trawl fishery.

Cluster analysis

Figure 6.1.4 shows the affinity between average daily catch rates of 157 bycatch species for different regions and sampling times. At an arbitrary similarity level of 56%, four groups can be delineated: a Gladstone (G) group, a Cairns (C) group consisting of a single observation, a Mackay (M) group and a large Cairns/Townsville (C and T) group. The Gladstone group split from the main stem of the dendrogram at the lowest level of similarity, indicating that bycatch from this area was the most dissimilar from the remaining observations. All observations from the Mackay region clustered into a single group. Observations from Townsville and Cairns contributed to a single large group, probably because of the way samples were obtained from the two regions. For example, some sampling trips from Townsville commenced in coastal waters close to port but if prawn catch rates were low, skippers made the decision to head northwards to Cairns, thus creating a spatial overlap between the two regions. Converse scenarios occurred during Cairns based trips.

The results suggest that the bycatch can be grouped on the basis of latitudinal regions. For example, the three observations that comprise the Gladstone group were from the southern-most latitude (23°54'S) while the Mackay group observations ranged between 20°30'S and 21°24'S. Depth is also likely to explain variation in the

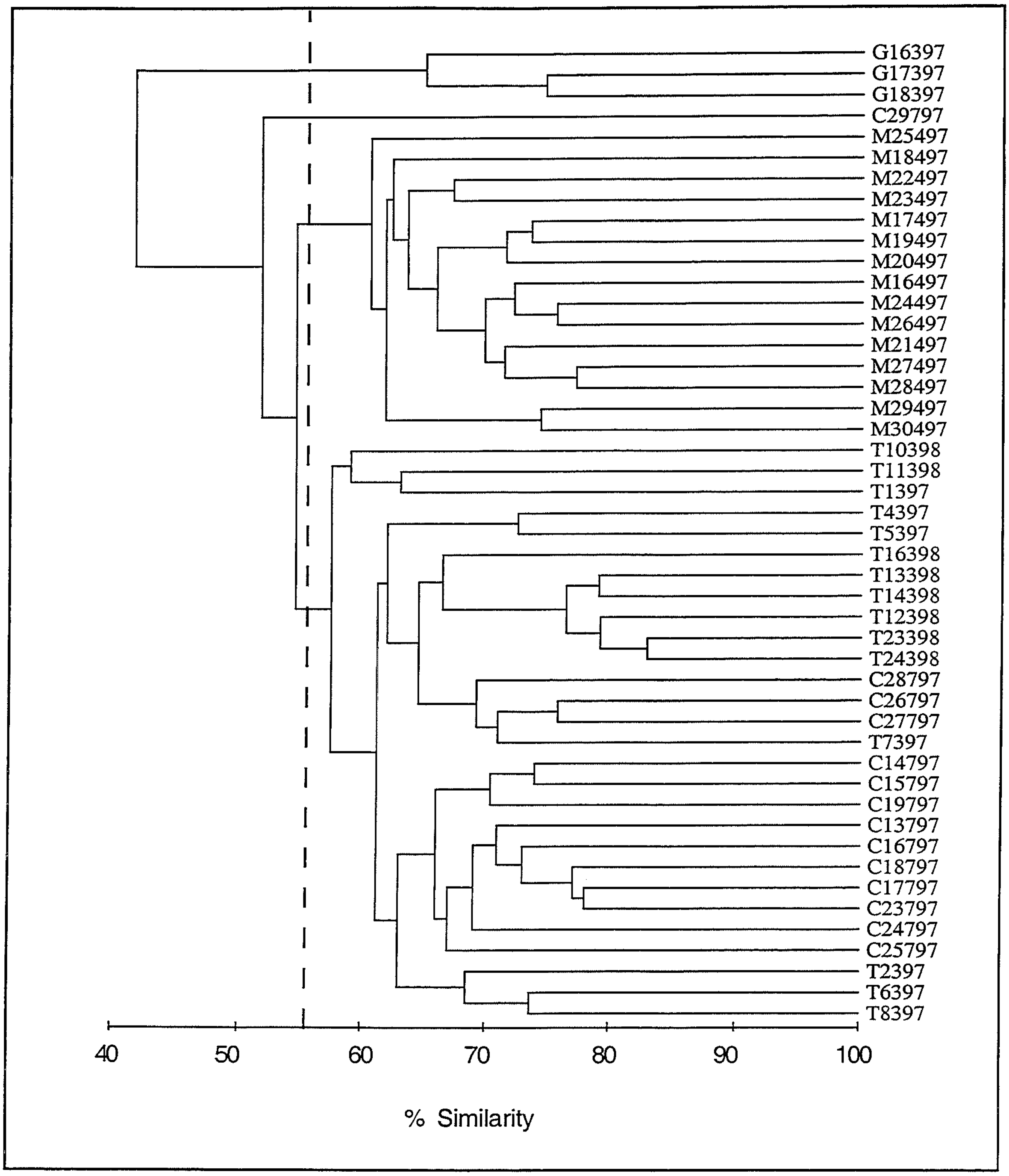

Figure 6.1.4 Dendrogram showing classification of 47 observations of average daily catch rate of 157 bycatch species from the Queensland banana prawn trawl fishery. Sub-samples of bycatch were obtained from 184 standard-net trawls. Each observation is based on an average derived from 2-6 trawls undertaken on a particular day. Regions are G = Gladstone, M = Mackay, T = Townsville and C = Cairns. T8397 represents the average catch rate of bycatch species from the Townsville area on 8/3/97. Catch rates were log-transformed before comparing Bray-Curtis measures. Four groups are distinguished at the arbitrary similarity level of 56% (X-axis).

composition of the bycatch. However, the narrow range of depths (mean = 4.5 ± 1.3 s.d. fathoms) sampled, a characteristic of the fishery, and the relatively large tidal variation in depth within and between sampling days reduced the likelihood of detecting depth effects.

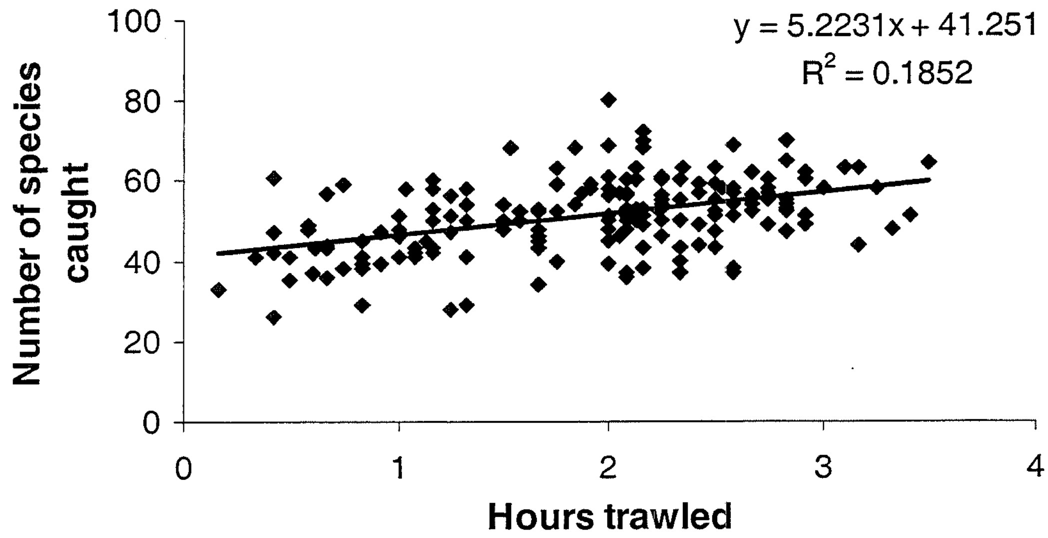

Figure 6.1.5 The number of species caught per hour of trawling, based on 184 trawls in the Queensland banana prawn trawl fishery.

Differences between groups

Differences between groups were not attributed to any single species, or small number of significant species, but rather differences were due to many species, each contributing a relatively small amount of the difference. For example, species that explained the highest amounts of dissimilarity between the Gladstone and Mackay groups were *Leiognathus splendens* (2.92%), *Terapon theraps* (2.50%), *Siphamia roseigaster* (2.32%), *Pellona ditchela* (1.84%), *Charybdis callianassa* (1.80%) and *Johnius borneensis* (1.69%) - collectively explaining about 13% of the dissimilarity. *Leiognathus splendens* was highly abundant in the Mackay samples, but absent from Gladstone samples.

The Gladstone group differed more from the Cairns/Townsville group than it did from the Mackay group; average dissimilarities between groups were 52.8% (Gladstone to Mackay) and 59.3% (Gladstone to Cairns/Townsville). Species that explained the highest amounts of dissimilarity between the Gladstone and Cairns/Townsville groups were *Leiognathus splendens* (2.62%), *Leiognathus bindus* (2.39%), *Siphamia roseigaster* (2.16%), *Metapenaeopsis sp.* (1.97%), *Pomadasys trifasciatus* (1.83%) and *Harpodon translucens* (1.81%). Collectively these species explained about 13% of the dissimilarity. Both *Leiognathids* were absent from Gladstone samples.

Species that explained the highest amounts of dissimilarity between the Mackay and Cairns/Townsville groups were *Pomadasys trifasciatus* (1.71%), *Leiognathus moretoniensis* (1.63%), *Oratosquilla inornata* (1.57%), *Harpodon translucens* (1.57%), *Leiognathus bindus* (1.52%), *Lactarius lactarius* (1.35%) and *Charybdis callianassa* (1.35%) – collectively accounting for about 11% of the dissimilarity.

Similarity within groups

Similarity within groups was determined by species abundance. For example, the 10 most numerically dominant species within the Gladstone group were *Johnius borneensis, Metapenaeopsis sp., Siphamia roseigaster, Pomadasys maculatum, Parapenaeopsis sp., Thryssa hamiltonii, Apogon fasciatus, Thryssa setirostris, Trachypenaeus sp,* and *Penaeus merguiensis*, in descending order of the amount of similarity explained. These species accounted for about 42% of the group similarity.

The 10 species that contributed most to the Mackay group similarity were *Charybdis callianassa, Leiognathus splendens, Pomadasys maculatum, Terapon theraps, Polynema multiradiatus, Trachypenaeus, Gazza minuta, Johnius borneensis, Oratosquilla inornata* and *Metapenaeus sp.* in descending order of the amount of similarity explained. These species accounted for about 28% of group similarity.

The 10 species that contributed most to the Townsville/Cairns group were *Leiognathus splendens, Leiognathus bindus, Terapon theraps, Metapenaeus sp., Trichiurus lepturus, Pomadasys maculatum, Johnius borneensis, Charybdis callianassa, Secutor ruconius* and *Caranx para* in decreasing order of importance. These species contributed 27% of the group similarity.

While a group specifically associated with the Cairns area was identified in the cluster analysis, it should be noted that this group was based on observations from only one day and as such, may be an anomaly. As such, no comparisons between and within the Cairns group are presented.

An average of 51 bycatch species were caught per net per trawl, based on the sub-sampling method described above. A generalised linear model indicated that the number of species was significantly ($P < 0.001$) influenced by the duration of the trawl, increasing by about five species for every hour trawled (Figure 6.1.5). Although the relationship was significant, the amount of variation explained by trawl duration was low (17%). The effect of latitude was then added to the model using a step-wise procedure, but no additional variation was explained by latitude or its interaction terms. Thus, while latitude affected the composition of the bycatch, it did not appear to have a significant effect on the number of species caught in trawls.

Bycatch species that contribute to other Queensland fisheries

While the trawler operators actively target banana prawns, some bycatch species are also retained and marketed as byproduct. For some of these species, such as Moreton Bay Bugs (*Thenus* sp.) and other penaeid prawns (*Metapenaeus* sp., *Trachypenaeus* sp., *Parapenaeopsis* sp. and *Penaeus* sp.) trawling is the sole method of harvest. However, other species such as portunid crabs (*Portunus pelagicus, Charybdis natator* and *Charybdis feriatus*) are targeted by recreational or other commercial fisheries. Conflict between sectors over these resources often develops in an atmosphere devoid of robust data. Results from the present study provide an opportunity to address these inter-sector concerns. To this end, a list of species that were included in the banana prawn fishery bycatch that also contribute to other Queensland fisheries, is provided in Table 6.1.3.

Of those bycatch species that contribute to other fisheries, the most numerous was the little jewfish, *Johnius borneensis* [12,532 individuals in the sub-samples, bootstrapped mean of 16.86 (± 2.01 s.d.) individuals per kilogram of banana prawns]. This is a small estuarine species caught largely by recreational line fishers. Hyland (1987) also noted it (previously as *Johnius vogleri*) was one of the most abundant species in the bycatch of the beam trawl fishery in southeast Queensland. The total number of *J. borneensis* caught by the banana prawn trawl fishery was estimated to be 11.3 (± 3.6 s.d.) x 10^6 per year, based on the methods described in section 6.1.2. Because of the relatively low commercial value of this species, little is known of its population dynamics or stock status. While the total catch estimates indicate the number of individuals that are caught and probably die from incidental capture in the banana prawn fishery is very high, the impact of the banana prawn fishery on the stock is unknown. The next most common species was the sandy tench or northern whiting, *Sillago sihama*, followed by tiger-toothed croaker *Otolithes ruber*, three-spot crab *Portunus sanguinolentus*, blue swimmer crab *Portunus pelagicus* and sole *Cynoglossus bilineatus* (Table 6.1.3). While *S. sihama* was the most common of the three whiting species, which included *S. maculata* and *S. robusta*, it appears to be of only very minor importance in recreational or commercial fisheries in Queensland. Inter-sector conflict over catches of *S. sihama* is likely to be minor, as there does not appear to be significant levels of fishing effort from any sector directed at this species. Assessment of *S. sihama* stocks has not been undertaken because it is considered to be of low priority and because the population parameters, particularly biomass estimates, catch landings and mortality rates, have not been quantified. The impact of the banana prawn fishery on this species, in terms of incidental fishing mortality, is unknown.

Sillago maculata is of major importance to the recreational winter whiting fishery located mainly between Hervey Bay and the NSW-Queensland border. It also contributes to byproduct retained by trawlers operating in waters mainly from Gladstone south to the border. Estimates of the number of the *S. maculata* taken as bycatch in the banana prawn trawl fishery alone are not enough to determine whether this sector is having a significant impact on the stock. Because the numbers of *S. maculata* caught by recreational and other trawl sectors operating in the area are unknown, it is not possible at present, to estimate and compare fishing mortality rates from the different sectors. The status of the *S. maculata* stock is unknown.

Stout whiting *S. robusta* constitute a separate trawl fishery operating south of Fraser Island, where they are taken mainly by a limited number of trawlers that have specific endorsements to target them and to a lesser extent by the eastern king prawn fishery. As such, potential for inter-sector conflict over this species is low, apart from these two trawl sectors. Periodic stock assessments of the stout whiting fishery are undertaken and the banana prawn trawl fishery is not currently included as a source of significant fishing mortality on the stock.

Of those bycatch species that contribute to other recreational or commercial fisheries, the tiger-toothed croaker, *O. ruber* was the third most common species. This species is of relatively minor importance to recreational fisheries in Queensland. Inter-sector conflict is minimal and because it is not considered a priority species for research and assessment, its population dynamics and stock status are unknown.

Legal-size male blue swimmer crabs, *P. pelagicus* are targeted in commercial and recreational crab pot fisheries, as well as retained as byproduct in the banana prawn trawl fishery. Since the commercial pot fishery is located mainly south of Bundaberg, the potential for conflict between the banana prawn fishery and commercial crabbers appears relatively small. Estimates of recreational fishing effort and catches of blue swimmers in the main banana prawn trawl grounds are unknown.

The queenfish (*Scomberoides commersonnianus*) is targeted by recreational line fishers and also contributes to commercial gill net catches. *Scomberoides lysan, S. tala* and *S. tol* are of lesser importance in the recreational line fishery.

The mackerels require special attention because unlike most of the species mentioned so far, there is a high degree of overlap in the spatial distribution of the net and line mackerel fisheries with the banana prawn fishery. As such, inter-sector conflict is relatively high. In addition, recent research initiatives have quantified mackerel fishery landings in the region, facilitating a comparison of the fishing mortalities from the different sectors.

The grey mackerel *Scomberomorus semifasciatus* and school mackerel *Scomberomorus queenslandicus* were equally abundant in the bycatch sub-samples. The spotted mackerel (*Scomberomorus munroi*) was comparatively rare (Table 6.1.3). There are significant recreational and commercial fisheries for the small mackerels in Queensland, some of which overlap spatially with the banana prawn trawl fishery. Because information on commercial and recreational catches are available for much of the area of interest, it's possible to examine the impact of the various sectors, including the incidental catch from the banana prawn fishery bycatch, on the small mackerels.

According to Cameron and Begg (1998) about 223 tonnes of grey mackerel, 14 tonnes of school mackerel and 57 tonnes of spotted mackerel are landed by the commercial sector in Queensland annually, mainly from gill netting. Most of the grey mackerel catch is from the eastern Gulf of Carpentaria, while the school and spotted mackerel landings are almost entirely from the east coast (Williams, 1997). There is no logbook program monitoring recreational landings of small mackerels in Queensland. Recreational landing estimates by Cameron and Begg (1998) were derived from bootstrapping survey data from recreational fishers who kept diaries for the period December 1994 to November 1995. These data indicate about 12 tonnes of grey mackerel, 44 tonnes of school mackerel and 70 tonnes of spotted mackerel were harvested by recreational fishers over the period.

In order to compare estimates of the number of mackerels caught in the recreational and commercial sectors with those from the banana prawn fishery bycatch, landings (in weight) were converted to numbers of fish. Estimates of the number of mackerels that were caught and retained by recreational fishers over a 12 month period were provided by Cameron and Begg (1998); 4,196 grey mackerel, 26,246 school mackerel and 30,927 spotted mackerel. (Note: significantly more were caught and released, but for the purposes of estimating the average weight of fish in the harvest these additional fish are not included). Using these figures, the average weight of individual fish caught by recreational fishers were 2.9 kg for grey mackerel, 1.7 kg for school mackerel and 2.3 kg for spotted mackerel. These averages were assumed to apply to the commercial sector as well, as there is some evidence that the size class frequency distributions are similar for the two sectors (at least for the spotted mackerel; see Figure 4.3.2 in Cameron and Begg, 1998). Under this assumption, and using the commercial landing weights reported above, the average number of mackerels caught in the commercial fishery per year is 76,896 (223 tonnes/2.9 kg) grey mackerel, 8,235 (14 tonnes/1.7 kg) school mackerel and 24,782 (57 tonnes/2.3 kg) spotted mackerel.

Table 6.1.3 Bycatch species that contribute to other recreational or commercial fisheries in Queensland (excluding species that are taken solely by trawling, such as Moreton Bay Bugs and other penaeid prawns). Listed in decreasing order of the number of individuals in 184 sub-samples of bycatch from the Queensland banana prawn fishery. Excludes species that contribute to bait fisheries.

Species	Common name	Number caught in samples	Percentage of bycatch
Johnius borneensis	Sharp toothed hammer croaker or little jewfish	12,532	7.62
Sillago sihama	Sandy tench/Northern whiting	976	0.60
Otolithes ruber	Tiger-toothed croaker	876	0.53
Portunus sanguinolentus	Three-spot crab	801	0.49
Portunus pelagicus	Blue swimmer crab	603	0.37
Cynoglossus bilineatus	Sole	86	0.05
Lutjanus malabaricus	Saddle-tailed sea-perch	81	0.05
Charybdis feriatus	Coral crab	66	0.04
Sillago maculata	Trumpeter whiting	51	0.03
Scomberoides tol	Needleskin Queenfish	54	0.03
Eleutheronema tetradactylum	Blue threadfin	49	0.03
Carcharhinus limbatus	Common blacktip shark	38	0.02
Scomberomorus queenslandicus	School mackerel	38	0.02
Scomberomorus semifasciatus	Grey mackerel	38	0.02
Epinephelus sexfasciatus	Six-banded rock cod	25	0.01
Lutjanus russelli	Moses perch	18	0.01
Platycephalus indicus	Bartail flathead	16	< 0.01
Sphyraena obtusata	Striped seaspike	13	< 0.01
Scomberoides tala	Queenfish	11	< 0.01
Platycephalus endrachtensis	Bar-tailed flathead	7	< 0.01
Scomberoides commersonnianus	Large Queenfish	7	< 0.01
Carcharhinus sorrah	Spot-tail or school shark	5	< 0.01
Lethrinus genivittatus	Emperor	5	< 0.01
Sphyraena flavicauda	Yellowtail barracuda	5	< 0.01
Choerodon cephalotes	Purple tuskfish	3	< 0.01
Platycephalus arenarius	Northern sand flathead	3	< 0.01
Sillago robusta	Stout whiting	3	< 0.01
Protonibea dicanthus	Black jewfish	3	< 0.01
Scomberoides lysan	Double spotted Queenfish/Giant dart	2	< 0.01
Scomberomorus munroi	Spotted mackerel	2	< 0.01
Charybdis natator	Rock crab	1	< 0.01

Grey mackerel in the banana prawn bycatch were found only in standard trawl net samples obtained from the northern strata (< 22° S). The bootstrapped mean catch rate from this strata was 0.207 (± 0.089 s.d.) grey mackerel per kilogram of banana prawns. Monte Carlo methods were then used to repeatedly estimate the total number of grey mackerel caught as bycatch in the northern sector in an average year. These estimates were based on the product of randomly selected values of ratios and annual landings, resulting in a mean of 69,609 (± 31,329 s.d.) individuals per year. This estimate is likely to be very conservative as there were additional grey mackerel caught off Bundaberg in the southern sector. However, because the vessel used in this region deployed a bycatch reduction grid in the net, it was not strictly representative of standard gear used in the fishery and as such, samples obtained with this gear were not included in the analysis.

Length frequency measures for grey mackerel obtained from the bycatch samples indicate the modal size of individuals in the bycatch is about 11 cm fork length (Figure 6.1.6).

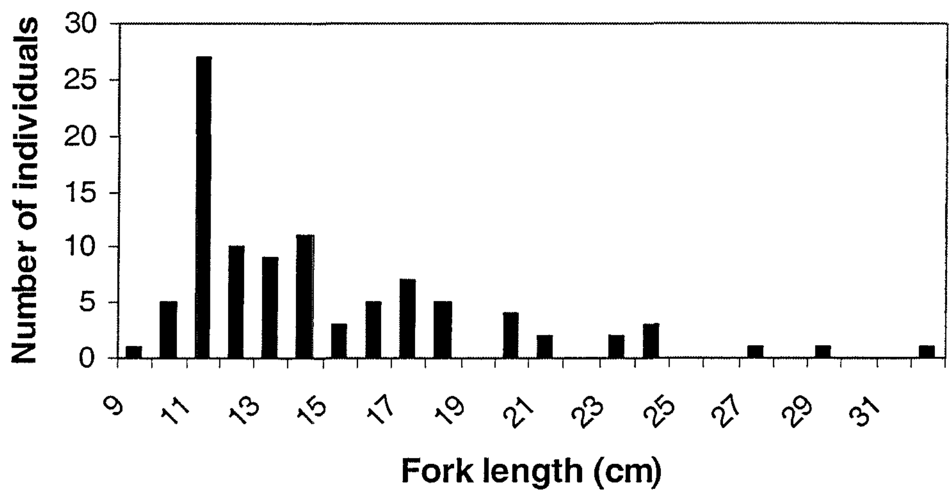

Figure 6.1.6 Size class frequency distribution of grey mackerel *S. semifasciatus* obtained from sub-samples of bycatch from the Queensland banana prawn trawl fishery.

At this length, individuals are in the order of 1-5 months old. According to Cameron and Begg (1998) grey mackerel are likely to be fully recruited to the commercial net fishery at 1-2 years of age. Assuming an instantaneous rate of natural mortality of 0.2 $year^{-1}$ and that those mackerel caught as bycatch would have experienced natural mortality for a period of approximately 1.5 years prior to recruiting to the fishery, then 74% of the 69,609 individuals (51,567) caught in the bycatch would have survived through to the age at recruitment to the net fishery.

School mackerel *S. queenslandicus* were found only in samples obtained from the northern sector and catch rates were similar to those of *S. semifasciatus* averaging 0.194 (± 0.065) school mackerel per kilogram of banana prawns. The total number of school mackerel caught as bycatch in the northern sector was estimated to be 65,337 (± 23,558 s.d.) per year. The length-frequency distribution, obtained from both standard nets and those with BRDs, indicated individuals ranged in size from 11-33 cm FL (Figure 6.1.7). If we assume that a) the average age of these individuals was in the order of 3 months, b) the instantaneous rate of natural mortality is 0.2 per year and c) recruitment to the fishery occurs at 1.5 years of age, then the number of these individuals that would have survived long enough to recruit to the fishery in the absence of the incidental trawl mortality would be ($65,337*e^{-0.2*1.2years}$) 51,395 per year.

Because only two spotted mackerel *S. munroi* were present in the 184 standard net sub-samples (Table 6.1.3), no total catch estimates were pursued for this species.

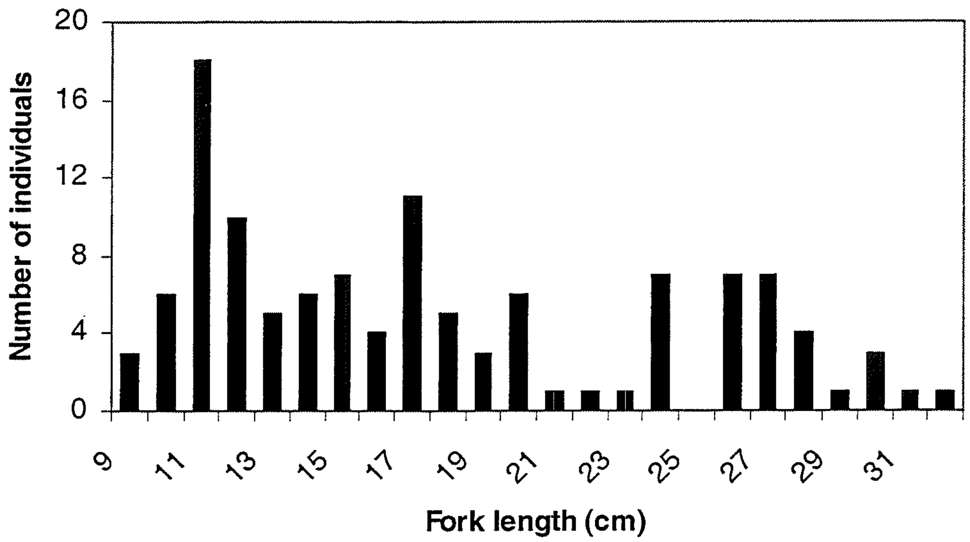

Figure 6.1.7 Size class frequency distribution of school mackerel *S. queenslandicus* obtained from sub-samples of bycatch from the Queensland banana prawn trawl fishery.

Estimating Total Bycatch Weight

Because the bycatch weight : prawn weight ratios strongly influence estimates of total bycatch, its imperative to examine how the ratios vary and to identify factors affecting them. To this end, the influence on the ratios of a) duration of the trawl, b) total weight of bycatch in the trawl and c) weight of banana prawns in the trawl, was examined. Prior to analyses, the ratios, bycatch weights and prawn weights were log-transformed to normalise the data. Bycatch weight was found to have a significant effect on the ratios ($P < 0.05$), although the amount of variation explained was low ($R^2 = 0.039$) the ratios increased slightly with increasing bycatch weight. Ratios decreased significantly ($P < 0.05$) with increasing weight of the prawn catch. The weight of bycatch and the weight of prawns in each trawl sample were positively correlated ($P < 0.05$). Although the weight of the bycatch increased significantly with the duration of trawls, the ratios were independent of the trawl duration ($P > 0.05$).

A bycatch weight : banana prawn weight ratio was estimated for each trawl and resulted in four ratio distributions (Figure 6.1.8) based on;

1.184 standard net trawls throughout the fishery,

2.58 standard net trawls from the Townsville region, 3.42 trawls with a grid fitted from the Bundaberg region,

4.58 trawls with BRDs fitted from the Townsville region.

All distributions were comprised of a wide range of ratio values that were skewed to the left and conformed to log-normal distributions (Figure 6.1.8). While the majority of ratios were between zero and 10:1, values between 10:1 and 30:1 were common in nets without BRDs. About 2% of ratios exceeded 40:1. The geometric mean ratio for the distribution based on the 184 measures from standard net trawls was 5.1:1. The 58 ratios obtained from trawls undertaken in the Townsville region with standard trawl nets resulted in a similar distribution with a geometric mean of 5.2:1 (Figure 6.1.8). The 58 ratios obtained from vessels with BRDs operating off Townsville had a geometric mean of 2.3:1, while ratios from the single vessel with a grid operating off Bundaberg had a geometric mean of 4.0:1.

While the raw bycatch : prawn ratios were log-normally distributed, the distributions of mean ratios and mean annual landings that were derived by bootstrapping conformed to a normal distribution. Bootstrapped mean ratios were 7.76 ± 0.69 for standard trawl gear and 3.51 ± 0.60 for nets with BRDs (Table 6.1.4) – larger than the geometric means of raw data above. Estimates of the mean annual total tonnage of bycatch, based on ratios from standard trawl gear, were 2,628 ± 479 tonnes for the northern strata and 1,886 ± 280 tonnes for the southern strata. These estimates suggest that if BRDs were deployed throughout the banana prawn sector the average annual weight of bycatch produced by the fishery would decline to 1,181 ± 276 tonnes and 850 ± 174 tonnes for the northern and southern strata, respectively. This is a significant reduction of about 55%.

6.1.4 Discussion

Comparisons with other trawl bycatch studies

Several studies have described aspects of prawn trawl bycatch in Australia, including those of Hyland (1987), Maclean (1973) and Stephenson et al. (1982a, b) in southeast Queensland, Jones and Derbyshire (1988), Watson and Goeden (1989), Watson et al. (1990) for the Great Barrier Reef, Harris and Poiner (1990, 1991) for Torres Strait and the southeast Gulf of Carpentaria, Gray et al. (1990) for the Hawkesbury River in New South Wales and McShane et al. (1999) for Spencer Gulf, South Australia. In general, findings common across these studies are that prawn trawl bycatch is comprised of many species - usually in the order of tens to hundreds, and the weight of bycatch greatly exceeds that of the prawn catch. These characteristics were also found to be common to the Queensland banana prawn fishery. A notable exception is the Spencer Gulf fishery, where the weight of the bycatch is only about half that of the prawn catch. Watson et al. (1990) examined the bycatch composition associated with a trawl fishery in the central Great Barrier Reef. They recorded a total 477 species - significantly more than the 316 reported here for the banana prawn fishery. The composition of the bycatch was dominated by coral reef/rubble associated species, mainly penaeid prawns of the genera *Metapenaeopsis* and *Trachypenaeus*, sea urchins (*Mareita planulata*), flatfish (*Engyprosopon grandisquamum*) and leatherjackets (*Paramonacanthus japonicus*). In contrast, bycatch from the Queensland banana prawn fishery was

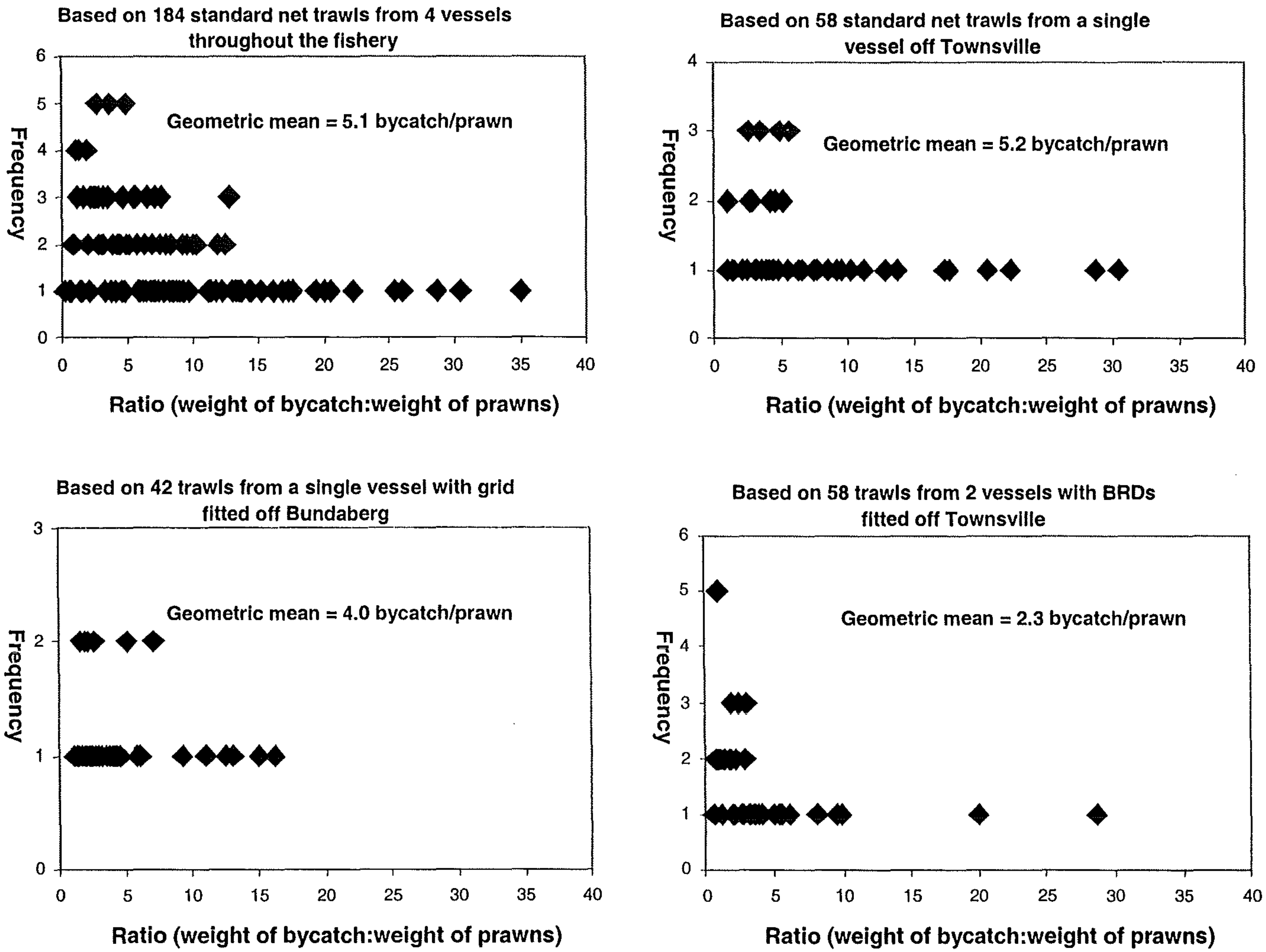

Figure 6.1.8 Frequency distributions and geometric means of bycatch weight:prawn weight ratios for the Queensland banana prawn trawl fishery. X-axes are standardised to a maximum of 40 for clarity of presentation, although about 2% of the ratios exceeded 40:1

characterised by shallow water, brackish-saltwater species, particularly the pony fishes *Leiognathus* spp., little jewfish *Johnius borneensis*, blotched javelin fish *Pomadasys maculatus*, penaeid prawns of the genus *Metapenaeus* and the carangid *Caranx para*. The composition of bycatch from these sub-tropical/tropical studies differs markedly from the temperate Spencer Gulf fishery, which was comprised of fewer species; 97% of the bycatch weight consisted of only 15 species, mainly monacanthids, carangids and portunid crabs (McShane et al., 1999).

Watson et al. (1990) also used cluster analysis to examine temporal and spatial variation in the bycatch composition. They found the composition of bycatch was affected more by location than by the time (ie., month) the samples were taken. Spatially, three broad groups of bycatch could be discerned, based on site location; a nearshore group, a midshelf group and an inter-reef group. Temporally, weak "wet" and "dry" seasonal groups were also identified. In the present study, it was not possible to undertake such a cross-continental shelf spatial analysis of bycatch composition because of the narrow depth range in which the fishery operates and was sampled. The only spatial difference that could be discerned was along a latitudinal axis with distinct groupings of species at different regions along the coast. Since the annual duration of the banana prawn fishery is relatively short (January to June) and the timing of sampling trips was largely opportunistic (ie., dependent on the cooperation of fishers), no seasonal analysis of variation in bycatch was pursued. Evidence of temporal clustering of the sub-samples obtained from the Townsville area in 1997 and again in 1998 was weak (Figure 6.1.4).

Table 6.1.4 Estimates of average annual total bycatch produced in the Queensland banana prawn fishery. Two bycatch:prawn weight ratio distributions were used; one based on measures from nets with standard trawl gear, the other based on measures from nets with BRDs. Means and confidence intervals for annual prawn landings and ratios were obtained by bootstrapping. Means for total annual bycatch weight estimates were derived using Monte Carlo sampling methods. All weight measures are in tonnes.

Strata	Mean annual banana prawn landings	Mean bycatch : prawn ratio from standard trawl nets	Mean total annual bycatch from fishery using standard trawl nets	Mean bycatch : prawn ratio from nets with BRDs	Mean total annual bycatch from fishery if BRDs were adopted
Northern sector (north of 22°S)	339.3 ± 55.3	7.76 ± 0.69	2,628 ± 479	3.51 ± 0.60	1,181 ± 276
Southern sector (south of 22°S)	243.6 ± 28.8	7.76 ± 0.69	1,886 ± 280	3.51 ± 0.60	850 ± 174

Interpreting bycatch weight:prawn weight ratios

In this study, and several others (see Harris and Ward, 1999 and Blaber et al., 1990), estimates of the total weight of bycatch in prawn trawl fisheries were heavily dependent upon and influenced by measures of the bycatch weight : prawn weight ratios obtained in the field. It is therefore prudent to briefly discuss some of the assumptions and limitations that are universal to ratio measures. For example, ratios express as a single value the relation that two variables have one to the other. As such, they provide no information on the size or robustness of the two individual variables - bycatch weight and prawn weight. Secondly, in the present study, although two ratios may have had the same value, one may have been obtained over a much longer duration of trawl sampling and therefore should be considered the more reliable of the two. In future studies, such bias could be corrected by standardising or weighting the ratios on trawl duration. Thirdly, observations containing zero prawn catch have to be omitted because the ratio cannot be defined (division by zero). This has potential to further bias estimates and result in over estimating total bycatch weight. Fourthly, as noted by Sokal and Rohlf (1981), ratios are often not normally distributed. This was found to be true in the present study. None of the ratios obtained from standard trawl gear or those with grids or BRDs conformed to normal distributions. While this can usually be addressed by log-transforming the data, studies quoting and deploying untransformed mean ratio estimates to derive total bycatch should be considered cautiously, as they are predisposed to underestimating the true mean ratio and hence total bycatch weight. Slightly more accurate estimates are obtained by referring to the ratio's geometric mean, but far better estimates are obtained using bootstrapped means.

The ratios obtained herein with standard gear were significantly influenced by the weight of the bycatch in the trawl; as the weight of bycatch increased there was a slight increase in the ratios. Conversely, the ratios were found to decrease with increasing prawn weight. It's reasonable to assume that the duration of the trawl also influences the ratio since the weight of bycatch increases at a greater rate than the weight of the prawn catch. However, the ratios were found to be independent of trawl duration, possibly due to the limited duration of the trawls (most were 2-3 hours long). Bycatch weight : prawn weight ratios are also likely to be affected by other factors. For example, although no such analyses were undertaken, the ratios are likely to vary between fishers and vessels. Again, it is reasonable to assume that fishers who are more skilled at locating schools or "boils" of banana prawns are likely to produce lower bycatch : prawn weight ratios than less skilled fishers. The ratios may also change through the fishing season - as the banana prawn population declines, trawl duration times, fishing effort and the relative contribution of bycatch to the total catch weight are all likely to increase up to a point where fishing is unviable and the season terminates. Such sources of variation in the ratios need to be considered as they directly influence estimates of total bycatch weight and hence, our ability to assess change in bycatch production.

Interactions with other fished resources

Bycatch species that occur in the banana prawn fishery that are of relatively high value and likely to be associated with inter-sector conflict include whiting, portunid crabs, mackerels and queenfish, sea perch, cod and to a lesser extent some flathead and shark species.

Of those species that contribute to other fisheries, the largest number of individuals caught for a particular species were for the little jewfish, *Johnius borneensis*. Extrapolative estimates suggest in the order of 11 million individuals are caught annually as bycatch in the banana prawn fishery. The impact of the trawl fishery on populations of *J. borneensis* is unknown, mainly because there are no records of total catches for this species. Anecdotal evidence suggests it is a common, fast growing, highly productive and fecund species, and despite these high annual incidental catches, there is no evidence of change in local or regional population sizes. The only fishery for this species appears to the recreational line fishery, and because it is not highly valued, the level of inter-sector conflict appears low.

For some of these species, there are multiple sources of fishing mortality underlying concerns over inter-sector conflict, or overfishing, but for others there are not. For example, the banana prawn fishery appears unlikely to a be a justifiable source of concern to the recreational whiting fishery because the main whiting species caught incidentally was the northern whiting *Sillago sihama* (which contributes extremely little to recreational landings) and because the spatial distribution of the main recreational whiting fishery (which is for winter whiting *S. maculata*) is located almost entirely south of the banana prawn fishery.

A similar scenario seems likely for the blue swimmer crab, *Portunus pelagicus*. It's likely that the banana prawn fishery is a significant source of fishing mortality for crab populations in the region. However, the recreational and commercial pot fisheries for blue swimmers occur well south of the banana prawn fishery. Stocks fished by the banana prawn trawlers and the recreational and commercial pot fisheries are most likely independent of each other, due to the considerable spatial separation.

The banana prawn fishery does, however, appear to be a likely source of fishing mortality and a justifiable source of concern for inter-sector conflict for some mackerel species, particularly school mackerel, *Scomberomorus queenslandicus*. This is because the spatial distribution of the recreational and commercial fisheries for school mackerel overlap significantly with the banana prawn fishery. The size of the school mackerel in the trawl sub-samples was 11-33 cm, suggesting that individuals are in the order of about 3 months old. If the incidental fishing mortality from trawling was removed, there would be approximately 51,000 more individual school mackerel surviving through to recruit to the recreational and commercial fisheries in the region. The impact of these additional recruits to landings was not calculated, but may be considerable.

The vast majority of grey mackerel *S. semifasciatus* landings in Queensland occur in the eastern Gulf of Carpentaria (Williams 1997) and therefore the banana prawn fishery is unlikely to be a major source of inter-sector conflict for this species, regardless of the level of incidental fishing mortality. While spotted mackerels *S. munroi* are also a valuable recreational and commercial species, and their distribution overlaps with the banana prawn fishery, the number of individuals in the sub-samples was extremely low, indicating low or negligible incidental trawl fishing mortality. The reasons for this are unclear, but possibly due to those smaller/younger stages that are vulnerable to trawling occurring in slightly greater depths than those in which the banana prawn fishery operates. The results suggest the banana prawn fishery is not a significant source of fishing mortality or a justifiable source for inter-sector conflict for this species.

Implications for management

The results suggest that the fishery has been generating in the order of about 4,500 tonnes of bycatch annually, the majority of which is comprised of small demersal and pelagic fish, portunid crabs and other penaeid prawns. There is considerable spatial variation in the composition of the bycatch, particularly along a latitudinal gradient. It also suggests that the recent mandatory use of BRDs introduced in this particular sector is likely to have a very positive effect reducing the total annual tonnage of bycatch by approximately 55% to about 2,000 tonnes. This reduction is higher than most other reported estimates which are generally in the order of 20-30%, possibly because the banana prawn fishery occurs during daylight and therefore the fish have higher visibility and a greater chance of escaping.

It should be noted that all 58 BRD ratio measures were obtained opportunistically, from a very limited number of vessels and BRD types, and in only one region (Townsville). As such, the ratios and subsequent estimated reductions in bycatch should be considered as preliminary and not necessarily representative of the BRD types that fishers are trialing or end up using. Thus, while the results are encouraging and indicate a high potential for bycatch reduction, truly robust estimates of the anticipated bycatch reduction (if any) remain elusive.

There are several problems facing industry and management in regard to the use and implementation of BRDs in the banana prawn fishery. For example, although their use is now mandatory in this particular sector, the definition of the devices is imprecise and therefore, difficult to legally enforce. While some fishers have adopted a responsible attitude and shown initiative in deploying, developing and improving BRDs, it's likely a considerable proportion of the fleet will adopt a minimalist stance which has little or no impact on bycatch reduction.

Another problem is the absence of any empirically robust estimate upon which to base the level of bycatch reduction. For example, there are no methods or estimates for maximum sustainable yield (MSY) in regard to bycatch or the level of fishing mortality required to sustain it. This conclusion was apparent at the Australian Society of Fish Biology Workshop on "*Establishing meaningful targets for reduction in Australian fisheries*" in September 1998 (see Proceedings of the Workshop, edited by Buxton and Eayrs 1999). This is unfortunate because, in the absence of any empirical approach, it's likely that bycatch reduction targets will be determined by other less objective approaches. The draft Queensland Trawl Fishery Management Plan recently included a target reference point reduction in bycatch of 40%. While this is widely considered to be a positive initiative, the method for deriving a 40% targeted reduction is subjective, open to criticisms pertaining to sustainability and likely to attract further debate.

Finally, it should be noted that identifying and implementing empirically robust sustainable levels of bycatch may prove to be inadequate if bycatch continues to wash up onto beaches. In such events, bycatch will still likely generate political concern even though the fish populations that make up the bycatch are experiencing sustainable levels of fishing mortality.

References

Alverson, D.L., Freeberg, M.H., Murawski and Pope, J.G., 1994. A global assessment of fisheries bycatch and discards. FAO Fish. Tech. Pap. 339. FAO, Rome, 233pp.

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

Bray, J.R., Curtis, J.T., 1957. An ordination of the upland forest communities of Southern Wisconsin. Ecol. Monogr. 27, 325-349.

Cameron, D., Begg, G., 1999. Fisheries biology and interaction in the northern Australian small mackerel fishery. Final report to the Fisheries Research and Development Corporation. Project #92/144. 222 pp.

Clarke, K.R., 1993. Non-parametric multivariate analyses of changes in community structure. Aust. J. Ecol. 18, 117-143.

Clarke, K.R., Green, R.H., 1988. Statistical design and analysis for a 'biological effects' study. Mar. Ecol. Prog. Ser. 46, 213-226.

Clarke, K.R., Ainsworthy, M., 1993. A method of linking multivariate community structure to environmental variables. Mar. Ecol. Prog. Ser. 92, 205-219.

Clarke, K.R., Warrick, R.M., 1994. Change in marine communities: an approach to statistical analysis and interpretation. Plymouth: Plymouth Marine Laboratories, 144 pp.

Dall, W., Hill, B.J., Rothlisberg, P.C., Staples, D.J., 1990. Chapter 8. Life Histories. In: Dall, W., Hill, B.J., Rothlisberg, P.C., Staples, D.J. (Eds.), Advances in Marine Biology Volume 27. The biology of the Penaeidae. pp. 283-314. (Academic Press: London)

Dredge, M., 1985. Importance of estuarine overwintering in the life cycle of the banana prawn, *Penaeus merguiensis*. In: Rothlisberg, P.C., Hill, B.J., Staples, D.J. (Eds.), Second Australian National Prawn Seminar. NPS2, Cleveland, Queensland, Australia, pp. 115-124.

Gray, C.A., McDonall, V.C., Reid, D.D., 1990. By-catch from prawn trawling in the Hawkesbury River, New South Wales: species composition, distribution and abundance. Aust. J. Mar. Freshwater Res. 41(1), 13-26.

Harris, A.N., Poiner, I.R., 1990. By catch of the prawn fishery of Torres Strait: Composition and partitioning of the discards into components that float or sink. Aust. J. Mar. Freshwat. Res. 41, 37-52

Harris, A.N., Poiner, I.R., 1991. Changes in species composition of demersal fish fauna of southeast Gulf of Carpentaria, Australia, after 20 years of fishing. Mar. Biol. 111, 503-519.

Harris, A., Ward, P., 1999. Non-target species in Australia's commonwealth fisheries. A critical review. Bureau of Rural Sciences, Canberra. Australia. 152 pp.

Hyland, S.J. 1987. An investigation of the nektobenthic organisms in Logan River and Moreton Bay, Queensland with an emphasis on penaeid prawn. Unpublished Masters Degree thesis, University of Queensland. 123 pp.

Jones, C.M., Derbyshire, K. 1988. Sampling the demersal fauna from a commercial penaeid prawn fishery off the central Queensland coast. Mem. Qld. Mus. 25, 403-415.

Maclean, J.L. 1973. An analysis of the catch by trawlers in Moreton Bay (Qld.) during the 1966-67 prawning season. Proc. Linnean Society of New South Wales. 98(1), 35-42.

Stephenson, W., Chant, D.C., Cook, S.D. 1982a. Trawled catches in northern Moreton Bay I. Effects of sampling variables. Mem. Qd Mus. 20, 375-386.

Stephenson, W., Chant, D.C., Cook, S.D. 1982b. Trawled catches in northern Moreton Bay II. Changes over two years. Mem. Qld. Mus. 20, 387-399.

McShane, P.E., Hall, S.J., Carrick, N.A., 1999. Trophic consequences of prawn trawling: linking bycatch to benthos. In: Buxton, C., Eayrs, S.,(Eds.) Establishing meaningful targets for bycatch reduction in Australian fisheries pp. 106-112. Australian Society for Fish Biology Workshop Proceedings, Hobart 24-25 September 1998.

Robins, J.B. and Courtney, A.J., 1999. Status report on bycatch within the Queensland Trawl Fishery. In: Buxton, C., Eayrs, S.,(Eds.) Establishing meaningful targets for bycatch reduction in Australian fisheries pp. 24-45. Australian Society for Fish Biology Workshop Proceedings, Hobart 24-25 September 1998.

Staples, D.J., 1985. Modelling the recruitment processes of the banana prawn, *Penaeus merguiensis* in southeastern Gulf of Carpentaria. In: Rothlisberg, P.C., Hill, B.J., Staples, D.J. (Eds.), Second Australian National Prawn Seminar, NPS2, Cleveland, Queensland, Australia, pp. 175-184.

Sokal, R.S., Rohlf, F.J., 1981. Biometry: The Principles and Practice of Statistics in Biological Research. 2nd edn, (Freeman: New York.) 859 pp.

Watson, R.A., Goeden, G., 1989.Temporal and spatial zonation of the demersal trawl fauna of the central Great Barrier Reef. Mem. Qld. Mus., pp. 611-620.

Watson, R.A., Dredge, M.C.L. and Maher, D.G., 1990. Spatial and seasonal variation in demersal trawl fauna associated with a prawn fishery on the central Great Barrier Reef, Australia. Aust. J. Mar. Freshwater Res. 41, 65-77.

Williams, L., 1997. Queensland's fisheries resources. Current condition and recent trends 1988-1995. Department of Primary Industries Queensland. 101pp.

6.2 Description of bycatch in the Northern Prawn Fishery and the Torres Strait Prawn Fishery

6.2.1 Introduction

In order to identify, understand and eventually manage the impact of trawling on bycatch species the levels of bycatch must be monitored. The first step towards this is to obtain a quantitative description of the bycatch and factors influencing its variation throughout a fishery. However, the characterisation of prawn trawl bycatch composition is relatively rare throughout the world and where available often published in 'grey' literature (reviewed by Andrew and Pepperell, 1992; Nance and Scott-Denton, 1995). Two crucial points that have to be established are whether bycatch composition varies seasonally or regionally within a fishery. Knowledge of these two factors will enable stratification of monitoring designs, which will reduce the variance of catch estimates, increasing the power to detect changes in catch rates. The prawn fisheries in north Australia are particularly suitable for establishing these points since they are spread over a large geographic range and are subject to seasonal monsoons (Somers, 1994).

Previously the bycatch of the NPF has been described from restricted regions of the fishery (Section 2). This study provides the first comparison of the full extent of the main tiger prawn fishing grounds in the NPF. This information is essential for determining the full extent of regional variation.

The specific objectives of this section were:

- To examine the species composition of bycatch from the NPF and TSPF, providing estimates of the catch rates of species,
- To examine the extent of spatial and temporal variation in bycatch, particularly vertebrate bycatch species.

6.2.2 Methods

Data for the description of the bycatch from the tiger prawn fishing grounds of the NPF and TSPF were collected from two sources, scientific research surveys and a scientific observer on commercial boats. Elasmobranch bycatch was also recorded by a crew member observer on the commercial boats she was working on. A trawl refers to a single net.

Research surveys
Research surveys were conducted in 1997 in the months February and October using the R.V. 'Southern Surveyor', a 66 m stern trawler (Table 6.2.1). We collected bycatch samples in the ten main prawn fishing regions in the NPF and the TSPF (Figure 6.2.1). Research surveys have the advantage of allowing substantial control over the sites and times where samples are collected, allowing spatial and temporal variation to be

examined in a systematic manner. Measures of abiotic variables in the environment can also be collected simultaneously, allowing the influence of these to be assessed.

Both the NPF and the TSPF are divided into 6 x 6 n. mile grids for the commercial fleet's reporting of catch. These grids were used to distribute the sampling effort in the surveys. The commercial trawling effort in these fisheries is highly aggregated (Somers, 1994) with the high effort grids containing most of the fishing effort. Therefore, we restricted our survey to the grids with the highest commercial fishing effort as these would be the areas where the majority of the bycatch is caught by the fisheries.

The commercial prawn trawling season in the NPF starts in April and usually ends in November, with a mid-season closure, usually from mid June until the start of August. The trawling season in the TSPF is from March to November. Our February survey sampled the bycatch composition prior to the start of the year's trawling and the October survey sampled it towards the end. Ten regions of high commercial fishing effort were sampled in February and nine regions in October (Table 6.2.1, Figure 6.2.1). Two to three nights were spent trawling in each region, except 'Cobourg', which was trawled for only one night in February. On each night, between 8 and 14 trawls were conducted within three (6 x 6 n. mile) grids. A trawl refers to a single net.

Trawls were conducted at night only, starting half an hour after dusk and ending half an hour before dawn. A single 14 fathom (26.5 m) Florida Flyer demersal prawn trawl with a codend cover was used. The body of the trawl was made of 57 mm stretched mesh with a 150 x 150 mesh codend of 45 mm stretched mesh. A codend cover, with 12 mm mesh, was used to examine mesh selectivity for bycatch species which will be reported elsewhere. The net was rigged with 100 m bridles and No. 9 Bison otter boards (490 kg). The net is consistent with those used by commercial trawlers, except that commercial trawlers tow two.

We completed 401 trawls averaging 0.51 h ($\pm$ 0.001 se) in duration, timed from the completion of the warp-out to the start of the hauling. Trawls were towed at an average speed of 3.2 knots ($\pm$ 0.02 se), similar to the speed of commercial trawls. Net height and wingspread were checked regularly by SCANMAR to ensure consistency in the way the net fished.

The weight of the entire catch for each trawl was recorded. The entire catch or a subsample (in larger catches) was then sorted to determine species composition. Large species (e.g. elasmobranchs) or those kept for biological information were not subsampled, therefore, their total numbers and weight were recorded. Once these species were removed, the remainder of the trawl catch was subsampled if necessary. The size of the subsample varied with the catch weight. The average subsample was 41.0% ($\pm$ 1.5 se) of catch weight (excluding the weight of species not subsampled). Individuals were identified to the lowest possible taxonomic level, species level for most. For each species the weight ($\pm$ 0.1 g) and number of individuals were recorded. Data were entered directly into an Oracle database on the ship.

Table 6.2.1 The number of trawls sampled in each region by the three methods. The number of nets sampled is also shown, the number of nets sampled for elasmobranchs is given in parentheses. The regions are labelled following Figure 6.2.1.

			Nets sampled	**Region**										
Type	**Year**	**Month**	**(n)**	**Me**	**Co**	**NG**	**SG**	**Va**	**WM**	**NM**	**EM**	**We**	**TS**	**Total**
Research survey	1997	February	1	36	7	23	22	26	20	22	19	16	19	210
Research survey	1997	October	1	15	—	28	20	31	20	19	20	19	19	191
Scientific observer	1996	September	1 (2)	—	—	52	—	31	—	—	—	—	—	83
Scientific observer	1997	May - June	1 (2)	—	—	—	—	—	—	76	—	—	—	76
Scientific observer	1997	September - October	1 (2)	—	—	60	—	—	—	—	—	—	—	60
Crew member observer	1997	August - October	(2)	—	—	—	—	—	4	9	49	79	—	143

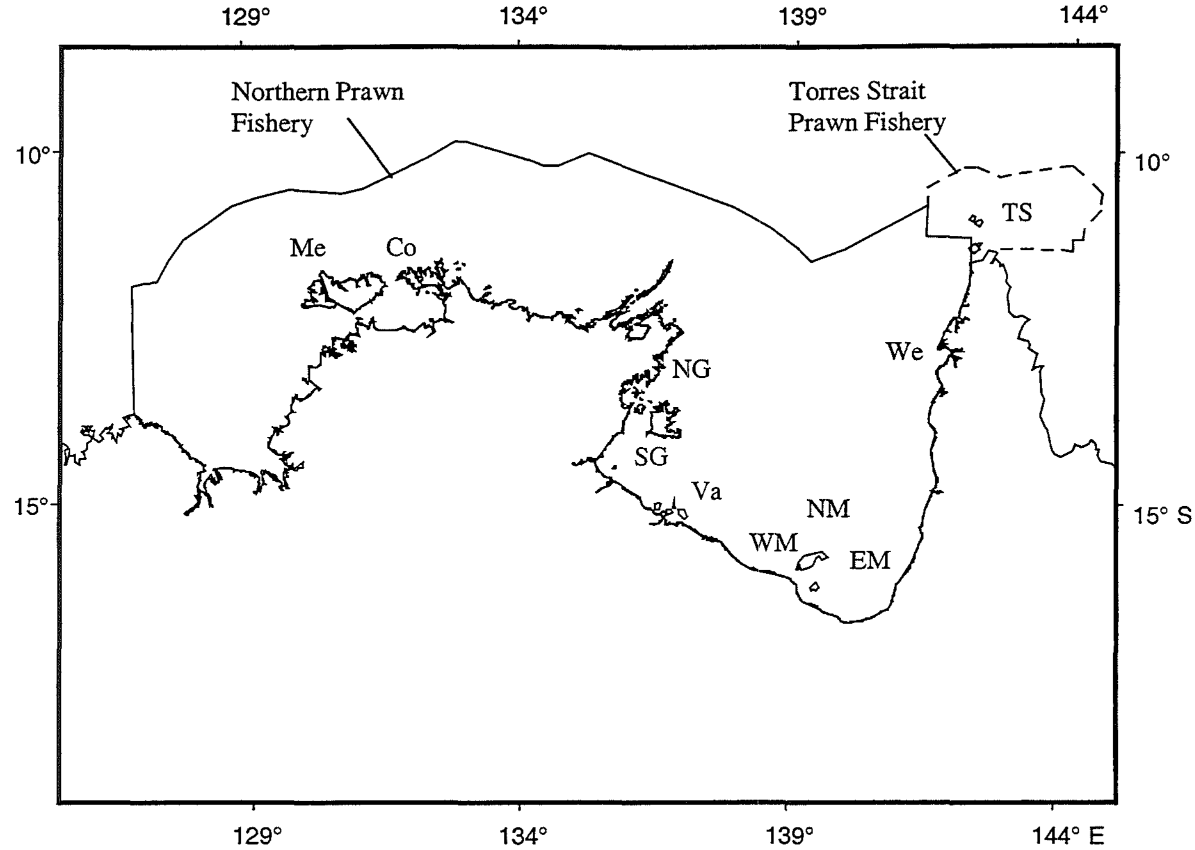

Figure 6.2.1 The main commercial fishing regions in the NPF and TSPF that were sampled in the present study. Me = 'Melville', Co = 'Cobourg', NG = 'North Groote', SG = 'South Groote', Va = 'Vanderlins', WM = 'West Mornington', NM = 'North Mornington', EM = 'East Mornington', We = 'Weipa', TS = 'Torres Strait'.

Abiotic measurements

The depth of each trawl was recorded by automatic dataloggers on the ship. Acoustic measures of the seabed were collected every 2 seconds, by RoxAnn, an echo integrator connected to the output of the echosounder. This provided measures of the roughness and hardness of the seabed. Spurious data, due to weather conditions or other factors, were identified and removed. The RoxAnn data for each individual trawl were then summarised as mean roughness and hardness and included in the analyses.

Commercial fishing effort data

A measure of the NPF commercial prawn trawling effort in the area of each research trawl was obtained from commercial logbook data (held by the Australian Fisheries Management Authority) that provide a yearly value of the number of days trawled in each 6 x 6 n. mile grid. The effort for each grid was calculated as the number of days trawled in a grid between 1987 – 1996. The effort data since 1987 was used as this year represents the start of substantial changes in the fishing effort and fleet characteristics (Robins and Sachse, 1994).

Scientific Observer

A scientific observer was placed on NPF trawlers for three trips to monitor the bycatch (Table 6.2.1). The trips ranged from 19 to 39 days, including time on the mother ships while travelling to and from trawlers. A total of 225 trawls on 4 different trawlers were sampled. The primary focus of the observer's work was to examine potential methods for monitoring bycatch (Section 9). However, the information collected can contribute to the description of the bycatch.

The catch weight was recorded from 139 codends and estimated for other trawls. It was not feasible to weigh each codend, due to the limitations of space and time on the commercial boats. The catch was handled in a similar manner to the research surveys. Individuals of large animals (turtles, seasnakes and elasmobranchs) were all recorded from both nets, as commercial trawlers tow two at once. The smaller bycatch was sampled from one net using a standard carton, which held approximately 10kg of bycatch. Some catches were sampled entirely for Section 9.3. The samples were then frozen and transported back to the CSIRO, Cleveland Laboratory, where they were sorted in the same manner as the research survey samples. The observer also recorded the depth and speed of the trawl.

Crew member observer

A crew member from the commercial fishing fleet was trained to identify the elasmobranchs and collected information from the boats she was working on. She identified the sharks to species where possible and recorded the number and sex of individuals and where possible also the weight and length. She recorded the elasmobranchs from 141 pairs of commercial trawls (Table 6.2.1).

Species Identification

Individuals were identified to the lowest possible taxonomic level. If the taxonomy was doubtful or there was inconstancy in discriminating among particular species they were grouped for analyses: *Sardinella gibbosa* includes *S. albella* and *S. gibbosa*; *Euristhmus nudiceps* includes *E. nudiceps* and *E. lepturus; Ulua aurochs* includes *U. aurochs* and *U. mentalis; Callionymus goodladi* includes *C. goodladi* and *C. margaretae; Gerres macracanthus* includes *G. macracanthus* and *G. filamentosus; Gerres macrosoma* includes *G. macrosoma* and *G. oyena; Saurida* sp. 2 may be more than one species, possibly *Saurida* sp. 2 and *S. undosquamis.*

Data Analyses

For the subsampled catches, the estimated catch of each species (in both weight and number of individuals) was calculated using a grossing factor (the ratio of the catch weight, excluding the weight of species not subsampled, to the weight of the subsample). Catches were standardised by the duration of the trawl and so data are presented as either the number of individuals per hour (n h^{-1}) or the weight of individuals per hour (kg h^{-1}).

General catch characteristics

For each trawl the following general catch characteristics were calculated: a) total catch rate of all species including invertebrates and vertebrates (kg h^{-1}), b) the total catch rate of bycatch species including invertebrates and vertebrates (kg h^{-1}), c) the proportion of the bycatch that was teleosts and elasmobranchs, d) the catch rate of all teleosts and elasmobranchs (kg h^{-1} and n h^{-1}) and e) the total catch rate of commercial prawns (kg h^{-1}).

Spatial and temporal variation in general catch characteristics

Spatial and temporal differences in the general catch characteristics were examined for the research survey data only. The model was an unbalanced two-way ANOVAs with the factors region (R) and time of year (T):

$$\mathbf{Y = R + T + R{*}T + e} \qquad \text{(model 6.2.1)}$$

Y represents the general catch characteristic being examined (e.g. total bycatch), R*T represents the interaction between region and time of year effects and e is the residual. Prior to the ANOVAs the dependent variables were examined for normality and heteroscedasticity and transformed where necessary. Total bycatch (kg h^{-1}), catch rate of teleosts and elasmobranchs (kg h^{-1}, n h^{-1}) and catch rate of prawns (kg h^{-1}, n h^{-1}) were log (x + 1) transformed and the proportion of the bycatch that was teleosts and elasmobranchs was arcsine (square root (x)) transformed. Type III sums of squares were used to determine the significance of the effects. When an ANOVA showed significant differences, *a posteriori* comparisons between least squares means were used to determine which means were significantly different. The error rate for each comparison was adjusted to maintain an overall error rate of 0.05. This procedure was followed with all analyses.

Spatial and temporal variation in teleost and elasmobranch bycatch composition

The total number of teleost and elasmobranchs species collected in a region at the two times of year and the number of species in common between regions at the two times of year were calculated for the research survey data. Different numbers of trawls were completed in each region, therefore, in order to make these comparisons, a random subsample of trawls was taken from each region at each time of year (15 trawls). The subsamples of trawls were used to determine the total number of species detected in a region at each time of year and the number of species in common between each pair of regions by time of year combinations. The number of species in common was converted to a proportion of the total number of species found in each pair. This random selection of trawls was repeated 20 times and we have presented the maximum values.

Spatial and temporal differences in the overall teleost and elasmobranch bycatch composition of the trawls were examined by ordination. The association matrix was formed using the Bray Curtis metric and the ordination was performed on a double centred matrix followed by principal coordinate analysis (Williams, 1976). The ordination was based on the abundance, log (n h^{-1}+ minimum n h^{-1}), of species recorded in at least 5% of trawls (135 species). This ensured that very rare species were not included in the analysis.

The ordination scores for each trawl on the first three principal components were then subjected to two-way ANOVAs (model 6.2.1) and *a posteriori* comparisons of the least-squares means to examine spatial and temporal differences. ANOVAs of the same design (model 6.2.1) were applied to the abundance of each species, to determine whether the individual species showed a similar pattern.

In order to determine which species had abundances that were strongly related to the pattern shown in the ordination, Pearson's correlations (Sokal and Rohlf, 1996) between the first three principal components and the individual species abundances were calculated.

The relationship between the abiotic variables (depth, roughness and hardness), prawn catch rate (kg h^{-1}), commercial effort data and the principal components from the ordination were also examined using Pearson's correlations. This was to determine which of these variables showed similar patterns across the trawls to those seen in the ordination.

Depth (D), start time of the trawl (S) roughness (U), hardness (H), prawn catch rate (P) and commercial effort (C) were used as covariates in ANCOVAs to investigate the extent to which they influenced the variation seen in bycatch composition. Two ANCOVAs were performed, the first included depth, start time of the trawl, roughness, hardness and prawn catch rate, with the design:

$$\mathbf{Y = R + T + R{*}T + D + S + U + H + P + e} \qquad \text{(model 6.2.2).}$$

The designs excluded any trawls where not all covariates were present.

A second ANCOVA added commercial effort to the covariates used in model 6.2.2. This ANCOVA was only applied to the data from the NPF as the same measure was not available for commercial effort in the TSPF.

$$\mathbf{Y = R + T + R{*}T + D + S + U + H + P + C + e} \qquad \text{(model 6.2.3).}$$

The ANCOVA designs were applied to the results from the ordination, the scores of each trawl on the first three principal components. This looked at the influence of the covariates on the overall composition of the bycatch and the extent to which the covariates contributed to the observed regional and time of year effects. The ANCOVA designs were also applied to the abundance of each species to see whether they displayed the same pattern as overall composition.

Prior to including the covariates in the ANCOVAs the correlations between the covariates were examined to determine if there were any significant relationships. The spatial and temporal variation in depth, roughness, hardness and commercial effort, was examined with two way ANOVAs (model 6.2.1) and *a posteriori* comparisons of the least-squares means. All the covariates were log (x+1) transformed prior to the analyses, in order to reduce their skewed distributions.

6.2.3 Results

General catch characteristics

The average catch rate of all animals, across all research survey trawls was 144.9 ($\pm$ 17.7 se) kg h^{-1} and 113.2 ($\pm$ 5.3 se) kg h^{-1} for the trawls recorded by the scientific observer (A trawl refers to a single net). The average catch rate of all bycatch across all research survey trawls was 142.0 (± 17.7 se) kg h^{-1} and 102.2 (± 5.1 se) kg h^{-1} for the scientific observer trawls. Commercial prawns were caught at an average rate of 2.83 (± 0.2 se) kg h^{-1} by the research survey and 11.0 (± 0.4 se) kg h^{-1} for the trawls recorded by the scientific observer.

Teleosts averaged 72.9% (± 1.19 se) and 63.2% (± 1.04 se) of the weight of the bycatch in the research survey trawls and scientific observer trawls respectively, while elasmobranchs averaged 3.9% (± 0.56 se) and 5.9% (± 0.6 se) in the two surveys. Invertebrates made up on average 19.7% (± 1.17 se) and 20.0% (± 0.7 se) and the reptiles 0.3% (± 0.2 se) and 0.98% (± 0.2 se) of the research survey trawls and scientific observer trawls respectively.

Teleost bycatch

We recorded at least 390 species of teleosts from 108 families in the bycatch (Table 6.2.2). The research surveys detected 345 species and the scientific observer 279 species. The Carangidae family had the most species (30), followed by the Apogonidae (20). The majority of families were represented by one or two species (Table 6.2.2). In terms of weight of bycatch the families Bathysauridae, Leiognathidae and Nemipteridae, which include at least 29 species, contributed over 41% of the weight of the bycatch. These families also contributed the greatest percentage of teleost bycatch in terms of the number of individuals (45%).

Saurida sp. 2, was the most common species, occurring in 83.3% of research survey trawls. However, *Saurida* sp. 2 is potentially a combination of two species *Saurida undosquamis* and *Saurida* sp. 2. These species can be differentiated only by genetic analysis (Thresher *et al.*, 1986) and the species composition in this region has not been investigated. *Pentaprion longimanus* and *Apogon poecilopterus* were the next most common species, occurring in 74.6% and 70.1% of research survey trawls respectively.

There were only eight species recorded in all areas in both months of the research surveys (*Apogon poecilopterus, Saurida micropectoralis, Nemipterus hexodon, Caranx bucculentus, Apogon fasciatus, Carangoides humerosus, Carangoides talamparoides, Priacanthus tayenus*). Nine species (*Saurida* sp. 2, *Leiognathus splendens, Leiognathus mortoniensis, Pentaprion longimanus, Leiognathus bindus, Upeneus sulphureus, Nemipterus nematopus, Nemipterus hexodon*) made up 50% of the catch by numbers. The majority of teleost species (269 species) were recorded in less than 10% of research survey trawls, while only 13 species were recorded in more than 50% of the research survey trawls. The predominance of rare species is illustrated by the fact that 362 species contributed < 1% to the total number of individuals in the bycatch.

Elasmobranch bycatch

We recorded 43 species of elasmobranchs from 12 families with the three methods (Table 6.2.3). There were 16 Dasyatidae, contributing 52% of the catch by numbers and 10 species of Carcharhinidae contributing 30% of the catch by numbers. The research surveys recorded 27 species, the scientific observer 35 and the crew member observer 31 species (Table 6.2.3). Dasyatis leylandi had the highest catch rate (33% of the numbers), then Carcharhinus dussumieri (18% of the numbers).

Invertebrate Bycatch

There were 234 invertebrate taxa identified in the bycatch (Table 6.2.4), however, most were identified to family level or higher. The crustaceans were the only group where most were identified to species. The taxonomic diversity is high with 11 phyla represented.

The Crustacea, Echinodermata and Porifera accounted for 46% of the weight of invertebrate bycatch, these groups contributed 20%, 14% and 12% respectively. Within the Crustacea, 94% of the weight was decapods, of which 76% was crabs and 24% non-commercial penaeid prawns. The portunid crabs made up 77% of the weight of crabs (Table 6.2.4).

Spatial and temporal variation in general catch characteristics

The total weight of bycatch (vertebrates and invertebrates) varied significantly among the regions ($F_{9,382} = 4.08$, $P < 0.0001$) and between the two times of year ($F_{1,382} = 4.66$, $P = 0.0315$), and there was a significant interaction ($F_{8,382} = 4.91$, $P < 0.0001$). Overall 'East Mornington' and 'Vanderlins' had the highest bycatch weights, these regions were also the most variable (Figure 6.2.2). 'East Mornington' and 'North Mornington' were the only regions which showed significant differences between the two times of year, with more bycatch caught in October.

The proportion of the bycatch that was fish and elasmobranchs also showed significant variation among regions ($F_{9,382} = 5.51$, $P < 0.0001$), but not between the times of year ($F_{1,382} = 3.72$, $P = 0.0544$). The interaction was significant ($F_{8,382} = 3.24$, $P = 0.0014$). 'Vanderlins' had the lowest proportion of fish and elasmobranchs in the bycatch, while 'Weipa' had the highest (Figure 6.2.2). 'North Groote' was the only region which showed a significantly greater proportion of fish and elasmobranchs in the bycatch in October, the other regions did not vary significantly between the two times of year.

The total catch rate of teleosts and elasmobranchs showed a similar pattern in both weight and the number of individuals caught. The weight of teleosts and elasmobranchs did not vary between the two times of year ($F_{1,382} = 1.58$, $P = 0.2092$), but did vary significantly among the regions ($F_{9,382} = 4.97$, $P < 0.0001$) and there was a significant interaction ($F_{1,382} = 5.75$, $P < 0.0001$). The number of individuals caught also showed significant regional variation ($F_{9,382} = 10.26$, $P < 0.0001$), differed between the two times of year ($F_{1,382} = 6.74$, $P = 0.0098$) and had a significant interaction ($F_{8,382} = 10.69$, $P < 0.0001$). For both measures of catch rate 'Weipa' and 'West Mornington' had the highest catch rates of fish and elasmobranchs, while 'Torres Strait' had the lowest (Figure 6.2.2). 'Melville' showed a significantly higher catch rate of teleosts and elasmobranchs in October than February, but the other regions did not vary significantly between the two times of year (Figure 6.2.2).

Table 6.2.2 The catch rate of teleost species overall and individually from the research surveys and the scientific observer.

		Overall				Research survey				Scientific observer			
		n h^{-1}		kg h^{-1}		n h^{-1}		kg h^{-1}		n h^{-1}		kg h^{-1}	
Family	**Species**	**mean**	**se**	**mean**	**se**	**mean**	**se**	**mean**	**se**	**mean**	**se**	**mean**	**se**
Antennariidae	*Antennarius hispidus*	0.0349	0.0206	0.0049	0.0035	—	—	—	—	0.1244	0.0730	0.0175	0.0123
	Antennarius nummifer	0.0655	0.0289	0.0004	0.0002	0.0678	0.0379	0.0003	0.0002	0.0595	0.0342	0.0004	0.0003
	Antennarius pictus	0.0034	0.0030	< 0.0001	< 0.0001	—	—	—	—	0.0120	0.0107	0.0001	0.0001
	Antennarius striatus	0.0932	0.0592	0.0012	0.0009	0.0217	0.0184	0.0001	< 0.0001	0.2762	0.2052	0.0043	0.0033
	Tathicarpus butleri	0.1815	0.0527	0.0028	0.0009	0.0392	0.0274	0.0006	0.0004	0.5457	0.1716	0.0085	0.0030
	Tetrabrachium ocellatum	0.5560	0.0748	0.0035	0.0005	0.2517	0.0743	0.0015	0.0004	1.3347	0.1758	0.0088	0.0013
	unidentified Antennariidae	0.0286	0.0221	0.0001	0.0001	0.0398	0.0307	0.0001	0.0001	—	—	—	—
Aploactinidae	*Adventor elongatus*	0.3179	0.0642	0.0044	0.0010	0.0609	0.0279	0.0008	0.0004	0.9759	0.2108	0.0135	0.0031
Apogonidae	*Apogon albimaculosus*	0.2589	0.0709	0.0022	0.0006	0.0528	0.0238	0.0005	0.0003	0.7837	0.2409	0.0064	0.0020
	Apogon aureus	0.0020	0.0020	< 0.0001	< 0.0001	—	—	—	—	0.0071	0.0071	< 0.0001	< 0.0001
	Apogon brevicaudata	0.1338	0.0622	0.0028	0.0016	0.1860	0.0865	0.0039	0.0022	—	—	—	—
	Apogon cavitiensis	0.0195	0.0187	0.0001	0.0001	0.0259	0.0259	0.0001	0.0001	0.0029	0.0029	< 0.0001	< 0.0001
	Apogon ellioti	35.8712	2.1711	0.3397	0.0176	27.7873	2.3891	0.2765	0.0195	56.4621	4.4241	0.5008	0.0358
	Apogon fasciatus	25.8047	2.2381	0.2328	0.0223	17.3082	2.2415	0.1707	0.0253	47.4467	5.2397	0.3912	0.0444
	Apogon melanopus	0.1974	0.0738	0.0038	0.0015	0.2746	0.1024	0.0053	0.0021	—	—	—	—
	Apogon nigripinnis	0.1313	0.0430	0.0014	0.0005	0.0333	0.0333	0.0004	0.0004	0.3820	0.1258	0.0040	0.0014
	Apogon nigrocincta	0.1019	0.1019	0.0003	0.0003	0.1418	0.1418	0.0004	0.0004	—	—	—	—
	Apogon notatus	0.0200	0.0178	0.0001	0.0001	0.0247	0.0247	0.0001	0.0001	0.0081	0.0061	0.0001	0.0001
	Apogon poecilopterus	78.1313	5.3186	0.9869	0.0671	83.0919	7.2798	0.9827	0.0911	65.4960	3.3544	0.9977	0.0533
	Apogon septemstriatus	0.9773	0.2083	0.0043	0.0009	0.0660	0.0457	0.0003	0.0002	3.3095	0.7084	0.0146	0.0032
	Apogon sp.	0.0133	0.0133	< 0.0001	< 0.0001	0.0185	0.0185	< 0.0001	< 0.0001	—	—	—	—
	Apogon sp. 2	0.0923	0.0541	0.0004	0.0002	0.1172	0.0750	0.0005	0.0003	0.0283	0.0164	0.0002	0.0001
	Pseudamia amblyuroptera	0.0622	0.0267	0.0005	0.0002	0.0565	0.0356	0.0005	0.0003	0.0767	0.0271	0.0006	0.0002
	Siphamia argyrogaster	0.1827	0.0735	0.0008	0.0003	0.2492	0.1021	0.0011	0.0004	0.0124	0.0124	0.0001	0.0001
	Siphamia fuscolineata	0.0479	0.0350	< 0.0001	< 0.0001	0.0419	0.0419	< 0.0001	< 0.0001	0.0632	0.0632	< 0.0001	< 0.0001
	Siphamia guttulatus	0.0429	0.0325	< 0.0001	< 0.0001	0.0009	0.0009	< 0.0001	< 0.0001	0.1504	0.1157	0.0002	0.0001
	Siphamia majimai	0.6929	0.1293	0.0005	0.0001	0.4367	0.1320	0.0004	0.0001	1.3486	0.3087	0.0007	0.0002
	Siphamia roseigaster	0.0616	0.0387	0.0001	0.0001	0.0857	0.0538	0.0002	0.0001	—	—	—	—
	unidentified Apogonidae	0.0243	0.0142	< 0.0001	< 0.0001	0.0321	0.0197	0.0001	< 0.0001	0.0044	0.0044	< 0.0001	< 0.0001
Ariidae	*Arius argyropleuron*	0.0259	0.0183	0.0016	0.0012	0.0361	0.0255	0.0023	0.0017	—	—	—	—
	Arius nella	0.0089	0.0089	0.0005	0.0005	—	—	—	—	0.0316	0.0316	0.0017	0.0017
	Netuma thalassinus	3.2662	0.5178	0.3256	0.0469	3.8925	0.7117	0.3574	0.0633	1.6932	0.3120	0.2458	0.0429

Table 6.2.2 The catch rate of teleost species overall and individually from the research surveys and the scientific observer.

		Overall				Research survey				Scientific observer			
		$n\ h^{-1}$		$kg\ h^{-1}$		$n\ h^{-1}$		$kg\ h^{-1}$		$n\ h^{-1}$		$kg\ h^{-1}$	
Family	**Species**	**mean**	**se**	**mean**	**se**	**mean**	**se**	**mean**	**se**	**mean**	**se**	**mean**	**se**
Ariommatidae	*Ariomma indica*	0.0027	0.0027	0.0001	0.0001	0.0037	0.0037	0.0001	0.0001	—	—	—	—
Balistidae	*Abalistes stellaris*	0.7284	0.1638	0.1852	0.0422	0.8996	0.2243	0.2105	0.0551	0.2904	0.0954	0.1202	0.0516
Bathysauridae	*Saurida longimanus*	1.4840	0.3756	0.0186	0.0048	1.9849	0.5202	0.0250	0.0066	0.2019	0.0744	0.0023	0.0009
	Saurida micropectoralis	39.1310	2.2174	4.5506	0.2453	34.3262	2.7015	3.3790	0.2492	51.3696	3.6881	7.5348	0.5446
	Saurida sp. 2	203.5393	10.4220	8.6136	0.4596	168.4328	10.1951	6.6760	0.4171	292.9616	25.3423	13.5492	1.1724
Batrachoididae	*Batrachomoeus trispinosus*	0.0037	0.0027	0.0005	0.0004	—	—	—	—	0.0132	0.0095	0.0017	0.0013
Blenniidae	unidentified Blenniidae	0.0008	0.0008	< 0.0001	< 0.0001	—	—	—	—	0.0028	0.0028	0.0000	0.0000
Bothidae	*Arnoglossus waitei*	1.9797	0.3303	0.0137	0.0026	1.4354	0.4400	0.0106	0.0035	3.3725	0.3198	0.0218	0.0028
	Engyprosopon grandisquamum	0.4563	0.1180	0.0052	0.0015	0.5985	0.1626	0.0068	0.0021	0.0923	0.0498	0.0011	0.0006
	Engyprosopon maldivensis	0.0509	0.0384	0.0010	0.0007	0.0708	0.0534	0.0013	0.0010	—	—	—	—
	Grammatobothus polyophthalmus	7.2573	0.7411	0.1572	0.0162	5.2595	0.8752	0.1164	0.0191	12.3460	1.3338	0.2612	0.0296
	Laeops parviceps	0.0267	0.0193	0.0001	0.0001	0.0371	0.0269	0.0002	0.0002	—	—	—	—
	Pseudorhombus argus	0.9172	0.2302	0.0434	0.0115	1.2732	0.3189	0.0602	0.0159	0.0061	0.0061	0.0002	0.0002
	Pseudorhombus arsius	0.9474	0.1876	0.0733	0.0143	1.1940	0.2569	0.0920	0.0196	0.3163	0.1053	0.0253	0.0088
	Pseudorhombus diplospilus	2.2811	0.2609	0.2298	0.0278	1.1951	0.2016	0.0990	0.0177	5.0605	0.7397	0.5647	0.0840
	Pseudorhombus dupliciocellatus	0.0338	0.0286	0.0096	0.0090	—	—	—	—	0.1203	0.1018	0.0340	0.0321
	Pseudorhombus elevatus	15.5987	1.3294	0.2893	0.0234	7.8064	1.2906	0.1511	0.0237	35.4472	2.9792	0.6413	0.0494
	Pseudorhombus jenynsii	0.2758	0.0910	0.0146	0.0050	0.3836	0.1263	0.0203	0.0070	—	—	—	—
	Pseudorhombus spinosus	2.1521	0.3114	0.1036	0.0141	2.1077	0.4108	0.0976	0.0177	2.2658	0.3524	0.1192	0.0214
	unidentified Bothidae	0.0368	0.0261	0.0003	0.0002	0.0472	0.0361	0.0003	0.0003	0.0101	0.0101	< 0.0001	< 0.000
Bregmacerotidae	*Bregmaceros mcclellandi*	2.2443	0.4597	0.0084	0.0015	2.4619	0.6271	0.0087	0.0021	1.6872	0.3178	0.0076	0.0014
	unidentified Bregmacerotidae	6.0416	0.8286	0.0086	0.0010	6.9917	1.1321	0.0097	0.0013	3.6214	0.5394	0.0059	0.0009
Caesionidae	*Caesio caerulaurea*	0.0080	0.0080	0.0005	0.0005	0.0111	0.0111	0.0007	0.0007	—	—	—	—
	Caesio teres	0.0033	0.0033	< 0.0001	< 0.0001	0.0046	0.0046	< 0.0001	< 0.0001	—	—	—	—
	Lutjanus carponotatus	0.0966	0.0385	0.0137	0.0058	0.1331	0.0534	0.0189	0.0080	0.0034	0.0034	0.0002	0.0002
	Pterocaesio digramma	0.0415	0.0198	0.0005	0.0002	0.0284	0.0249	0.0003	0.0003	0.0751	0.0300	0.0011	0.0005
Callionymidae	*Callionymus goodladi*	10.8835	1.1407	0.0940	0.0092	5.6813	0.8860	0.0581	0.0081	24.1342	3.1876	0.1856	0.0244
	Callionymus grossi	3.2011	0.4689	0.0763	0.0115	4.1761	0.6407	0.1028	0.0159	0.7058	0.2387	0.0083	0.0024
	Callionymus japonicus	3.4542	0.5491	0.0678	0.0104	2.0144	0.6235	0.0306	0.0096	7.1390	1.0905	0.1631	0.0270
	Callionymus meridionalis	1.3222	0.2947	0.0206	0.0046	1.8388	0.4077	0.0286	0.0064	—	—	—	—
	Dactylopus dactylopus	0.9232	0.1667	0.0260	0.0042	0.7326	0.1995	0.0149	0.0034	1.4108	0.3004	0.0545	0.0120
	Synchiropus rameus	0.0090	0.0069	0.0003	0.0002	—	—	—	—	0.0321	0.0245	0.0010	0.0007

Table 6.2.2 The catch rate of teleost species overall and individually from the research surveys and the scientific observer.

		Overall				Research survey				Scientific observer			
		$n\ h^{-1}$		$kg\ h^{-1}$		$n\ h^{-1}$		$kg\ h^{-1}$		$n\ h^{-1}$		$kg\ h^{-1}$	
Family	**Species**	**mean**	**se**	**mean**	**se**	**mean**	**se**	**mean**	**se**	**mean**	**se**	**mean**	**se**
Carangidae	*Alectis ciliaris*	0.0027	0.0027	0.0000	0.0000	0.0037	0.0037	0.0001	0.0001	—	—	—	—
	Alectis indicus	0.3185	0.1086	0.0199	0.0097	0.3362	0.1300	0.0226	0.0129	0.2732	0.1973	0.0132	0.0110
	Alepes sp.	1.2780	0.1764	0.1402	0.0199	1.4109	0.2318	0.1516	0.0260	0.9394	0.2064	0.1111	0.0238
	Atule mate	0.5525	0.2032	0.0229	0.0061	0.6711	0.2786	0.0251	0.0075	0.2490	0.1211	0.0173	0.0099
	Carangidae	0.0065	0.0049	0.0000	0.0000	0.0090	0.0068	0.0001	0.0000	—	—	—	—
	Carangoides caeruleopinnatus	4.6833	0.4253	0.3335	0.0393	4.2877	0.4667	0.2978	0.0451	5.6909	0.9273	0.4245	0.0787
	Carangoides chrysophrys	1.0320	0.2208	0.0796	0.0161	1.1676	0.2991	0.0931	0.0219	0.6850	0.1767	0.0449	0.0121
	Carangoides fulvoguttatus	0.0198	0.0143	0.0035	0.0029	0.0275	0.0199	0.0049	0.0040	—	—	—	—
	Carangoides gymnostethus	0.0207	0.0131	0.0013	0.0008	0.0288	0.0182	0.0018	0.0011	—	—	—	—
	Carangoides hedlandensis	0.6610	0.1153	0.0403	0.0078	0.8617	0.1576	0.0536	0.0107	0.1471	0.0639	0.0065	0.0029
	Carangoides humerosus	7.6258	0.6002	0.6521	0.0613	7.9715	0.7700	0.6397	0.0723	6.7454	0.8278	0.6837	0.1159
	Carangoides malabaricus	9.3630	2.3424	0.3650	0.0799	8.3880	3.1117	0.2782	0.0989	11.8583	2.4700	0.5872	0.1288
	Carangoides talamparoides	9.0322	1.0704	0.3925	0.0421	7.9478	1.3771	0.3610	0.0528	11.8076	1.4341	0.4730	0.0643
	Caranx bucculentus	16.7575	1.2355	1.8858	0.1474	20.4872	1.5895	2.3576	0.1931	7.2125	1.4841	0.6784	0.1470
	Caranx kleinii	0.5379	0.4400	0.0185	0.0145	0.7389	0.6117	0.0253	0.0202	0.0234	0.0234	0.0009	0.0009
	Decapterus macrosoma	0.0702	0.0319	0.0066	0.0030	0.0072	0.0072	0.0007	0.0007	0.2314	0.1115	0.0217	0.0104
	Decapterus russelli	0.9011	0.1754	0.0873	0.0172	0.6469	0.1712	0.0659	0.0188	1.5514	0.4425	0.1420	0.0378
	Gnathanodon speciosus	0.2026	0.0648	0.0217	0.0060	0.2741	0.0897	0.0271	0.0080	0.0196	0.0152	0.0079	0.0062
	Megalaspis cordyla	0.2003	0.0586	0.0143	0.0049	0.1746	0.0633	0.0151	0.0066	0.2659	0.1313	0.0121	0.0051
	Pantolabus radiatus	0.2967	0.1078	0.0174	0.0061	0.3837	0.1483	0.0221	0.0083	0.0743	0.0538	0.0056	0.0039
	Parastromateus niger	0.6681	0.1178	0.1611	0.0374	0.6228	0.1501	0.1578	0.0500	0.7839	0.1685	0.1695	0.0370
	Scomberoides commersonnianus	0.0052	0.0052	0.0049	0.0049	0.0072	0.0072	0.0069	0.0069	—	—	—	—
	Scomberoides tala	0.0475	0.0233	0.0041	0.0020	0.0660	0.0324	0.0057	0.0027	—	—	—	—
	Scomberoides tol	0.1659	0.1099	0.0139	0.0103	0.1990	0.1516	0.0176	0.0143	0.0812	0.0522	0.0045	0.0030
	Selar boops	1.8585	0.2538	0.1409	0.0207	1.6848	0.3154	0.1216	0.0260	2.3029	0.4050	0.1903	0.0314
	Selar crumenophthalmus	1.2461	0.2238	0.1001	0.0181	0.6866	0.1886	0.0613	0.0173	2.6780	0.6241	0.1992	0.0462
	Selaroides leptolepis	48.3267	3.9631	1.9299	0.1730	62.3438	5.3694	2.4587	0.2355	12.6227	1.5102	0.5829	0.0715
	Seriolina nigrofasciata	0.3657	0.0878	0.0934	0.0227	0.2000	0.0845	0.0529	0.0205	0.7896	0.2233	0.1972	0.0610
	Ulua aurochs	0.7001	0.1319	0.0532	0.0114	0.6379	0.1666	0.0546	0.0152	0.8594	0.1967	0.0496	0.0119
	Uraspis uraspis	0.0676	0.0265	0.0073	0.0028	0.0146	0.0098	0.0022	0.0015	0.2032	0.0905	0.0203	0.0093
Carapidae	*Onuxodon margaritiferae*	0.0331	0.0331	0.0001	0.0001	0.0460	0.0460	0.0001	0.0001	—	—	—	—
Centriscidae	*Centriscus scutatus*	5.0703	0.5761	0.0091	0.0012	2.8501	0.4893	0.0059	0.0011	10.7523	1.5596	0.0175	0.0031

Table 6.2.2 The catch rate of teleost species overall and individually from the research surveys and the scientific observer.

		Overall				Research survey				Scientific observer			
		n h^{-1}		kg h^{-1}		n h^{-1}		kg h^{-1}		n h^{-1}		kg h^{-1}	
Family	**Species**	**mean**	**se**	**mean**	**se**	**mean**	**se**	**mean**	**se**	**mean**	**se**	**mean**	**se**
Centrolophidae	*Psenopsis humerosa*	0.5474	0.1727	0.0467	0.0155	0.0899	0.0731	0.0066	0.0057	1.7181	0.5788	0.1493	0.0527
	Psammoperca waigiensis	0.0053	0.0053	0.0006	0.0006	0.0074	0.0074	0.0009	0.0009	—	—	—	—
Cepolidae	*Acanthocepola abbreviata*	0.2973	0.0557	0.0081	0.0018	0.2373	0.0678	0.0067	0.0023	0.4509	0.0953	0.0115	0.0024
Chaetodontidae	*Chaetodontoplus duboulayi*	0.0887	0.0532	0.0113	0.0075	0.1234	0.0740	0.0157	0.0104	—	—	—	—
	Chelmon marginalis	0.1134	0.0847	0.0101	0.0091	0.1578	0.1177	0.0140	0.0127	—	—	—	—
	Chelmon muelleri	0.0841	0.0529	0.0027	0.0017	0.1169	0.0736	0.0038	0.0024	—	—	—	—
	Chelmonops truncatus	0.1475	0.1135	0.0010	0.0008	—	—	—	—	0.5249	0.4035	0.0037	0.0027
	Coradion chrysozonus	0.1116	0.0430	0.0022	0.0009	0.1552	0.0598	0.0030	0.0012	—	—	—	—
	Parachaetodon ocellatus	0.3055	0.0737	0.0167	0.0042	0.3576	0.0975	0.0197	0.0055	0.1722	0.0811	0.0092	0.0046
	Pomacanthus sexstriatus	0.0276	0.0276	0.0294	0.0294	0.0383	0.0383	0.0408	0.0408	—	—	—	—
Champsodontidae	*Champsodontidae*	0.8145	0.1673	0.0016	0.0004	0.9006	0.2215	0.0019	0.0005	0.5942	0.1822	0.0010	0.0003
Chirocentridae	*Chirocentrus dorab*	0.2423	0.0580	0.0443	0.0120	0.1120	0.0503	0.0209	0.0122	0.5760	0.1593	0.1042	0.0287
Citharidae	*Brachypleura novaezeelandiae*	2.0552	0.4365	0.0282	0.0054	1.2564	0.5633	0.0162	0.0067	4.0997	0.5566	0.0587	0.0081
Clupeidae	*Amblygaster sirm*	0.1111	0.0355	0.0083	0.0029	0.0807	0.0351	0.0050	0.0026	0.1888	0.0885	0.0166	0.0081
	Anodontostoma chacunda	7.0374	2.0350	0.4056	0.1201	8.3082	2.7882	0.4809	0.1651	3.7853	1.2282	0.2130	0.0646
	Clupeidae	1.3528	0.9492	0.0018	0.0013	1.8786	1.3197	0.0025	0.0017	0.0071	0.0071	< 0.0001	< 0.0001
	Dussumieria elopsoides	1.8454	0.3927	0.0232	0.0053	2.3383	0.5407	0.0241	0.0069	0.5899	0.1831	0.0211	0.0066
	Escualosa thoracata	0.0859	0.0499	0.0002	0.0001	0.1194	0.0694	0.0003	0.0002	—	—	—	—
	Herklotsichthys koningsbergeri	0.1600	0.0595	0.0050	0.0018	0.2226	0.0826	0.0070	0.0026	—	—	—	—
	Herklotsichthys lippa	9.9520	2.0274	0.3172	0.0663	8.7249	2.4528	0.2334	0.0734	13.0925	3.5583	0.5318	0.1422
	Pellona ditchela	31.6542	5.3387	0.9258	0.1296	36.2868	7.2034	1.0597	0.1720	19.7983	4.5303	0.5834	0.1356
	Sardinella gibbosa	31.8945	5.9418	0.5181	0.0726	41.0506	8.2009	0.6337	0.0986	8.4621	1.8351	0.2224	0.0504
Congridae	*Ariosoma anago*	0.0009	0.0009	< 0.0001	< 0.0001	—	—	—	—	0.0031	0.0031	0.0001	0.0001
	Conger cinereus	0.0029	0.0029	0.0001	0.0001	—	—	—	—	0.0102	0.0102	0.0004	0.0004
	Congridae	0.0538	0.0162	0.0009	0.0003	0.0111	0.0083	< 0.0001	< 0.0001	0.1632	0.0528	0.0030	0.0010
	Gnathophis sp.	0.0075	0.0052	< 0.0001	< 0.0001	0.0098	0.0072	< 0.0001	< 0.0001	0.0014	0.0014	< 0.0001	< 0.0001
	Lumiconger arafura	0.0204	0.0107	0.0003	0.0001	0.0111	0.0111	0.0001	0.0001	0.0441	0.0256	0.0007	0.0005
	Uroconger lepturus	0.0143	0.0143	0.0008	0.0008	0.0199	0.0199	0.0010	0.0010	—	—	—	—
Congrogadidae	*Congrogadus amplimaculatus*	0.0340	0.0168	0.0002	0.0001	—	—	—	—	0.1210	0.0594	0.0007	0.0003
Cynoglossidae	*Cynoglossus arel*	0.0142	0.0118	0.0002	0.0002	0.0198	0.0164	0.0003	0.0002	—	—	—	—
	Cynoglossus bilineatus	0.0039	0.0039	0.0001	0.0001	—	—	—	—	0.0140	0.0140	0.0002	0.0002
	Cynoglossus kopsii	0.0688	0.0463	0.0009	0.0006	0.0957	0.0644	0.0012	0.0008	—	—	—	—

Table 6.2.2 The catch rate of teleost species overall and individually from the research surveys and the scientific observer.

		Overall				Research survey				Scientific observer			
		$n\ h^{-1}$		$kg\ h^{-1}$		$n\ h^{-1}$		$kg\ h^{-1}$		$n\ h^{-1}$		$kg\ h^{-1}$	
Family	**Species**	**mean**	**se**	**mean**	**se**	**mean**	**se**	**mean**	**se**	**mean**	**se**	**mean**	**se**
	Cynoglossus macrophthalmus	0.0483	0.0298	0.0004	0.0002	—	—	—	—	0.1720	0.1057	0.0014	0.0008
	Cynoglossus maculipinnis	0.0033	0.0033	0.0001	0.0001	0.0046	0.0046	0.0002	0.0002	—	—	—	—
	Paraplagusia bilineata	0.0125	0.0074	0.0010	0.0006	0.0130	0.0093	0.0013	0.0009	0.0112	0.0112	0.0002	0.0002
	Paraplagusia longirostris	0.6587	0.1766	0.0211	0.0064	0.6723	0.2396	0.0261	0.0089	0.6239	0.1385	0.0081	0.0020
	unidentified Cynoglossidae	0.5533	0.1134	0.0074	0.0016	0.1042	0.0473	0.0012	0.0005	1.7028	0.3741	0.0235	0.0053
Dactylopteridae	*Dactyloptena macracanthus*	0.0052	0.0036	0.0001	0.0000	0.0072	0.0051	0.0001	0.0001	—	—	—	—
	Dactyloptena papilio	8.8993	1.2244	0.1277	0.0153	3.4360	0.5875	0.0870	0.0162	22.8153	3.9245	0.2315	0.0343
Diodontidae	*Cyclichthys hardenbergi*	0.0480	0.0194	0.0266	0.0143	0.0668	0.0270	0.0370	0.0199	—	—	—	—
	Lophodiodon calori	0.0167	0.0167	0.0002	0.0002	0.0232	0.0232	0.0003	0.0003	—	—	—	—
	Tragulichthys jaculiferus	0.6779	0.1086	0.0965	0.0180	0.4916	0.1139	0.0677	0.0189	1.1544	0.2512	0.1704	0.0418
	unidentified Diodontidae	0.0468	0.0327	0.0001	0.0001	0.0651	0.0455	0.0002	0.0001	—	—	—	—
Drepanidae	*Drepane punctata*	0.2665	0.1253	0.0152	0.0083	0.3061	0.1708	0.0163	0.0112	0.1650	0.0882	0.0121	0.0062
Echeneidae	*Echeneis naucrates*	0.1851	0.0409	0.0768	0.0186	0.1830	0.0470	0.0742	0.0216	0.1904	0.0819	0.0835	0.0364
Engraulididae	*Setipinna tenuifilis*	5.8583	1.8855	0.0958	0.0336	8.1474	2.6163	0.1332	0.0467	—	—	—	—
	Thryssa hamiltonii	0.2649	0.0721	0.0130	0.0037	0.3642	0.0998	0.0177	0.0051	0.0107	0.0107	0.0009	0.0009
	Thryssa marasriae	0.2104	0.1616	0.0009	0.0006	0.2926	0.2247	0.0013	0.0009	—	—	—	—
	Thryssa setirostris	3.2714	0.5155	0.1000	0.0142	4.0277	0.7020	0.1103	0.0183	1.3359	0.3414	0.0738	0.0184
	unidentified Engraulididae	11.9851	1.7813	0.0570	0.0090	15.8154	2.4525	0.0747	0.0123	2.1823	0.4329	0.0117	0.0050
Ephippidae	*Platax batavianus*	0.0027	0.0027	0.0039	0.0039	0.0037	0.0037	0.0054	0.0054	—	—	—	—
	Platax teira	0.1031	0.0485	0.0260	0.0215	0.1358	0.0670	0.0359	0.0300	0.0194	0.0180	0.0006	0.0005
	Zabidius novaemaculatus	0.4581	0.1200	0.0745	0.0248	0.5837	0.1654	0.1003	0.0345	0.1368	0.0532	0.0085	0.0038
Exocoetidae	unidentified Exocoetidae	0.0509	0.0241	0.0009	0.0004	0.0615	0.0326	0.0009	0.0004	0.0239	0.0197	0.0010	0.0010
Fistulariidae	*Fistularia commersonii*	0.0014	0.0014	0.0000	0.0000	—	—	—	—	0.0049	0.0049	0.0000	0.0000
	Fistularia petimba	14.2874	1.4769	0.1972	0.0197	4.2007	0.5254	0.0959	0.0158	39.9800	4.6244	0.4554	0.0533
Gerreidae	*Gerres baconensis*	0.5262	0.1859	0.0237	0.0087	0.7318	0.2580	0.0329	0.0121	—	—	—	—
	Gerres macracanthus	14.8580	2.1751	0.5038	0.0587	14.6408	2.8976	0.4761	0.0747	15.4138	2.2327	0.5748	0.0845
	Gerres macrosoma	8.3176	1.7199	0.4007	0.0688	10.9701	2.3762	0.5205	0.0948	1.5293	0.4533	0.0942	0.0246
	Gerres subfasciatus	1.4008	0.4520	0.0571	0.0205	1.9256	0.6273	0.0783	0.0285	0.0578	0.0270	0.0026	0.0013
	Pentaprion longimanus	156.4437	11.7545	2.8727	0.2347	133.1393	12.4277	2.3359	0.2366	215.8039	26.7620	4.2401	0.5647
Glaucosomatidae	*Glaucosoma magnificum*	0.1598	0.0786	0.0041	0.0019	0.2222	0.1093	0.0058	0.0027	—	—	—	—
Gobiidae	*Acentrogobius caninus*	0.0220	0.0165	0.0006	0.0004	0.0222	0.0222	0.0006	0.0006	0.0216	0.0153	0.0007	0.0005
	Oxyurichthys papuanus	0.0785	0.0444	0.0014	0.0007	0.1091	0.0617	0.0019	0.0010	—	—	—	—

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		Overall				Research survey				Scientific observer			
		$n\ h^{-1}$		$kg\ h^{-1}$		$n\ h^{-1}$		$kg\ h^{-1}$		$n\ h^{-1}$		$kg\ h^{-1}$	
Family	**Species**	**mean**	**se**	**mean**	**se**	**mean**	**se**	**mean**	**se**	**mean**	**se**	**mean**	**se**
	Oxyurichthys sp.	0.0495	0.0169	0.0009	0.0003	0.0102	0.0056	0.0002	0.0001	0.1501	0.0578	0.0029	0.0012
	Parachaeturichthys polynema	0.0646	0.0219	0.0010	0.0004	0.0611	0.0286	0.0010	0.0005	0.0734	0.0269	0.0010	0.0004
	Siganus canaliculatus	2.8218	0.4126	0.1691	0.0317	3.8267	0.5654	0.2276	0.0435	0.2500	0.1425	0.0192	0.0119
	Siganus fuscescens	0.1048	0.0838	0.0194	0.0168	0.1411	0.1165	0.0263	0.0233	0.0119	0.0119	0.0017	0.0017
	Trimma taylori	0.0960	0.0860	0.0039	0.0034	0.1335	0.1195	0.0055	0.0047	—	—	—	—
	unidentified Gobiidae	0.2407	0.0632	0.0024	0.0009	0.2570	0.0842	0.0030	0.0012	0.1988	0.0643	0.0007	0.0004
	Yongeichthys nebulosus	1.6633	0.2358	0.0377	0.0056	1.4950	0.3071	0.0346	0.0074	2.0940	0.2941	0.0458	0.0065
Haemulidae	*Diagramma pictum*	0.8144	0.1690	0.1934	0.0678	0.7203	0.2141	0.2486	0.0932	1.0539	0.2487	0.0527	0.0382
	Pomadasys argenteus	0.0258	0.0186	0.0009	0.0008	0.0359	0.0259	0.0012	0.0012	—	—	—	—
	Pomadasys kaakan	2.6954	0.6285	0.4192	0.0895	3.7486	0.8701	0.5830	0.1238	—	—	—	—
	Pomadasys maculatus	68.6278	22.4462	2.8283	0.8918	95.2034	31.1501	3.9182	1.2375	0.6145	0.2033	0.0389	0.0122
	Pomadasys trifasciatus	54.1316	10.4117	1.0789	0.2217	74.4014	14.3874	1.4874	0.3066	2.2562	0.6734	0.0334	0.0093
Harpadontidae	*Harpadon translucens*	1.0145	0.4210	0.0669	0.0255	1.4109	0.5847	0.0930	0.0355	—	—	—	—
Hemiramphidae	*Hyporhamphus affinis*	0.0103	0.0103	0.0002	0.0002	0.0143	0.0143	0.0003	0.0003	—	—	—	—
	unidentified Hemiramphidae	0.0461	0.0461	0.0004	0.0004	0.0641	0.0641	0.0005	0.0005	—	—	—	—
Holocentridae	*Myripristis botche*	0.0409	0.0409	0.0045	0.0045	0.0569	0.0569	0.0063	0.0063	—	—	—	—
	Myripristis hexagona	0.0495	0.0301	0.0049	0.0032	0.0689	0.0419	0.0068	0.0045	—	—	—	—
	Myripristis murdjan	0.0023	0.0023	0.0001	0.0001	—	—	—	—	0.0081	0.0081	0.0003	0.0003
	Sargocentron rubrum	0.2783	0.1436	0.0485	0.0255	0.3871	0.1995	0.0675	0.0354	—	—	—	—
Labridae	*Choerodon cephalotes*	2.1293	0.3892	0.1823	0.0461	2.9381	0.5372	0.2520	0.0639	0.0595	0.0343	0.0039	0.0024
	Choerodon monostigma	1.5071	0.3338	0.0694	0.0139	1.6904	0.4526	0.0785	0.0189	1.0382	0.2632	0.0461	0.0110
	Choerodon schoenleinii	0.0027	0.0027	0.0002	0.0002	0.0037	0.0037	0.0003	0.0003	—	—	—	—
	Choerodon sugillatum	0.8788	0.1720	0.0175	0.0033	1.0068	0.2300	0.0186	0.0042	0.5512	0.1668	0.0148	0.0043
	Xiphocheilus typus	0.2632	0.0802	0.0078	0.0026	0.2158	0.0980	0.0069	0.0033	0.3846	0.1365	0.0100	0.0037
Lactariidae	*Lactarius lactarius*	1.3895	0.4533	0.0699	0.0209	1.9324	0.6291	0.0972	0.0290	—	—	—	—
Leiognathidae	*Gazza minuta*	13.8178	2.1935	0.3797	0.0645	11.1281	2.6406	0.2843	0.0762	20.7011	3.8788	0.6238	0.1195
	Leiognathus aureus	0.0025	0.0025	0.0000	0.0000	—	—	—	—	0.0088	0.0088	0.0001	0.0001
	Leiognathus bindus	131.7172	30.4090	1.5294	0.3882	124.1280	35.0311	1.6098	0.5026	151.0482	60.7225	1.3246	0.5083
	Leiognathus decorus	12.4190	3.9784	0.1862	0.0450	17.2550	5.5203	0.2587	0.0624	0.0424	0.0295	0.0008	0.0007
	Leiognathus elongatus	0.0030	0.0030	0.0000	0.0000	—	—	—	—	0.0108	0.0108	0.0001	0.0001
	Leiognathus equulus	26.7159	7.9095	1.1212	0.3100	33.8563	10.9386	1.3478	0.4260	8.4418	2.6552	0.5410	0.1656
	Leiognathus fasciatus	3.3864	2.1293	0.1685	0.1136	2.9141	2.7364	0.1584	0.1502	4.5950	2.9044	0.1943	0.1253

Table 6.2.2 The catch rate of teleost species overall and individually from the research surveys and the scientific observer.

		Overall				Research survey				Scientific observer			
		n h^{-1}		kg h^{-1}		n h^{-1}		kg h^{-1}		n h^{-1}		kg h^{-1}	
Family	**Species**	**mean**	**se**	**mean**	**se**	**mean**	**se**	**mean**	**se**	**mean**	**se**	**mean**	**se**
	Leiognathus leuciscus	33.2428	4.4346	0.6463	0.0910	40.1399	6.0102	0.7593	0.1232	15.5917	3.2613	0.3572	0.0713
	Leiognathus moretoniensis	161.8175	13.2536	1.4101	0.1237	189.0648	17.6704	1.6008	0.1638	92.4140	12.4194	0.9244	0.1305
	Leiognathus ruconius	10.6625	6.1713	0.0777	0.0431	14.3844	8.5771	0.1060	0.0600	1.1372	0.5352	0.0053	0.0024
	Leiognathus smithursti	0.0884	0.0484	0.0057	0.0033	0.0514	0.0375	0.0023	0.0016	0.1831	0.1431	0.0144	0.0111
	Leiognathus sp.	33.7714	6.1477	0.6168	0.1068	41.7006	8.4858	0.6906	0.1450	13.5745	2.4328	0.4288	0.0844
	Leiognathus splendens	189.3524	51.4674	3.6009	0.9610	229.9250	71.1330	4.3558	1.3288	85.5175	19.0566	1.6687	0.3414
	Secutor insidiator	28.6233	6.2480	0.4141	0.0938	17.5393	4.5372	0.2400	0.0653	56.9900	18.8592	0.8597	0.2872
	unidentified Leiognathidae	0.1466	0.0870	0.0013	0.0008	0.2039	0.1210	0.0018	0.0011	—	—	—	—
Lethrinidae	*Lethrinus genivittatus*	7.3448	1.8024	0.2921	0.0541	9.9940	2.4957	0.3821	0.0730	0.5649	0.2811	0.0617	0.0434
	Lethrinus laticaudis	2.2081	0.7287	0.5167	0.1597	3.0616	1.0113	0.7168	0.2216	0.0236	0.0236	0.0044	0.0044
	Lethrinus lentjan	5.7675	1.7495	1.0848	0.3385	7.9208	2.4271	1.4921	0.4697	0.2567	0.1074	0.0424	0.0190
Lutjanidae	*Lutjanus argentimaculatus*	0.0067	0.0052	0.0338	0.0300	0.0081	0.0072	0.0452	0.0417	0.0032	0.0023	0.0047	0.0034
	Lutjanus erythropterus	0.0117	0.0099	0.0098	0.0086	0.0162	0.0137	0.0137	0.0120	—	—	—	—
	Lutjanus johnii	0.0565	0.0433	0.1625	0.1282	0.0778	0.0603	0.2211	0.1781	0.0019	0.0019	0.0125	0.0125
	Lutjanus lutjanus	1.7432	0.5325	0.0660	0.0267	2.1910	0.7378	0.0864	0.0371	0.5971	0.1426	0.0137	0.0032
	Lutjanus malabaricus	1.9519	0.2239	0.4202	0.1037	1.6009	0.2709	0.5223	0.1432	2.8460	0.3872	0.1603	0.0430
	Lutjanus quinquelineatus	0.0021	0.0018	0.0001	0.0001	—	—	—	—	0.0077	0.0064	0.0005	0.0004
	Lutjanus russelli	1.0067	0.2134	0.1755	0.0370	1.3206	0.2942	0.2297	0.0509	0.2033	0.0777	0.0368	0.0154
	Lutjanus sebae	0.4211	0.1277	0.1203	0.0491	0.3236	0.1141	0.1362	0.0625	0.6704	0.3485	0.0794	0.0704
	Lutjanus vitta	4.0444	0.7735	0.3531	0.0846	5.0539	1.0620	0.4620	0.1169	1.4610	0.3895	0.0743	0.0288
	Symphorus nematophorus	0.0324	0.0280	0.0500	0.0357	0.0451	0.0389	0.0695	0.0496	—	—	—	—
Megalopidae	*Megalops cyprinoides*	0.0265	0.0144	0.0248	0.0112	—	—	—	—	0.0943	0.0512	0.0881	0.0398
Melanostomiidae	*Bathophilus nigerrimus*	0.0117	0.0117	< 0.0001	< 0.0001	—	—	—	—	0.0416	0.0416	0.0001	0.0001
	Eustomias multifilis	0.0243	0.0243	0.0007	0.0007	—	—	—	—	0.0866	0.0866	0.0026	0.0026
Menidae	*Mene maculata*	2.7839	1.5003	0.1121	0.0815	1.4955	0.4271	0.0276	0.0124	6.0812	5.2289	0.3284	0.2884
Microdesmidae	*Siganus argenteus*	0.0107	0.0107	< 0.0001	< 0.0001	0.0148	0.0148	0.0000	0.0000	—	—	—	—
Monacanthidae	*Aluterus monoceros*	0.0357	0.0191	0.0017	0.0009	—	—	—	—	0.1269	0.0676	0.0062	0.0031
	Anacanthus barbatus	0.1278	0.0396	0.0023	0.0009	0.0210	0.0110	0.0003	0.0002	0.4012	0.1365	0.0076	0.0030
	Monacanthus chinensis	0.1245	0.0597	0.0015	0.0007	0.1731	0.0829	0.0021	0.0010	—	—	—	—
	Paramonacanthus choirocephalus	8.7670	1.4990	0.0923	0.0137	10.5668	2.0535	0.1127	0.0186	4.1608	0.8491	0.0403	0.0088
	Paramonacanthus filicauda	17.3775	1.9107	0.2382	0.0240	4.7740	0.7938	0.1216	0.0234	49.6329	5.9480	0.5366	0.0559
	Pseudomonacanthus elongatus	0.0597	0.0382	0.0019	0.0012	0.0830	0.0531	0.0026	0.0016	—	—	—	—

Table 6.2.2 The catch rate of teleost species overall and individually from the research surveys and the scientific observer.

		Overall				**Research survey**				**Scientific observer**			
		n h^{-1}		**kg h^{-1}**		**n h^{-1}**		**kg h^{-1}**		**n h^{-1}**		**kg h^{-1}**	
Family	**Species**	**mean**	**se**	**mean**	**se**	**mean**	**se**	**mean**	**se**	**mean**	**se**	**mean**	**se**
	Pseudomonacanthus peroni	0.2438	0.0695	0.0183	0.0065	0.2199	0.0814	0.0163	0.0076	0.3048	0.1335	0.0235	0.0123
	unidentified Monacanthidae	0.0193	0.0193	0.0057	0.0057	0.0268	0.0268	0.0079	0.0079	—	—	—	—
Mugilidae	unidentified Mugilidae	0.1776	0.0820	0.0114	0.0053	—	—	—	—	0.6323	0.2901	0.0404	0.0187
	Valamugil cunnesius	0.2720	0.0873	0.0196	0.0066	0.3176	0.1175	0.0230	0.0089	0.1554	0.0778	0.0110	0.0054
Mullidae	*Parupeneus heptacanthus*	0.5876	0.2459	0.0406	0.0137	0.7459	0.3402	0.0481	0.0185	0.1827	0.0829	0.0214	0.0119
	Upeneus asymmetricus	37.3751	7.8963	1.2182	0.2601	31.7443	8.3570	0.9674	0.2579	51.7854	18.2333	1.8602	0.6485
	Upeneus bensasi	0.0107	0.0107	0.0002	0.0002	0.0148	0.0148	0.0003	0.0003	—	—	—	—
	Upeneus luzonius	5.2934	0.9534	0.3000	0.0567	7.3606	1.3156	0.4172	0.0783	0.0031	0.0031	0.0001	0.0001
	Upeneus moluccensis	0.1716	0.0703	0.0028	0.0010	0.2387	0.0976	0.0039	0.0014	—	—	—	—
	Upeneus sp. 1	9.6306	1.4581	0.2116	0.0376	9.4570	1.8856	0.2336	0.0507	10.0750	1.9161	0.1553	0.0329
	Upeneus sulphureus	101.4979	12.3856	2.9826	0.3798	97.7640	14.6413	2.8169	0.4396	111.0089	23.2662	3.4047	0.7497
	Upeneus sundaicus	17.0069	1.7037	0.6589	0.0632	20.0857	2.2341	0.7934	0.0847	9.1274	1.9241	0.3148	0.0543
	Upeneus tragula	17.3288	4.4965	0.2656	0.0566	24.0590	6.2311	0.3689	0.0783	0.1045	0.0431	0.0013	0.0006
Muraenesocidae	*Muraenesox cinereus*	0.6648	0.0862	0.1063	0.0172	0.2450	0.0717	0.0528	0.0178	1.7390	0.2303	0.2438	0.0395
Muraenidae	*Gymnothorax reticularis*	0.0004	0.0004	0.0001	0.0001	—	—	—	—	0.0014	0.0014	0.0005	0.0005
	Gymnothorax sp.	0.0175	0.0175	0.0014	0.0014	0.0243	0.0243	0.0019	0.0019	—	—	—	—
	unidentified Muraenidae	0.0217	0.0132	0.0021	0.0015	0.0222	0.0166	0.0011	0.0010	0.0205	0.0205	0.0048	0.0048
Myctophidae	unidentified Myctophidae	0.3915	0.1775	0.0002	0.0001	0.5444	0.2467	0.0003	0.0001	—	—	—	—
Nemipteridae	*Nemipterus celebicus*	0.0406	0.0339	0.0011	0.0008	0.0565	0.0472	0.0015	0.0012	—	—	—	—
	Nemipterus furcosus	15.8858	2.1401	1.0512	0.1615	20.5716	2.9274	1.3038	0.2196	3.8937	0.9866	0.4048	0.1087
	Nemipterus hexodon	85.7157	6.1752	3.2490	0.2012	70.8560	7.8024	2.7184	0.2496	123.5660	8.7099	4.6005	0.3063
	Nemipterus marginatus	19.9400	4.7069	0.4413	0.1085	27.7314	6.5171	0.6137	0.1503	—	—	—	—
	Nemipterus nematopus	88.9022	8.8387	2.3725	0.2355	39.9668	6.2433	1.1089	0.1732	213.5491	25.1025	5.5913	0.6608
	Nemipterus peronii	29.7219	3.1027	1.2107	0.1169	35.5457	4.2489	1.3757	0.1589	14.8879	1.6197	0.7902	0.0853
	Pentapodus paradiseus	6.6774	1.3349	0.2589	0.0461	9.2551	1.8451	0.3583	0.0636	0.0804	0.0489	0.0044	0.0028
	Pentapodus porosus	0.0117	0.0117	0.0012	0.0012	—	—	—	—	0.0416	0.0416	0.0043	0.0043
	Scolopsis affinis	0.0029	0.0029	< 0.0001	< 0.0001	—	—	—	—	0.0103	0.0103	< 0.0001	< 0.0001
	Scolopsis monogramma	0.2015	0.0742	0.0256	0.0094	0.2802	0.1030	0.0356	0.0131	—	—	—	—
	Scolopsis taeniopterus	36.3905	3.4210	1.4097	0.1097	42.0785	4.5953	1.6724	0.1471	21.9022	2.9941	0.7404	0.0898
	Scolopsis vosmeri	0.0264	0.0177	0.0007	0.0006	0.0185	0.0185	0.0002	0.0002	0.0466	0.0414	0.0021	0.0020
	unidentified Nemipteridae	0.0055	0.0055	< 0.0001	< 0.0001	0.0077	0.0077	< 0.0001	< 0.0001	—	—	—	—
Nettastomatidae	*Nettastoma parviceps*	0.3037	0.0797	0.0029	0.0009	0.0681	0.0386	0.0007	0.0004	0.9064	0.2620	0.0084	0.0030

Table 6.2.2 The catch rate of teleost species overall and individually from the research surveys and the scientific observer.

		Overall				Research survey				Scientific observer			
		n h^{-1}		kg h^{-1}		n h^{-1}		kg h^{-1}		n h^{-1}		kg h^{-1}	
Family	**Species**	**mean**	**se**	**mean**	**se**	**mean**	**se**	**mean**	**se**	**mean**	**se**	**mean**	**se**
Ogcocephalidae	unidentified Ogcocephalidae	0.0164	0.0164	< 0.0001	< 0.0001	0.0228	0.0228	< 0.0001	< 0.0001	—	—	—	—
Ophichthidae	unidentified Ophichthidae	0.0350	0.0324	< 0.0001	< 0.0001	0.0486	0.0451	0.0001	< 0.0001	—	—	—	—
Ophidiidae	*Sirembo imberbis*	2.1765	0.2185	0.0556	0.0056	1.6417	0.2520	0.0360	0.0060	3.5389	0.4213	0.1054	0.0121
Opisthognathidae	*Opistognathus latitabundus*	0.0903	0.0329	0.0178	0.0092	0.0835	0.0427	0.0160	0.0123	0.1076	0.0423	0.0223	0.0088
Ostraciidae	*Ostracion nasus*	2.9402	0.4396	0.1254	0.0200	1.1600	0.2674	0.0503	0.0145	7.4961	1.3598	0.3176	0.0588
	Tetrosomus gibbosus	0.1779	0.1368	0.0065	0.0041	0.2474	0.1902	0.0090	0.0057	—	—	—	—
Pegasidae	*Eurypegasus draconis*	0.0004	0.0004	< 0.0001	< 0.0001	—	—	—	—	0.0015	0.0015	< 0.0001	< 0.0001
	Pegasus volitans	0.7667	0.4069	0.0032	0.0017	1.0663	0.5655	0.0045	0.0024	—	—	—	—
Pempherididae	*Leptobrama mulleri*	0.0240	0.0179	0.0004	0.0003	0.0333	0.0248	0.0005	0.0004	—	—	—	—
	Pempheris analis	0.0331	0.0241	0.0018	0.0013	0.0461	0.0335	0.0025	0.0019	—	—	—	—
Photichthyidae	*Pholidichthys leucotaenia*	0.0070	0.0070	< 0.0001	< 0.0001	—	—	—	—	0.0251	0.0251	0.0001	0.0001
Pinguipedidae	*Parapercis diplospilus*	0.0100	0.0079	< 0.0001	< 0.0001	0.0104	0.0104	0.0001	0.0001	0.0088	0.0088	0.0000	0.0000
	Parapercis nebulosa	0.5094	0.1156	0.0233	0.0056	0.7085	0.1600	0.0323	0.0077	—	—	—	—
	Parapercis xanthozona	0.0040	0.0040	< 0.0001	< 0.0001	0.0056	0.0056	< 0.0001	< 0.0001	—	—	—	—
Platycephalidae	*Cociella hutchinsi*	0.1046	0.0714	0.0036	0.0026	0.1430	0.0993	0.0050	0.0036	0.0063	0.0063	0.0002	0.0002
	Cymbacephalus nematophthalmus	0.0382	0.0145	0.0033	0.0014	0.0416	0.0170	0.0034	0.0016	0.0293	0.0280	0.0031	0.0030
	Elates ransonnetii	32.3669	3.6513	0.3545	0.0327	17.4403	1.5038	0.2056	0.0189	70.3873	12.0026	0.7338	0.1012
	Inegocia harrisii	0.0338	0.0244	0.0053	0.0052	0.0469	0.0339	0.0074	0.0072	—	—	—	—
	Inegocia japonica	14.4017	1.0582	0.4818	0.0345	16.4897	1.4388	0.5177	0.0465	9.0833	0.6924	0.3904	0.0302
	Onigocia macrolepis	0.0693	0.0322	0.0002	0.0001	0.0242	0.0182	0.0001	0.0001	0.1848	0.1046	0.0005	0.0003
	Onigocia spinosa	0.1153	0.0853	0.0003	0.0002	—	—	—	—	0.4105	0.3032	0.0010	0.0007
	Papilloculiceps bosschei	0.0040	0.0040	0.0003	0.0003	0.0056	0.0056	0.0005	0.0005	—	—	—	—
	Platycephalidae	0.0018	0.0018	< 0.0001	< 0.0001	—	—	—	—	0.0063	0.0063	< 0.0001	< 0.0001
Platycehpalidae	*Platycephalus endrachtensis*	0.2249	0.0920	0.0320	0.0117	0.3016	0.1277	0.0411	0.0162	0.0287	0.0141	0.0088	0.0045
	Platycephalus indicus	0.1563	0.0774	0.0153	0.0063	0.2173	0.1075	0.0213	0.0087	—	—	—	—
	Rogadius asper	4.8659	0.6491	0.0697	0.0113	1.3271	0.3465	0.0149	0.0037	13.8798	2.0003	0.2095	0.0373
	Sorsogona tuberculata	0.6203	0.2090	0.0083	0.0033	0.7600	0.2878	0.0108	0.0046	0.2629	0.1010	0.0018	0.0008
	Suggrundus macracanthus	18.8959	1.3368	0.4156	0.0302	14.1988	1.5553	0.3077	0.0354	30.8603	2.4243	0.6904	0.0537
	Suggrundus rodericensis	2.7372	0.2978	0.0610	0.0075	1.9562	0.3665	0.0411	0.0093	4.7267	0.4681	0.1116	0.0116
Pleuronectidae	*Samaris cristatus*	0.0063	0.0063	0.0001	0.0001	—	—	—	—	0.0226	0.0226	0.0003	0.0003
Plotosidae	*Euristhmus nudiceps*	16.8516	1.5401	0.7533	0.0664	3.7585	1.1978	0.1823	0.0533	50.2019	3.6428	2.2079	0.1521
	Plotosus lineatus	2.6404	1.5391	0.0475	0.0279	3.5114	2.1379	0.0632	0.0388	0.4115	0.2326	0.0073	0.0051

Table 6.2.2 The catch rate of teleost species overall and individually from the research surveys and the scientific observer.

		Overall				Research survey				Scientific observer			
		n h^{-1}		kg h^{-1}		n h^{-1}		kg h^{-1}		n h^{-1}		kg h^{-1}	
Family	**Species**	**mean**	**se**	**mean**	**se**	**mean**	**se**	**mean**	**se**	**mean**	**se**	**mean**	**se**
Polynemidae	*Polydactylus multiradiatus*	10.0783	2.4269	0.5283	0.1400	14.0026	3.3610	0.7335	0.1941	0.0350	0.0327	0.0029	0.0027
	Polydactylus nigripinnis	1.6425	0.6397	0.0746	0.0335	2.2842	0.8884	0.1038	0.0465	—	—	—	—
Pomacentridae	*Pristotis jerdoni*	1.9082	0.2614	0.0192	0.0030	1.7893	0.3007	0.0210	0.0039	2.2110	0.5231	0.0146	0.0040
Priacanthidae	*Priacanthus tayenus*	49.2762	4.0148	2.1061	0.1557	43.6686	5.0243	2.0523	0.2044	63.5595	6.1565	2.2430	0.1846
Psettodidae	*Psettodes erumei*	4.6843	0.3470	1.0609	0.0769	4.3779	0.4572	0.8343	0.0906	5.4648	0.3943	1.6382	0.1385
Pseudochromidae	*Pseudochromis quinquedentatus*	0.1369	0.0428	0.0008	0.0002	0.0033	0.0033	< 0.0001	< 0.0001	0.4790	0.1500	0.0027	0.0009
Rachycentridae	*Rachycentron canadum*	0.1447	0.0426	0.0925	0.0464	0.1152	0.0465	0.1017	0.0631	0.2202	0.0940	0.0691	0.0342
Rhinoprenidae	*Rhinoprenes pentanemus*	0.6701	0.2629	0.0239	0.0089	0.9319	0.3652	0.0333	0.0124	—	—	—	—
Scaridae	*Scarus ghobban*	0.0156	0.0119	0.0052	0.0042	0.0217	0.0166	0.0073	0.0058	—	—	—	—
Scatophagidae	*Scatophagus argus*	0.0383	0.0383	0.0015	0.0015	0.0532	0.0532	0.0020	0.0020	—	—	—	—
Sciaenidae	*Atrobucca brevis*	1.4352	0.6849	0.0685	0.0334	1.9960	0.9517	0.0953	0.0463	—	—	—	—
	Austronibea oedogenys	0.9042	0.4505	0.0115	0.0047	1.2576	0.6260	0.0160	0.0065	—	—	—	—
	Johnius amblycephalus	1.7585	0.8893	0.1672	0.1092	2.4374	1.2359	0.2315	0.1519	0.0213	0.0151	0.0024	0.0017
	Johnius borneensis	8.6221	2.3061	0.4113	0.0918	11.9519	3.1965	0.5676	0.1270	0.1002	0.0466	0.0115	0.0056
	Johnius laevis	0.8473	0.6944	0.0072	0.0066	1.1784	0.9657	0.0100	0.0092	—	—	—	—
	Otolithes ruber	0.1526	0.1061	0.0036	0.0026	0.2123	0.1475	0.0049	0.0035	—	—	—	—
	Protonibea diacanthus	0.0313	0.0248	0.2574	0.2533	0.0402	0.0343	0.3558	0.3522	0.0085	0.0085	0.0055	0.0055
	unidentified Sciaenidae	1.8600	1.0956	0.0255	0.0155	2.5868	1.5230	0.0355	0.0216	—	—	—	—
Scombridae	*Cybiosarda elegans*	0.0027	0.0027	0.0021	0.0021	0.0037	0.0037	0.0029	0.0029	—	—	—	—
	Rastrelliger kanagurta	1.6198	0.3014	0.1902	0.0377	0.5712	0.1661	0.0527	0.0175	4.3034	0.9623	0.5424	0.1235
	Scomberomorus munroi	0.0506	0.0267	0.0278	0.0147	0.0035	0.0035	0.0016	0.0016	0.1712	0.0943	0.0950	0.0519
	Scomberomorus queenslandicus	0.2788	0.0541	0.1340	0.0284	0.1701	0.0504	0.1189	0.0348	0.5556	0.1409	0.1726	0.0482
Scombridae	*Scomberomorus semifasciatus*	0.0027	0.0027	0.0082	0.0082	0.0037	0.0037	0.0114	0.0114	—	—	—	—
Scorpaenidae	*Brachypterois serrulatus*	2.5903	0.3373	0.0493	0.0064	0.9914	0.2667	0.0170	0.0050	6.6628	0.9297	0.1317	0.0176
	Cottapistus cottoides	0.6793	0.1334	0.0072	0.0016	0.1567	0.0669	0.0010	0.0005	2.0105	0.4287	0.0232	0.0052
	Cottapistus praepositus	0.1290	0.0551	0.0019	0.0011	0.1637	0.0761	0.0024	0.0015	0.0403	0.0225	0.0006	0.0003
	Dendrochirus zebra	0.0087	0.0063	0.0002	0.0001	0.0074	0.0074	0.0002	0.0002	0.0122	0.0122	0.0002	0.0002
	Erosa erosa	0.0234	0.0186	0.0005	0.0004	—	—	—	—	0.0834	0.0663	0.0017	0.0013
	Apistus carinatus	24.0324	1.9563	0.4245	0.0326	20.8536	2.2530	0.3797	0.0393	32.1295	3.8545	0.5385	0.0575
	Inimicus sinensis	0.2939	0.1141	0.0154	0.0060	0.2455	0.1539	0.0118	0.0079	0.4176	0.0990	0.0245	0.0065
	Minous trachycephalus	1.6946	0.3198	0.0122	0.0025	1.1334	0.3806	0.0088	0.0030	3.1212	0.5794	0.0210	0.0041
	Minous versicolor	0.3070	0.0533	0.0066	0.0012	0.1115	0.0447	0.0023	0.0011	0.8072	0.1463	0.0176	0.0032

Table 6.2.2 The catch rate of teleost species overall and individually from the research surveys and the scientific observer.

		Overall				Research survey				Scientific observer			
		$n\ h^{-1}$		$kg\ h^{-1}$		$n\ h^{-1}$		$kg\ h^{-1}$		$n\ h^{-1}$		$kg\ h^{-1}$	
Family	**Species**	**mean**	**se**	**mean**	**se**	**mean**	**se**	**mean**	**se**	**mean**	**se**	**mean**	**se**
	Neomerinthe amplisquamiceps	0.1256	0.1256	0.0017	0.0017	0.1746	0.1746	0.0023	0.0023	—	—	—	—
	Neomerinthe megalepis	0.1095	0.0398	0.0015	0.0006	—	—	—	—	0.3899	0.1402	0.0052	0.0020
	Paracentropogon longispinus	0.0385	0.0280	0.0003	0.0002	0.0535	0.0389	0.0004	0.0003	—	—	—	—
	Pterois russelli	0.6008	0.1080	0.0274	0.0058	0.4886	0.1385	0.0207	0.0071	0.8879	0.1472	0.0447	0.0096
	Scorpaenopsis diabolus	0.0237	0.0156	0.0007	0.0005	—	—	—	—	0.0844	0.0555	0.0026	0.0017
	Scorpaenopsis venosa	0.0338	0.0272	0.0004	0.0003	0.0470	0.0378	0.0005	0.0005	—	—	—	—
	unidentified Scorpaenidae	0.1053	0.0331	0.0020	0.0007	0.0175	0.0175	0.0002	0.0002	0.3298	0.1076	0.0066	0.0022
Serranidae	*Centrogenys vaigiensis*	0.0213	0.0188	0.0003	0.0003	0.0296	0.0262	0.0004	0.0004	—	—	—	—
	Cephalopholis boenack	0.0120	0.0105	< 0.0001	< 0.0001	—	—	—	—	0.0428	0.0373	< 0.0001	< 0.0001
	Epinephelus areolatus	0.4489	0.1637	0.0360	0.0182	0.3796	0.1898	0.0444	0.0252	0.6257	0.3224	0.0146	0.0057
	Epinephelus coioides	0.0142	0.0081	0.0901	0.0628	0.0197	0.0113	0.1252	0.0873	—	—	—	—
	Epinephelus heniochus	0.0144	0.0144	0.0020	0.0020	—	—	—	—	0.0514	0.0514	0.0071	0.0071
	Epinephelus malabaricus	0.0015	0.0009	0.0073	0.0042	—	—	—	—	0.0052	0.0030	0.0259	0.0150
	Epinephelus quoyanus	0.0076	0.0058	0.0009	0.0008	0.0074	0.0074	0.0010	0.0010	0.0081	0.0081	0.0008	0.0008
	Epinephelus sexfasciatus	3.0487	0.2839	0.1986	0.0192	1.8434	0.2696	0.1143	0.0183	6.1333	0.6956	0.4144	0.0467
	Plectropomus leopardus	0.0026	0.0026	0.0007	0.0007	0.0036	0.0036	0.0009	0.0009	—	—	—	—
	unidentified Serranidae	0.0028	0.0020	0.0000	0.0000	—	—	—	—	0.0099	0.0070	0.0001	0.0001
Siganidae	*Siganus lineatus*	0.0007	0.0007	0.0003	0.0003	0.0009	0.0009	0.0005	0.0005	—	—	—	—
Sillaginidae	*Sillago analis*	0.2805	0.2280	0.0211	0.0176	0.3900	0.3171	0.0293	0.0244	—	—	—	—
	Sillago burrus	5.1925	1.0858	0.2720	0.0530	7.0628	1.5022	0.3656	0.0733	0.4061	0.1060	0.0326	0.0088
	Sillago ingenuua	2.5267	0.5423	0.0909	0.0198	3.4522	0.7481	0.1236	0.0273	0.1580	0.1580	0.0070	0.0070
	Sillago lutea	0.3773	0.1162	0.0167	0.0039	0.3237	0.1492	0.0103	0.0039	0.5143	0.1594	0.0331	0.0096
	Sillago sihama	0.0345	0.0220	0.0016	0.0010	0.0480	0.0306	0.0022	0.0013	—	—	—	—
Soleidae	*Dexillus muelleri*	1.0204	0.1162	0.0941	0.0108	0.3834	0.1130	0.0292	0.0086	2.6431	0.2643	0.2596	0.0284
	Pardachirus pavoninus	0.0177	0.0133	0.0006	0.0003	0.0045	0.0037	0.0004	0.0004	0.0516	0.0465	0.0009	0.0007
	Strabozebrias cancellatus	0.0059	0.0044	0.0001	0.0001	0.0056	0.0056	0.0001	0.0001	0.0068	0.0068	0.0001	0.0001
	Zebrias quagga	0.4077	0.0779	0.0122	0.0025	0.1929	0.0805	0.0057	0.0025	0.9572	0.1807	0.0288	0.0058
	unidentified Soleidae	0.0893	0.0276	0.0015	0.0005	0.0150	0.0150	0.0003	0.0003	0.2797	0.0891	0.0045	0.0016
Sparidae	*Argyrops spinifer*	0.1435	0.0849	0.0165	0.0122	0.1324	0.1146	0.0181	0.0168	0.1717	0.0722	0.0122	0.0067
Sphyraenidae	*Sphyraena barracuda*	0.0027	0.0027	0.0026	0.0026	0.0037	0.0037	0.0036	0.0036	—	—	—	—
	Sphyraena flavicauda	0.2498	0.0993	0.0179	0.0078	0.2844	0.1350	0.0208	0.0107	0.1613	0.0740	0.0107	0.0051
	Sphyraena forsteri	0.6332	0.1465	0.0492	0.0105	0.2782	0.1002	0.0253	0.0090	1.5417	0.4487	0.1103	0.0292

Table 6.2.2 The catch rate of teleost species overall and individually from the research surveys and the scientific observer.

		Overall				Research survey				Scientific observer			
		n h^{-1}		kg h^{-1}		n h^{-1}		kg h^{-1}		n h^{-1}		kg h^{-1}	
Family	**Species**	**mean**	**se**	**mean**	**se**	**mean**	**se**	**mean**	**se**	**mean**	**se**	**mean**	**se**
	Sphyraena obtusata	1.8465	0.8772	0.1088	0.0495	0.2899	0.1041	0.0186	0.0067	5.8112	3.0889	0.3386	0.1741
	Sphyraena putnamiae	0.4838	0.1841	0.1106	0.0361	0.2614	0.1802	0.0698	0.0384	1.0502	0.4631	0.2145	0.0826
	Sphyraena qenie	0.0943	0.0434	0.0502	0.0206	0.1312	0.0603	0.0697	0.0286	—	—	—	—
Sternoptychidae	*Polyipnus elongatus*	0.0444	0.0444	0.0005	0.0005	—	—	—	—	0.1580	0.1580	0.0017	0.0017
Syngnathidae	*Haliichthys taeniophorus*	0.0175	0.0175	0.0001	0.0001	0.0243	0.0243	0.0001	0.0001	—	—	—	—
	Trachyrhamphus longirostris	0.0236	0.0151	0.0002	0.0001	—	—	—	—	0.0842	0.0538	0.0006	0.0004
	unidentified Syngnathidae	0.0338	0.0214	0.0001	0.0001	0.0470	0.0297	0.0001	0.0001	—	—	—	—
Synodontidae	*Synodus hoshinonis*	1.8618	0.3347	0.0518	0.0098	0.7076	0.1701	0.0174	0.0053	4.8157	1.0846	0.1398	0.0316
	Synodus sageneus	0.3849	0.0805	0.0146	0.0033	0.4289	0.1054	0.0149	0.0042	0.2725	0.0961	0.0138	0.0048
	Trachinocephalus myops	1.1982	0.1699	0.0711	0.0118	0.2618	0.0814	0.0090	0.0028	3.5834	0.5325	0.2298	0.0394
	unidentified Synodontidae	0.0399	0.0374	0.0000	0.0000	0.0555	0.0520	0.0001	0.0001	—	—	—	—
Terapontidae	*Pelates quadrilineatus*	36.6028	10.0604	0.9980	0.2919	50.6142	13.9484	1.3783	0.4048	0.7442	0.2442	0.0248	0.0077
	Pelates sexlineatus	0.0678	0.0486	0.0017	0.0011	0.0943	0.0676	0.0024	0.0015	—	—	—	—
	Terapon jarbua	2.1115	0.4243	0.1022	0.0207	1.6166	0.5195	0.0774	0.0251	3.3781	0.7104	0.1656	0.0356
	Terapon puta	0.4638	0.1375	0.0106	0.0033	0.6406	0.1907	0.0147	0.0046	0.0115	0.0115	0.0003	0.0003
	Terapon theraps	42.1367	4.3489	2.0672	0.1895	56.9149	5.8741	2.7942	0.2535	4.3158	2.0709	0.2067	0.1085
Tetraodontidae	*Arothron stellatus*	0.0073	0.0054	0.0162	0.0120	0.0102	0.0076	0.0226	0.0167	—	—	—	—
	Chelonodon patoca	2.4197	0.6154	0.1898	0.0418	3.1629	0.8524	0.2480	0.0578	0.5177	0.1315	0.0409	0.0114
	Feroxodon multistriatus	0.0922	0.0268	0.0350	0.0135	0.0897	0.0293	0.0424	0.0184	0.0985	0.0591	0.0160	0.0091
	Lagocephalus inermis	0.0977	0.0765	0.0046	0.0041	0.1208	0.1053	0.0064	0.0057	0.0385	0.0385	0.0000	0.0000
Tetraodontidae	*Lagocephalus lunaris*	0.7174	0.1664	0.0341	0.0079	0.9793	0.2303	0.0438	0.0108	0.0470	0.0222	0.0093	0.0046
	Lagocephalus sceleratus	8.6891	0.8557	0.2842	0.0246	9.0824	1.1286	0.2526	0.0290	7.6828	0.9664	0.3650	0.0459
	Lagocephalus spadiceus	2.6145	0.3422	0.1227	0.0174	2.6548	0.4380	0.1288	0.0228	2.5113	0.4780	0.1070	0.0203
	Torquigener hicksi	0.0295	0.0209	0.0019	0.0013	0.0405	0.0290	0.0026	0.0018	0.0014	0.0014	0.0001	0.0001
	Torquigener pallimaculatus	0.7706	0.1972	0.0376	0.0103	1.0717	0.2733	0.0523	0.0143	—	—	—	—
	Torquigener tuberculiferus	2.2111	0.6966	0.0846	0.0238	2.6952	0.9655	0.0881	0.0325	0.9722	0.1850	0.0758	0.0146
	Torquigener whitleyi	6.0634	1.0234	0.1375	0.0209	8.3216	1.4112	0.1874	0.0288	0.2841	0.1042	0.0098	0.0037
Triacanthidae	*Trixiphichthys weberi*	10.4191	1.0106	0.3479	0.0342	13.6171	1.3279	0.4475	0.0441	2.2347	0.9784	0.0927	0.0406
Trichiuridae	*Trichiurus lepturus*	8.6215	1.8494	0.2726	0.0780	5.5023	1.5868	0.2860	0.1055	16.6041	5.1494	0.2382	0.0659
Triglidae	*Lepidotrigla argus*	0.9159	0.3292	0.0126	0.0043	1.2144	0.4566	0.0161	0.0060	0.1519	0.0653	0.0035	0.0015
	Lepidotrigla sp. 2	4.4192	0.6937	0.0665	0.0109	2.4691	0.6175	0.0299	0.0083	9.3864	1.8523	0.1599	0.0315
	Lepidotrigla spiloptera	0.9419	0.4530	0.0148	0.0066	1.3099	0.6295	0.0206	0.0092	—	—	—	—

Table 6.2.2 The catch rate of teleost species overall and individually from the research surveys and the scientific observer.

		Overall				Research survey				Scientific observer			
		$n\ h^{-1}$		$kg\ h^{-1}$		$n\ h^{-1}$		$kg\ h^{-1}$		$n\ h^{-1}$		$kg\ h^{-1}$	
Family	**Species**	**mean**	**se**	**mean**	**se**	**mean**	**se**	**mean**	**se**	**mean**	**se**	**mean**	**se**
	Lepidotrigla sp.	0.4801	0.2533	0.0057	0.0031	0.6677	0.3520	0.0080	0.0043	—	—	—	—
	unidentified Triglidae	0.5527	0.1999	0.0070	0.0027	—	—	—	—	1.9671	0.7035	0.0251	0.0094
Uranoscopidae	unidentified Uranoscopidae	0.0016	0.0016	< 0.0001	< 0.0001	—	—	—	—	0.0056	0.0056	0.0000	0.0000
	Uranoscopus cognatus	2.9903	0.2803	0.1161	0.0113	1.2504	0.2373	0.0420	0.0091	7.4220	0.7042	0.3049	0.0292
	Uranoscopus sp. 1	0.3682	0.3161	0.0119	0.0100	0.5121	0.4396	0.0165	0.0139	—	—	—	—
Veliferidae	*Velifer hypselopterus*	0.5845	0.1501	0.0245	0.0062	0.5261	0.1719	0.0235	0.0075	0.7341	0.3038	0.0273	0.0106

Table 6.2.3 The catch rate of elasmobranch bycatch species overall and individually from each data collection method.

		Overall		**Research surveys**				**Scientific observer**		**Crew member observer**	
		n h^{-1}		**n h^{-1}**		**kg h^{-1}**		**n h^{-1}**		**n h^{-1}**	
Family	**Species**	**mean**	**se**	**mean**	**se**	**mean**	**se**	**mean**	**se**	**mean**	**se**
Carcharhinidae	*Carcharhinus albimarginatus*	0.0003	0.0003	—	—	—	—	0.0008	0.0008	—	—
	Carcharhinus amboinensis	0.0041	0.0039	0.0092	0.0092	0.6897	0.6897	—	—	0.0009	0.0009
	Carcharhinus dussumieri	0.4418	0.0500	0.3160	0.0550	0.5393	0.0908	0.2547	0.0399	1.3977	0.2766
	Carcharhinus fitzroyensis	0.0007	0.0005	—	—	—	—	0.0015	0.0011	—	—
	Carcharhinus macloti	0.0005	0.0004	—	—	—	—	0.0013	0.0009	—	—
	Carcharhinus sorrah	0.0088	0.0038	0.0048	0.0048	0.0100	0.0100	0.0041	0.0020	0.0351	0.0217
	Carcharhinus tilstoni	0.1523	0.0167	0.0818	0.0254	0.8071	0.3274	0.1955	0.0213	0.2347	0.0603
	Galeocerdo cuvier	0.0005	0.0004	0.0008	0.0008	0.0024	0.0024	—	—	0.0014	0.0014
	Negaprion acutidens	0.0002	0.0002	—	—	—	—	—	—	0.0014	0.0014
	Rhizoprionodon acutus	0.1286	0.0236	0.2377	0.0540	0.2969	0.0817	0.0326	0.0052	0.0907	0.0212
	unidentified Carcharhinidae	0.0131	0.0056	—	—	—	—	0.0303	0.0129	—	—
Dasyatidae	*Amphotistius annotatus*	0.1241	0.0362	0.2547	0.0812	0.0652	0.0216	0.0350	0.0225	—	—
	Dasyatis kuhlii	0.0252	0.0080	0.0380	0.0169	0.0434	0.0224	0.0154	0.0075	0.0161	0.0058
	Dasyatis leylandi	0.8295	0.1152	1.5052	0.2553	0.3056	0.0598	0.3628	0.0718	0.2038	0.0390
	Dasyatis sp. A	0.0005	0.0005	—	—	—	—	—	—	0.0035	0.0035
	Dasyatis thetidis	0.0015	0.0008	—	—	—	—	0.0029	0.0018	0.0017	0.0012
	Gymnura australis	0.0797	0.0152	0.1264	0.0315	0.0942	0.0382	0.0512	0.0158	0.0252	0.0074
	Himantura fai	0.0003	0.0003	—	—	—	—	0.0006	0.0006	—	—
	Himantura granulata	0.0007	0.0005	0.0009	0.0009	0.0414	0.0414	0.0007	0.0007	—	—
	Himantura jenkinsii	0.0024	0.0010	—	—	—	—	0.0056	0.0024	—	—
	Himantura sp. A	0.0106	0.0038	0.0115	0.0083	0.0269	0.0195	0.0021	0.0012	0.0343	0.0098
	Himantura toshi	0.1830	0.0254	0.1668	0.0443	0.6788	0.2188	0.2320	0.0388	0.0822	0.0137
	Himantura uarnak	0.0030	0.0012	—	—	—	—	0.0035	0.0016	0.0107	0.0072
	Himantura undulata	0.0167	0.0074	0.0371	0.0173	1.9154	0.9208	0.0013	0.0009	0.0023	0.0016
	Pastinachus sephen	0.0289	0.0134	0.0461	0.0311	1.8297	1.0551	0.0038	0.0016	0.0532	0.0122
	Taeniura meyeni	0.0003	0.0003	—	—	—	—	0.0006	0.0006	—	—
	unidentified Dasyatididae	0.0068	0.0038	0.0086	0.0086	0.4655	0.4655	0.0035	0.0018	0.0117	0.0050

Table 6.2.3 The catch rate of elasmobranch bycatch species overall and individually from each data collection method.

		Overall		Research surveys				Scientific observer		Crew member observer	
		n h^{-1}		n h^{-1}		kg h^{-1}		n h^{-1}		n h^{-1}	
Family	**Species**	**mean**	**se**	**mean**	**se**	**mean**	**se**	**mean**	**se**	**mean**	**se**
	Urogymnus asperrimus	0.0009	0.0005	—	—	—	—	0.0009	0.0009	0.0034	0.0020
Ginglymostomatidae	*Nebrius ferrugineus*	0.0003	0.0003	—	—	—	—	0.0007	0.0007	—	—
Hemiscylliidae	*Chiloscyllium punctatum*	0.0379	0.0111	0.0182	0.0123	0.0061	0.0035	0.0665	0.0225	0.0099	0.0038
	Hemigaleus microstoma	0.1611	0.0272	0.1930	0.0519	0.0993	0.0296	0.1050	0.0328	0.2359	0.0492
	Hemipristis elongata	0.0021	0.0020	0.0046	0.0046	0.0050	0.0050	—	—	0.0012	0.0012
Myliobatidae	*Aetobatus narinari*	0.0024	0.0020	0.0046	0.0046	0.0920	0.0920	0.0007	0.0007	0.0009	0.0009
	Aetomylaeus nichofii	0.0110	0.0058	0.0190	0.0134	0.0559	0.0447	0.0043	0.0020	0.0071	0.0040
Orectolobidae	*Orectolobus ornatus*	0.0571	0.0571	0.1335	0.1335	0.0019	0.0019	—	—	—	—
Pristidae	*Anoxypristis cuspidata*	0.0131	0.0060	0.0267	0.0139	0.7114	0.4826	0.0030	0.0015	0.0026	0.0018
	Pristis zijsron	0.0020	0.0020	0.0046	0.0046	0.3218	0.3218	—	—	—	—
Rhinobatidae	*Rhinobatos typus*	0.0008	0.0004	—	—	—	—	0.0013	0.0009	0.0017	0.0012
Rhynchobatidae	*Rhina ancylostoma*	0.0076	0.0043	0.0141	0.0098	0.4046	0.3086	0.0029	0.0015	0.0023	0.0016
	Rhynchobatus djiddensis	0.1102	0.0207	0.0009	0.0009	0.0013	0.0013	0.2370	0.0473	0.0548	0.0104
Scyliorhinidae	*Atelomycterus fasciatus*	0.0045	0.0025	—	—	—	—	0.0097	0.0058	0.0021	0.0015
Sphyrnidae	*Eusphyra blochii*	0.0040	0.0037	0.0086	0.0086	0.0095	0.0095	0.0008	0.0008	—	—
	Sphyrna lewini	0.0112	0.0022	—	—	—	—	0.0244	0.0050	0.0050	0.0025
	Sphyrna mokarran	0.0025	0.0020	0.0046	0.0046	0.2069	0.2069	—	—	0.0037	0.0021
	unidentified Sphyrnidae	0.0002	0.0002	—	—	—	—	—	—	0.0012	0.0012
Stegastomatidae	*Stegastoma fasciatum*	0.0109	0.0045	0.0110	0.0090	0.2462	0.1842	0.0043	0.0017	0.0306	0.0160

Table 6.2.4 The average catch rate of invertebrate bycatch species overall and individually from research surveys and the scientific observer.

	Overall kg h^{-1}		**Research survey** kg h^{-1}		**Scientific observer** kg h^{-1}	
Taxa	**mean**	**se**	**mean**	**se**	**mean**	**se**
PORIFERA						
Ancorinidae	<0.0001	0.0000	0.0001	0.0001	—	—
Aplysinidae	0.0025	0.0019	0.0038	0.0029	—	—
Geodiidae	0.0002	0.0002	—	—	0.1273	0.0000
Tetillidae	0.0002	0.0002	0.0003	0.0003	—	—
Darwinellidae	0.0003	0.0002	—	—	0.0123	0.0000
Dysideidae	0.0013	0.0009	0.0019	0.0013	—	—
Irciniidae	0.1267	0.0609	0.1736	0.0913	1.9842	0.2293
Spongiidae	0.0407	0.0274	0.0604	0.0417	0.2277	0.0159
Spirastrellidae	0.0012	0.0012	0.0018	0.0018	—	—
Suberitidae	0.0300	0.0223	0.0458	0.0340	—	—
Axinellidae	0.0019	0.0012	0.0029	0.0018	—	—
Desmoxyidae	0.0383	0.0357	0.0584	0.0545	—	—
Halichondriidae	0.0008	0.0008	0.0013	0.0013	—	—
Callyspongiidae	0.0017	0.0008	0.0018	0.0010	0.1010	0.0109
Niphatidae	0.0146	0.0069	0.0220	0.0106	0.1221	0.0000
Petrosiidae	0.0082	0.0041	0.0020	0.0014	1.0605	0.0486
Phloeodictyidae	0.0888	0.0295	0.0770	0.0309	3.9120	0.2824
Coelosphaeridae	0.0189	0.0143	0.0288	0.0218	—	—
Desmacellidae	0.0013	0.0013	0.0020	0.0020	—	—
Microcionidae	0.0030	0.0023	0.0046	0.0035	—	—
Mycalidae	0.0176	0.0093	—	—	0.8301	0.0970
Myxillidae	0.0029	0.0024	0.0044	0.0036	—	—
Phoriospongiidae	0.0002	0.0002	0.0003	0.0003	—	—
Raspailiidae	0.0083	0.0050	0.0127	0.0077	—	—
Druinelliidae	0.0001	0.0001	0.0001	0.0001	—	—
Ianthellidae	<0.0001	0.0000	0.0001	0.0001	—	—
unidentified Porifera	2.3983	0.3809	0.4371	0.3841	9.1020	0.8650
CNIDARIA						
Alcyonaria	0.0008	0.0008	0.0012	0.0012	—	—
Alcyonacea	0.0246	0.0045	0.0058	0.0025	0.1484	0.0168
Gorgonacea	0.3223	0.2927	0.4902	0.4467	0.1362	0.0188
Pennatulacea	0.0149	0.0046	0.0190	0.0070	0.0646	0.0051
Actiniaria	<0.0001	0.0000	<0.0001	0.0000	—	—
Corallimorpharia 1	<0.0001	0.0000	<0.0001	0.0000	—	—
Duncanopsammia	0.0001	0.0001	0.0002	0.0002	—	—
Scleractinia	0.0002	0.0002	0.0003	0.0003	—	—
Hard coral 2	0.0001	0.0001	0.0002	0.0002	—	—
Sphaenopus marsupialis	0.0135	0.0081	0.0206	0.0124	—	—
Sphaenopus sp	<0.0001	0.0000	<0.0001	0.0000	—	—
Chironex fleckeri	0.0117	0.0045	0.0178	0.0068	—	—
Hydrozoa	0.0016	0.0006	0.0023	0.0010	0.0097	0.0007
unidentified Cnidaria	0.0004	0.0003	—	—	0.1081	0.0056
CTENOPHORA	0.4429	0.1968	0.6745	0.2998	0.0790	0.0068
POLYCHAETA	0.0227	0.0150	0.0344	0.0229	0.0124	0.0007
ECHIURA	0.0028	0.0028	0.0043	0.0043	—	—
SIPUNCULA	<0.0001	0.0000	<0.0001	0.0000	0.0028	0.0000
CRUSTACEA*						
Penaeidae						
Atypopenaeus spp	0.0465	0.0152	0.0691	0.0231	0.0153	0.0012
Metapenaeopsis spp	0.6365	0.0634	0.1582	0.0334	1.5679	0.1550

Table 6.2.4 The average catch rate of invertebrate bycatch species overall and individually from research surveys and the scientific observer.

	Overall kg h^{-1}		Research survey kg h^{-1}		Scientific observer kg h^{-1}	
Taxa	**mean**	**se**	**mean**	**se**	**mean**	**se**
Parapenaeopsis spp	0.0018	0.0013	0.0027	0.0019	0.0042	0.0001
Parapenaeus spp	<0.0001	0.0000	—	—	0.0038	0.0000
Trachypenaeus spp	0.3648	0.0312	0.1171	0.0237	0.8558	0.0679
unidentified Penaeidae	0.0001	0.0001	0.0002	0.0002	—	—
Sicyoniidae	0.0020	0.0005	0.0004	0.0004	0.0331	0.0020
Solenoceridae	0.0520	0.0094	0.0729	0.0141	0.0373	0.0056
Diogenidae						
Dardanus asperus	<0.0001	0.0000	<0.0001	0.0000	—	—
Dardanus hessii	0.0012	0.0004	0.0006	0.0004	0.0185	0.0010
Dardanus imbricata	0.0001	0.0000	<0.0001	0.0000	0.0126	0.0003
Dardanus pedunculatuss	<0.0001	0.0000	—	—	0.0145	0.0000
Dardanus sp. Nov.	<0.0001	0.0000	<0.0001	0.0000	—	—
Diogenes sp. 3	0.0002	0.0002	0.0003	0.0003	0.0003	0.0000
Paguridae						
Spiropagurus sp. 1	0.0012	0.0002	0.0004	0.0002	0.0092	0.0006
unidentified Paguridae	0.0004	0.0002	0.0005	0.0002	0.0082	0.0000
Porcellanidae						
Porcellanidae 3	<0.0001	0.0000	—	—	0.0011	0.0001
Porcellanidae 4	<0.0001	0.0000	—	—	0.0030	0.0003
unidentified Porcellanidae	<0.0001	0.0000	—	—	0.0014	0.0001
Thalassinidae						
Thalassinia sp. 1	<0.0001	0.0000	—	—	0.0009	0.0000
Thalassinia sp. 2	<0.0001	0.0000	—	—	0.0032	0.0000
Upogiibidae	<0.0001	0.0000	—	—	0.0005	0.0000
Corystidae						
Gomeza bicornis	<0.0001	0.0000	0.0001	0.0001	—	—
Xenophthalmus pinnotheroides	<0.0001	0.0000	—	—	0.0025	0.0002
Dorippidae						
Dorippe quadridens	0.0032	0.0009	0.0032	0.0013	0.0248	0.0011
Paradorippe australiensis	0.0001	0.0000	<0.0001	0.0000	0.0032	0.0002
Dromiidae						
Conchoecetes artifisciosus	<0.0001	0.0000	<0.0001	0.0000	—	—
Dromia dehaani	0.0003	0.0002	0.0005	0.0004	—	—
Calappidae						
Calappa gallus	<0.0001	0.0000	<0.0001	0.0000	—	—
Calappa philargius	0.0024	0.0024	0.0037	0.0037	—	—
Calappa terraereginae	0.0012	0.0006	0.0011	0.0009	0.0150	0.0013
Matuta granulosa	0.0001	0.0001	0.0002	0.0002	—	—
Matuta inermis	0.0002	0.0001	0.0003	0.0002	—	—
Leucosiidae						
Arcania novemspinosa	0.0004	0.0003	0.0005	0.0004	0.0048	0.0003
Arcania septemspinosa	0.0002	0.0001	0.0002	0.0001	0.0038	0.0001
Ebalia spp	<0.0001	0.0000	<0.0001	0.0000	—	—
Iphiculus spongiosus	<0.0001	0.0000	—	—	0.0019	0.0000
Ixa inermis	0.0002	0.0001	0.0002	0.0001	0.0044	0.0002
Ixoides cornutus	<0.0001	0.0000	—	—	0.0113	0.0000
Leucosia magna	0.0005	0.0005	0.0007	0.0007	—	—
Leucosia ocellata	0.0001	0.0001	<0.0001	0.0000	0.0066	0.0006
Leucosia sp. 1	<0.0001	0.0000	<0.0001	0.0000	—	—
Myra biconica	0.0033	0.0007	0.0027	0.0010	0.0212	0.0014
Pariphiculus marianne	0.0002	0.0001	—	—	0.0275	0.0010

Table 6.2.4 The average catch rate of invertebrate bycatch species overall and individually from research surveys and the scientific observer.

	Overall kg h^{-1}		Research survey kg h^{-1}		Scientific observer kg h^{-1}	
Taxa	mean	se	mean	se	mean	se
Majidae						
Camposcia retusa	<0.0001	0.0000	<0.0001	0.0000	—	—
Chlorinoides aculeatus	<0.0001	0.0000	<0.0001	0.0000	—	—
Majidae 82	<0.0001	0.0000	—	—	0.0075	0.0000
Hyastenus cambelli	0.0001	0.0001	0.0002	0.0001	—	—
Hyastenus sp.	<0.0001	0.0000	<0.0001	0.0000	—	—
Hyastenus sp. 1	0.0003	0.0002	0.0002	0.0002	0.0223	0.0021
Hyastenus sp. 4	0.0029	0.0029	0.0044	0.0044	—	—
Micippa sp.	<0.0001	0.0000	<0.0001	0.0000	—	—
Phalangipes australiensis	0.0001	0.0000	0.0001	0.0001	—	—
Phalangipes longipes	0.0007	0.0003	0.0010	0.0005	0.0026	0.0002
Schizophrys dama	0.0001	0.0001	0.0001	0.0001	—	—
Parthenopidae						
Cryptopodia sp. 1	0.0006	0.0003	0.0009	0.0004	0.0096	0.0000
Cryptopodia sp. 5	<0.0001	0.0000	<0.0001	0.0000	—	—
Parthenope harpax	0.0004	0.0003	0.0007	0.0005	—	—
Parthenope hoplonotus	0.0009	0.0006	0.0014	0.0009	—	—
Parthenope longimanus	0.0009	0.0004	0.0011	0.0006	0.0086	0.0007
Parthenope longispinus	0.0002	0.0001	0.0002	0.0002	—	—
Parthenope sp. 3	<0.0001	0.0000	<0.0001	0.0000	—	—
Parthenopus nodosus	0.0001	0.0001	0.0001	0.0001	—	—
Portunidae						
Charybdis anisodon	0.0353	0.0123	0.0505	0.0185	1.3244	0.0000
Charybdis callianassa	0.0288	0.0156	0.0439	0.0237	0.0048	0.0001
Charybdis feriatus	0.0770	0.0126	0.0343	0.0113	0.4509	0.0422
Charybdis jaubertensis	0.0032	0.0008	0.0010	0.0005	0.0654	0.0047
Charybdis miles	0.0036	0.0013	—	—	0.1857	0.0104
Charybdis natator	0.0038	0.0027	0.0058	0.0041	0.0077	0.0004
Charybdis truncata	0.4456	0.0364	0.1479	0.0390	1.0669	0.0568
Charybdis yaldwin	0.0020	0.0008	0.0025	0.0011	0.0240	0.0016
Libystes edwardsii	<0.0001	0.0000	—	—	0.0035	0.0002
Lupocyclus rotundatus	0.0106	0.0028	0.0075	0.0028	0.1762	0.0156
Lupocyclus tugelae	<0.0001	0.0000	—	—	0.0050	0.0003
Podopthalmus vigil	0.0389	0.0057	0.0044	0.0022	0.2721	0.0195
Portunus acerbiterminalis	0.0277	0.0045	0.0039	0.0023	0.1082	0.0135
Portunus argentatus	<0.0001	0.0000	<0.0001	0.0000	—	—
Portunus gladiator	0.0147	0.0044	0.0070	0.0024	0.2589	0.0314
Portunus gracilimanus	0.1634	0.0163	0.0076	0.0032	0.5417	0.0403
Portunus pelagicus	0.7805	0.0741	0.4755	0.0862	1.9791	0.1375
Portunus rubromarginatus	0.7112	0.0786	0.1204	0.0257	2.7639	0.2214
Portunus rugosus	0.0001	0.0001	0.0001	0.0001	0.0149	0.0014
Portunus sanguinolentus	0.1347	0.0181	0.0602	0.0206	0.5548	0.0381
Portunus sp. 1	0.0002	0.0001	0.0001	0.0001	0.0079	0.0005
Portunus spinipes	0.0001	0.0000	<0.0001	0.0000	0.0022	0.0002
Portunus tenuipes	0.0574	0.0154	0.0672	0.0233	0.0985	0.0068
Thalamita sexlobata	0.0001	0.0001	0.0001	0.0001	0.0014	0.0001
Thalamita sima	0.0038	0.0009	0.0004	0.0003	0.0557	0.0047
Thalamita sp. 2	<0.0001	0.0000	0.0001	0.0001	—	—
Thalamita spinifer	<0.0001	0.0000	—	—	0.0002	0.0000
unidentified Portunidae	<0.0001	0.0000	<0.0001	0.0000	—	—
Raninidae						

Table 6.2.4 The average catch rate of invertebrate bycatch species overall and individually from research surveys and the scientific observer.

Taxa	Overall kg h^{-1} mean	Overall se	Research survey kg h^{-1} mean	Research survey se	Scientific observer kg h^{-1} mean	Scientific observer se
Jonas luteanus	0.0058	0.0010	0.0012	0.0008	0.0627	0.0035
Xanthidae						
Demania cultripes	0.0002	0.0002	—	—	0.1212	0.0000
Galene bispinosa	0.0051	0.0017	0.0039	0.0022	0.0661	0.0075
Liagore rubromaculata	0.0011	0.0003	0.0004	0.0004	0.0205	0.0012
Liomera rubra	0.0001	0.0001	0.0001	0.0001	—	—
Neoxanthops sp.	<0.0001	0.0000	<0.0001	0.0000	—	—
Gonoplacidae						
Carcinoplax purpurea	0.0040	0.0006	0.0005	0.0004	0.0310	0.0022
Eucrate dorsalis	0.0015	0.0004	0.0002	0.0002	0.0463	0.0023
Eucrate sp. 2	0.0001	0.0000	—	—	0.0029	0.0002
Eucrate sp. 4	<0.0001	0.0000	—	—	0.0204	0.0000
Eucrate sp. 5	<0.0001	0.0000	—	—	0.0005	0.0000
Eucrate sp. 6	<0.0001	0.0000	<0.0001	0.0000	—	—
Ommatocarcinus macgillivrayi	<0.0001	0.0000	<0.0001	0.0000	—	—
Pilumnidae						
Actumnus dorsipes	<0.0001	0.0000	—	—	0.0041	0.0000
Bathypilumnus nigrispinifer	<0.0001	0.0000	—	—	0.0020	0.0000
Bathypilumnus pugilator	0.0007	0.0004	0.0007	0.0005	0.0270	0.0033
Ceratoplax sp. 1	0.0003	0.0001	0.0004	0.0002	0.0002	0.0000
Ceratoplax sp. 2	0.0003	0.0002	—	—	0.0043	0.0002
Ceratoplax sp. 3	<0.0001	0.0000	—	—	0.0044	0.0000
Cryptocoeloma haswelli	<0.0001	0.0000	—	—	0.0043	0.0000
Lophopilumnus globosus	0.0016	0.0011	—	—	0.4875	0.0031
Pilumnus semilanatus	0.0001	0.0001	—	—	0.0195	0.0012
Pilumnus sp. 1	<0.0001	0.0000	—	—	0.0063	0.0005
Pilumnus sp. 4	0.0001	0.0001	—	—	0.0187	0.0021
unidentified Pilumnidae	<0.0001	0.0000	—	—	0.0025	0.0001
Alpheidae	0.0002	0.0001	0.0002	0.0002	0.0016	0.0001
Crangonidae						
Crangon sp. 1	<0.0001	0.0000	<0.0001	0.0000	0.0009	0.0000
Crangon sp. 2	<0.0001	0.0000	—	—	0.0023	0.0001
unidentified Crangonidae	<0.0001	0.0000	<0.0001	0.0000	0.0005	0.0000
Caridea	0.0062	0.0010	0.0023	0.0011	0.0199	0.0023
Palicoides longimanus	0.0001	0.0001	0.0002	0.0002	—	—
Zebra sp.	<0.0001	0.0000	—	—	0.0015	0.0001
Palinuridae						
Panulirus ornatus	0.0017	0.0017	0.0026	0.0026	—	—
Panulirus polyphagus	<0.0001	0.0000	<0.0001	0.0000	—	—
Scyllaridae						
Scyllarus sp.	0.0078	0.0015	0.0078	0.0021	0.0473	0.0032
Thenus sp. nov.	0.6479	0.0556	0.7450	0.0764	0.7297	0.0803
Stenopodidae						
Stenopus hispidus	0.0001	0.0001	<0.0001	0.0000	0.0274	0.0005
Pleocyemata	0.0001	0.0001	0.0001	0.0001	0.0058	0.0000
Eurysquillidae						
Manningia notalis	0.0001	0.0001	0.0001	0.0001	—	—
Lysiosquillidae						
Lysiosquilla tredecimdentata	0.0001	0.0001	0.0001	0.0001	—	—
unidentified Lysiosquillidae	<0.0001	0.0000	0.0001	0.0001	—	—
Odontodactylidae						

Table 6.2.4 The average catch rate of invertebrate bycatch species overall and individually from research surveys and the scientific observer.

Taxa	Overall kg h^{-1} mean	Overall kg h^{-1} se	Research survey kg h^{-1} mean	Research survey kg h^{-1} se	Scientific observer kg h^{-1} mean	Scientific observer kg h^{-1} se
Odontodactylus cultrifer	0.0005	0.0004	<0.0001	0.0000	0.1390	0.0080
Harpiosquillidae						
Harpiosquilla annandalei	0.0003	0.0002	0.0002	0.0002	0.0380	0.0015
Harpiosquilla harpax	0.0524	0.0104	0.0114	0.0061	0.5183	0.0443
Harpiosquilla melanoura	0.0002	0.0002	0.0003	0.0003	—	—
Squillidae						
Acanthosquilla multifasciata	0.0008	0.0005	0.0012	0.0008	—	—
Clorida chlorida	0.0001	0.0001	0.0002	0.0002	0.0011	0.0001
Clorida decorata	0.0012	0.0004	0.0012	0.0006	0.0298	0.0014
Clorida granti	0.0002	0.0001	0.0002	0.0002	—	—
Clorida latispina	<0.0001	0.0000	<0.0001	0.0000	0.0037	0.0001
Clorida latreillei	0.0005	0.0004	0.0007	0.0006	0.0046	0.0003
Clorida malaccensis	<0.0001	0.0000	—	—	0.0101	0.0000
Meiosquilla sp. 1	<0.0001	0.0000	—	—	0.0252	0.0000
Oratosquilla inornata	0.1390	0.0127	0.0291	0.0080	0.4149	0.0290
Oratosquilla interupta	0.0032	0.0017	0.0049	0.0026	—	—
Oratosquilla nepa	0.0232	0.0083	0.0355	0.0127	—	—
Oratosquilla quinquendentata	0.0096	0.0020	0.0022	0.0019	0.1028	0.0067
Oratosquilla woodmasoni	0.0319	0.0049	0.0054	0.0024	0.2415	0.0170
Carinosquilla carinata	0.0006	0.0003	<0.0001	0.0000	0.0585	0.0029
Carinosquilla multicarinata	<0.0001	0.0000	<0.0001	0.0000	—	—
Dictyosquilla foveolata	0.0092	0.0021	0.0039	0.0027	0.0650	0.0039
Lenisquilla lata	0.0004	0.0004	0.0006	0.0006	—	—
unidentified Stomatopoda	<0.0001	0.0000	0.0001	0.0001	—	—
Cirripedia	<0.0001	0.0000	<0.0001	0.0000	—	—
MOLLUSCA						
Arcticidae	0.0004	0.0003	—	—	0.1210	0.0088
Cardiidae	0.0003	0.0003	0.0005	0.0004	—	—
Mactridae	0.0022	0.0016	0.0034	0.0024	—	—
Solenidae	<0.0001	0.0000	<0.0001	0.0000	—	—
Tellinidae	<0.0001	0.0000	<0.0001	0.0000	—	—
Veneridae	0.0035	0.0030	0.0051	0.0046	0.0137	0.0010
Arcidae	<0.0001	0.0000	<0.0001	0.0000	—	—
Glycymerididae	<0.0001	0.0000	<0.0001	0.0000	—	—
Malleidae	<0.0001	0.0000	<0.0001	0.0000	—	—
Pectinidae	0.0119	0.0041	0.0134	0.0060	0.1193	0.0114
Amussiidae	0.0001	0.0001	0.0002	0.0002	—	—
Amusium pleuronectes	0.6558	0.0509	0.3478	0.0401	1.3362	0.1182
Spondylidae	<0.0001	0.0000	<0.0001	0.0000	—	—
Solemyidae	<0.0001	0.0000	0.0001	0.0001	—	—
Bivalvia	0.0048	0.0016	0.0045	0.0021	0.0472	0.0060
Sepiidae	0.6420	0.0562	0.0209	0.0102	1.4992	0.1280
Sepiolidae	0.0002	0.0001	0.0003	0.0002	—	—
Teuthoidea	0.3334	0.0606	0.1955	0.0332	0.7707	0.1837
Octopoda	0.0662	0.0173	0.0724	0.0260	0.1979	0.0150
Nudibranchia	0.0086	0.0058	0.0125	0.0088	0.2380	0.0000
Opisthobranchia	0.0001	0.0001	0.0002	0.0002	—	—
Trochidae	<0.0001	0.0000	<0.0001	0.0000	—	—
Turbinidae	<0.0001	0.0000	<0.0001	0.0000	—	—
Bursidae	0.0007	0.0006	0.0011	0.0009	—	—
Cypraeidae	<0.0001	0.0000	<0.0001	0.0000	—	—

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	Overall kg h^{-1}		**Research survey kg h^{-1}**		**Scientific observer kg h^{-1}**	
Taxa	**mean**	**se**	**mean**	**se**	**mean**	**se**
Tonnidae	0.0030	0.0030	0.0045	0.0045	—	—
Turritellidae	<0.0001	0.0000	<0.0001	0.0000	—	—
Xenophoridae	0.0001	0.0001	0.0001	0.0001	—	—
Conidae	0.0001	0.0001	0.0001	0.0001	0.0333	0.0000
Muricidae	0.0019	0.0015	0.0027	0.0023	0.0157	0.0010
Olividae	<0.0001	0.0000	0.0001	0.0001	—	—
Volutidae	0.0063	0.0045	0.0005	0.0005	0.9128	0.0809
Gastropoda	0.0032	0.0014	0.0031	0.0019	0.0619	0.0079
Ranellidae	0.0002	0.0001	0.0002	0.0002	0.0151	0.0000
unidentified Mollusca	<0.0001	0.0000	<0.0001	0.0000	—	—
ECTOPROCTA						
Bryozoa	0.0073	0.0029	0.0094	0.0045	0.0219	0.0017
ECHINODERMATA						
Loveniidae	1.6038	0.4086	2.4476	0.6198	—	—
Spatangoida	0.8514	0.1994	0.0024	0.0013	10.6146	0.9829
Clypeasteroida	0.0018	0.0009	0.0022	0.0014	0.0220	0.0013
Echinoidea	0.0225	0.0145	0.0309	0.0220	0.2007	0.0146
Chaetodiadema granulatum	0.3679	0.1384	0.3164	0.2089	0.8619	0.0714
Holothuroidea	0.4304	0.1360	0.5142	0.2065	0.7945	0.0540
Crinoidea	0.0068	0.0033	0.0104	0.0050	0.0027	0.0002
Asteroidea	0.0950	0.0285	0.1147	0.0428	0.4670	0.0302
Ophiuroidea	0.0013	0.0004	0.0013	0.0005	0.0128	0.0011
Gorgonocephalidae	0.0094	0.0076	0.0136	0.0116	0.0545	0.0034
unidentified Echinodermata	<0.0001	0.0000	—	—	0.0227	0.0000
CHORDATA						
Ascidiacea	0.0131	0.0031	0.0105	0.0039	0.1365	0.0104

The catch rate for prawns varied significantly among regions both in terms of n h^{-1} ($F_{9,382} = 10.55$, $P < 0.0001$) and kg h^{-1} ($F_{9,382} = 18.06$, $P < 0.0001$) and between the two times of year (n h^{-1}, $F_{1,382} = 10.36$ $P < 0.0001$ and kg h^{-1}, $F_{1,382} = 7.85$, $P < 0.0001$). There was a significant interaction (n h^{-1}, $F_{8,382} = 5.17$, $P < 0.0005$ and kg h^{-1}, $F_{8,382} = 4.32$, $P < 0.0001$). 'Cobourg' in February and 'Weipa' in October had the highest catch rates while 'East Mornington' in both months had the lowest for both measures of catch rate (Figure 6.2.2). The catch rate was highest in February in terms of the n h^{-1} but highest in October in terms of kg h^{-1}. This suggests that in February the catch consisted of numerous small prawns, while in October it consisted of fewer but larger prawns.

The size of the F ratios from the ANOVAs on most of the general catch characteristics (percentage of bycatch that were teleosts and elasmobranchs, catch rate of teleosts and elasmobranchs and catch rate of commercial prawns) was larger for the region effect than for the effect of time of year. This suggests that the variation due to differences among the regions is greater than the variation due to the time of year.

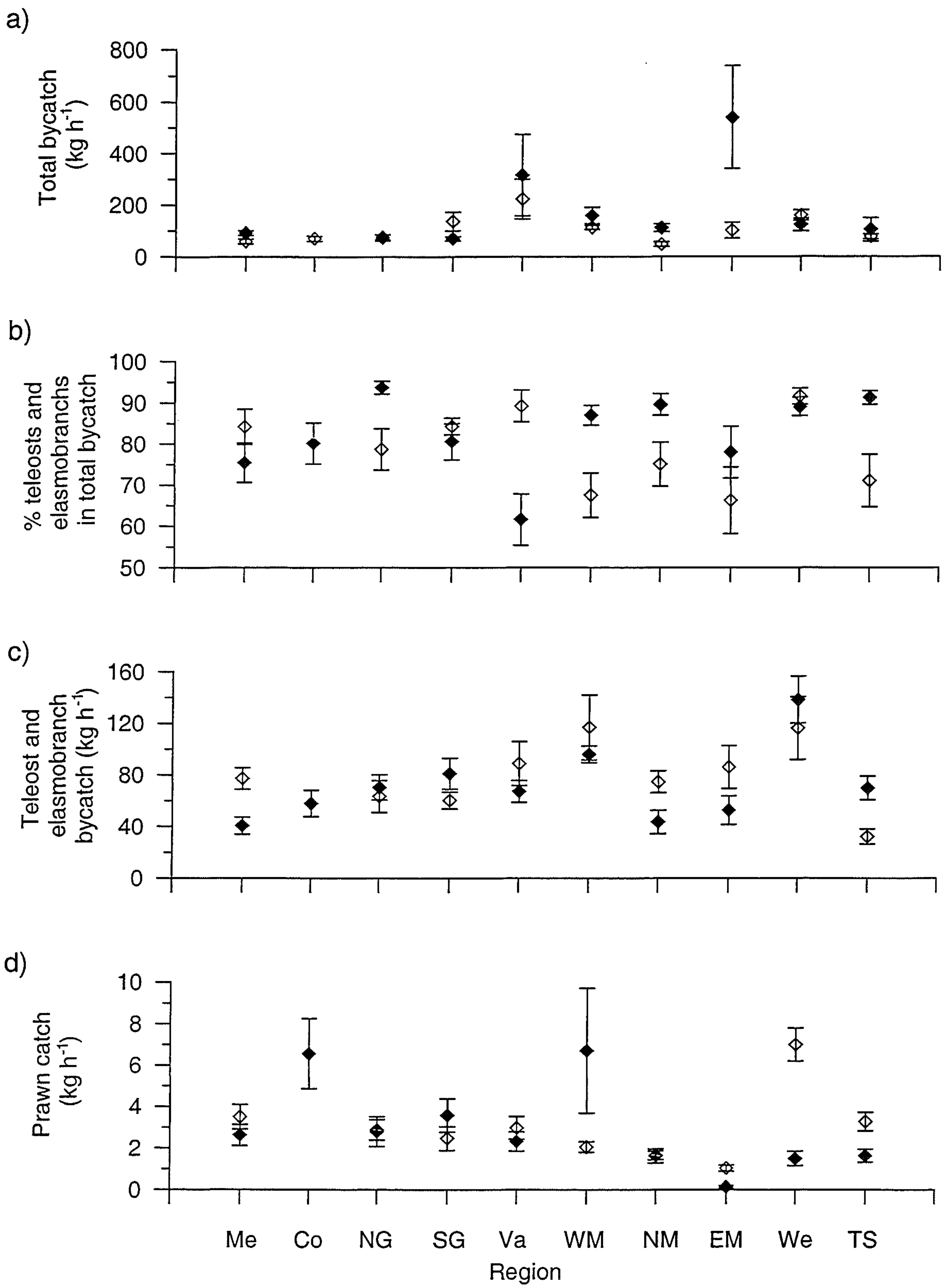

Figure 6.2.2 The mean (± se) (a) total bycatch, (b) proportion of teleosts and elasmobranchs in the total bycatch, (c) catch rate of teleosts and elasmobranch bycatch, (d) catch rate of commercial prawns in each region, at the two times of year, from research surveys. The regions are labelled following Figure 6.2.1., open symbols = February, closed symbols = October.

Spatial and temporal variation in the composition of teleost and elasmobranch bycatch from the research surveys

Overall, there were 359 teleost and elasmobranch bycatch species were recorded in the research surveys. In each region, at one time, between 23 and 45% of the species were detected. However, this is not corrected for the different number of trawls in each region. Therefore, we used 20 simulations that randomly selected 15 trawls from each region, to calculate the number of fish and elasmobranch species present in each region and the number of species in common between regions at the two times of year. 'North Mornington' in October showed the highest number of species (148) and 'East Mornington' in February the lowest (108) (Table 6.2.5). When comparing a single region between the two times of year, most had over half the species in common, ranging from 52% to 63% (Table 6.2.5). In general, in a single region at the two times of year, there were more species in common than in comparison with other regions. The 'Torres Strait' region, overall, tended to have fewer species in common with other regions, than other pairs of regions (Table 6.2.5).

The ordination of the 401 trawls was based on abundance (n h^{-1}) of 135 species (those in at least 5% of trawls). The first principal component explained 14.5% of the variation and the first three account for 34% of the variation among trawls (Figure 6.2.3).

The ANOVAs and *a posteriori* comparisons performed on the first three principal component scores for the trawls showed significant differences among regions and between the two times of year, as well as a significant interaction (Table 6.2.6). Figure 6.2.3 shows the groups of regions which are not significantly different on the first principal component. In terms of the regional differences, the first principal component of the ordination separates out a group of sites containing 'Weipa', 'Melville', 'Cobourg' and 'North Groote', while 'Torres Strait' is separated at the other extreme (Figure 6.2.3). 'East Mornington' and 'West Mornington' were the only regions to show significant differences between the two times of year on the first principal component. On the second principal component the regions that showed a significant difference between February and October were the 'Torres Strait', 'East Mornington', 'North Mornington', 'Vanderlins' and 'Melville'. The size of the F ratios from the ANOVAs on the first three principal components (Table 6.2.6), suggest that variation due to regional differences is much greater than variation due to the time of year or the interaction effects. This confirms the patterns seen in Figure 6.2.3, where the mean location for regions at different times of year, are similar.

Individual ANOVAs on the catch rate of each species show a similar pattern with nearly 99% of the species showing a significant region effect (Table 6.2.7), the majority (101 species) showed the greatest F ratio for region, while only 29 species showed the most variation due to the time of year and 2 species to the interaction. These results suggest that regional differences contribute more to the variation in bycatch composition, than variation due to the time of year or interaction effects. This pattern, with greater variation among regions than between times of year, is similar to the pattern seen in the variation in the general catch characteristics and the number of species in common between regions.

Correlations between the ordination results and species abundances were calculated to determine which species influenced the ordination. There were 17 species that were relatively strongly negatively correlated with the first principal component ($r < -0.4$, $P < 0.05$) and 11 species which were positively correlated with this principal component ($r > 0.4$, $P < 0.05$) (Table 6.2.8). Regions such as 'Melville', 'Weipa' and 'North Groote' have higher abundances of species such as *A. poecilopterus, P. tayenus, L. splendens* and lower abundances of species such as *S. taeniopterus, N. furcosus*, and *S. leptolepis*. The latter species showed higher abundances in the 'Torres Strait' region. On the second principal component community changes appear to reflect changes in 15 species which show a negative correlation with the principal component (Table 6.2.8), with no species showing strong positive correlations. The third principal component had 18 species positively correlated with it (Table 6.2.8).

The differences in bycatch composition among the regions cannot be clearly seen at the family level, as the dominant families are similar in the different regions (Table 6.2.9). However, within families the catch rate of individual species varied substantially among the regions (Table 6.2.10).

The influence of abiotic factors (depth, roughness and hardness), prawn catch rate and commercial effort on the patterns seen in bycatch composition was examined firstly by looking at the correlation between these factors and the principal components of the ordination. The first principal component was significantly negatively correlated with the mean hardness ($r = -0.551$, $P < 0.05$) of trawls. Overall the 'Torres Strait' region had a harder bottom type than the other regions (Figure 6.2.4). The second principal component did not show any strong correlations with abiotics. The third principal component showed significant negative correlations with mean depth ($r = -0.683$, $P < 0.05$).

ANCOVAs were used to examine further the extent to which the factors (depth, roughness, hardness, start time of the trawl, prawn catch rate and commercial effort) contributed to the observed changes in bycatch composition and whether these factors explained the regional or time of year effects. The correlations among the covariates were low and are shown in Table 6.2.11. Those correlations which are significant have low correlation coefficients and so all covariates were included in the analysis.

The ANCOVA (model 6.2.2) on the principal components from the ordination shows that for the first principal component hardness and roughness were significant covariates. The size of the F ratio associated with hardness suggests that this covariate contributes to a large amount of the variation in communities (Table 6.2.6). When model 6.2.3 is applied, which only covers regions in the NPF, hardness is still a significant covariate and depth of the trawls is also significant (Table 6.2.6).

The second principal component has hardness, prawn catch and depth as significant covariates in both models 6.2.2 and 6.2.3. The F ratios associated with these three covariates are large, with prawn catch particularly so (Table 6.2.6). The third principal component has depth and prawn catch and commercial effort as significant covariates on both models (Table 6.2.6).

Although it is clear that the covariates explain significant amounts of the variation in the communities, the F ratios for the region effect on all three principal components remained large, even after the inclusion of the covariates (Table 6.2.6). This suggests that there is still significant variation in bycatch composition due to the effect of regions, that is not accounted for by these covariates.

ANCOVAs on the abundances of species showed a similar pattern (Table 6.2.7) with each covariate significant for some species. Depth, catch rate of prawns and hardness were significant covariates for the greatest number of species (Table 6.2.7). The start time of trawls was not a significant covariate for the principal component scores from the ordination (Table 6.2.6), but was for some species (Table 6.2.7). The differences among regions, however, were still significant in over 88 % of species even with the presence of the covariates. These results suggest that the strong regional variation seen in individual species abundances is not fully explained by these covariates.

The covariates themselves showed strong spatial variation (Figure 6.2.4). Model 6.2.1 ANOVAs on depth, roughness, hardness and effort all had significant regional effects (Table 6.2.12). The roughness and effort also showed significant seasonal variation and there was a significant interaction for depth, roughness and hardness (Table 6.2.12). Depth, hardness and effort all had much larger F ratios for the regional effect suggesting that this accounted for most of the variation in these factors (Table 6.2.12). Roughness showed larger variation between the two times of year (Table 6.2.12), due to changes in the sampling sites within some regions between the two times of year ('Torres Strait', 'North Groote' and 'Melville' regions.

6.2.4 Discussion

The bycatch from the NPF and TSPF examined here is characterised by a high proportion of teleosts, high diversity, predominance of species occurring at low abundance and significant spatial and temporal variation. These characteristics will influence the potential ecological impact of the prawn trawling on bycatch species and the approach to management and monitoring strategies.

The NPF and TSPF are clearly characterised by high levels of bycatch, with variable compositions. The total catches were high, with an average of 145 kg h^{-1} in the research surveys and 113 kg h^{-1} recorded by the scientific observer. The differences between these catch rates may be due to differences in the regions covered by the scientific observer in comparison to the research surveys. This difference may also be contributed to by differences in the duration of the trawls, the research survey trawls were shorter in duration. Wassenberg *et al.* (1998) examined the differences between short duration trawls and trawls of a similar duration to the commercial trawls. They found that short duration trawls accurately represented the species composition, but may over-estimated the catch rates of some species. The species for which the short duration trawls had higher catch rates only contributed to 10% of the weight of the trawls.

Table 6.2.5 The number of species present in each region at each time of year (shaded) and the proportion of species in common between each pair of region by time of year combinations. The bold proportions are comparisons between different times of year in the same region. These results are from 20 simulations of randomly selecting 15 trawls in each region by season combination and the maximums are shown. The region labels follow Figure 6.2.1.

		February									October								
		Me	NG	SG	Va	WM	NM	EM	We	TS	Me	NG	SG	Va	WM	NM	EM	We	TS
February	Me	112	0.60	0.54	0.45	0.46	0.51	0.37	0.43	0.44	**0.55**	0.51	0.48	0.47	0.46	0.46	0.30	0.46	0.37
	NG		114	0.59	0.52	0.45	0.55	0.43	0.54	0.51	0.50	**0.60**	0.57	0.52	0.44	0.49	0.47	0.48	0.40
	SG			124	0.56	0.43	0.51	0.46	0.57	0.45	0.39	0.52	**0.63**	0.61	0.42	0.48	0.52	0.53	0.40
	Va				131	0.51	0.55	0.42	0.51	0.40	0.33	0.47	0.50	**0.59**	0.39	0.45	0.48	0.50	0.37
	WM					113	0.36	0.40	0.41	0.39	0.40	0.45	0.43	0.46	**0.52**	0.37	0.36	0.39	0.28
	NM						129	0.41	0.46	0.55	0.50	0.54	0.51	0.49	0.37	**0.59**	0.44	0.44	0.45
	EM							108	0.56	0.48	0.40	0.32	0.43	0.41	0.37	0.31	**0.57**	0.50	0.39
	We								121	0.42	0.44	0.38	0.52	0.47	0.40	0.34	0.61	**0.63**	0.37
	TS									114	0.44	0.50	0.43	0.42	0.42	0.50	0.45	0.43	**0.56**
October	Me										113	0.52	0.41	0.37	0.39	0.43	0.36	0.48	0.41
	NG											116	0.53	0.44	0.48	0.51	0.34	0.43	0.47
	SG												133	0.60	0.45	0.54	0.46	0.50	0.40
	Va													146	0.43	0.47	0.50	0.52	0.41
	WM														120	0.43	0.42	0.40	0.34
	NM															148	0.35	0.40	0.47
	EM																124	0.58	0.43
	We																	132	0.46
	TS																		116

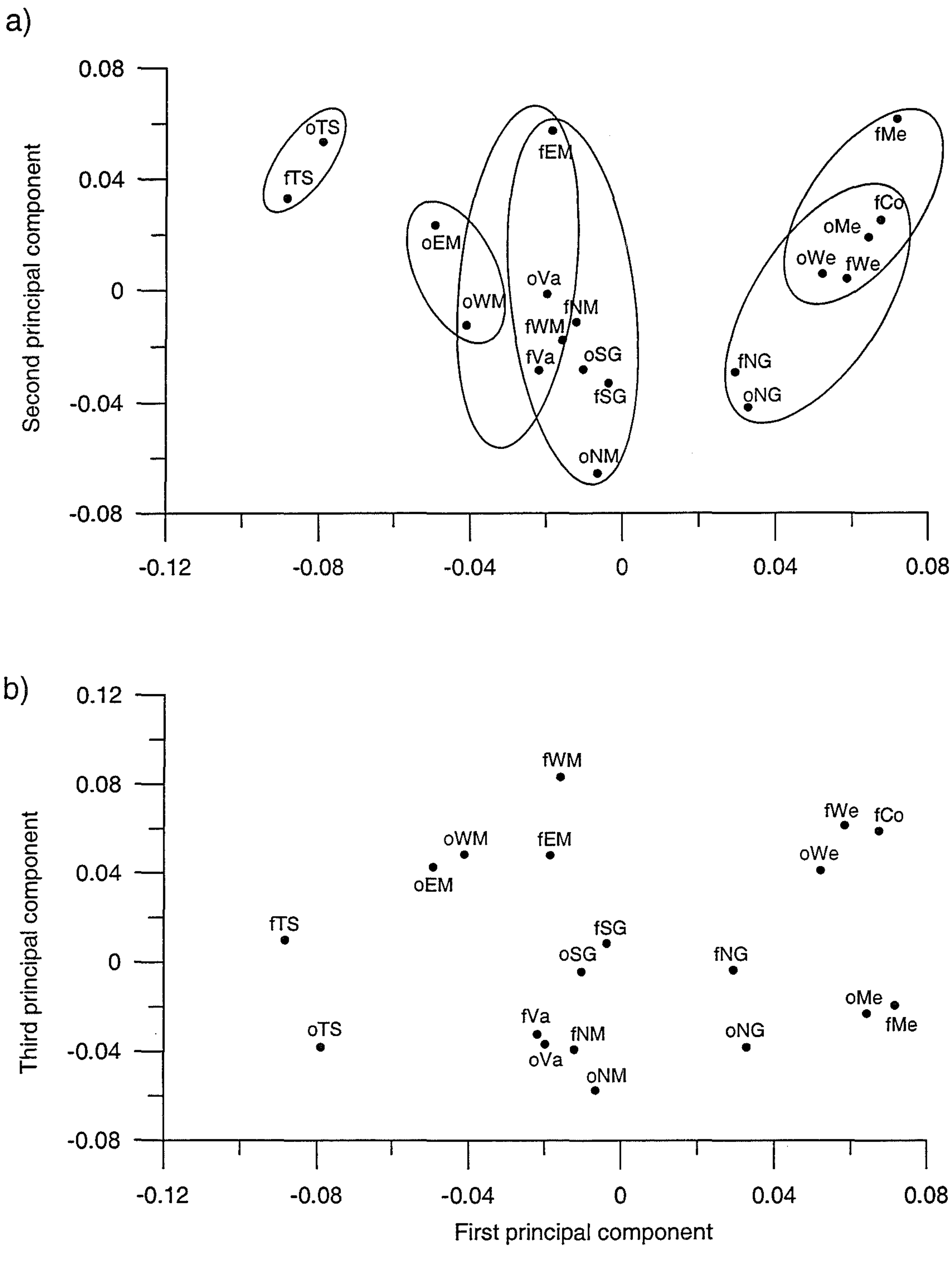

Figure 6.2.3 The results of the ordination on the trawls based on the species composition of the teleost and elasmobranch bycatch. The figure shows the mean position of each region at the two times of year on (a) the first and second principal components and (b) the first and third principal components. The elipses in (a) show which groups of regions by time of year combinations were not significantly different on the first principal components. The labeling follows Figure 6.2.1, o = October, f = February.

Table 6.2.6 Results from the ANOVA and ANCOVAs on the scores for trawls on the first three principal components.

Model 6.2.1

		Effects		
Principal component		**Time of year**	**Region**	**Interaction**
1	F	7.98	183.53	4.22
	P	*0.005*	*< 0.0001*	*< 0.0001*
2	F	6.44	34.07	6.95
	P	*0.0115*	*< 0.0001*	*< 0.0001*
3	F	40.83	67.72	2.83
	P	*< 0.0001*	*< 0.0001*	*0.0046*

Model 6.2.2

		Effects			Covariates				
Principal component		**Time of year**	**Region**	**Interaction**	**Depth**	**Start time**	**Prawn catch**	**Roughness**	**Hardness**
1	F	2.74	108.59	5.79	3.50	0.11	0.25	6.86	23.29
	P	*0.099*	*< 0.0001*	*< 0.0001*	*0.0623*	*0.736*	*0.6171*	*0.0092*	*< 0.0001*
2	F	10.63	42.14	10.56	24.53	2.43	123.29	6.56	20.88
	P	*0.0012*	*< 0.0001*	*< 0.0001*	*< 0.0001*	*0.1201*	*< 0.0001*	*0.0109*	*< 0.0001*
3	F	53.6	20.13	4.08	59.37	0.79	21.22	3.37	0.04
	P	*< 0.0001*	*< 0.0001*	*0.0003*	*< 0.0001*	*0.3735*	*< 0.0001*	*0.0675*	*0.8372*

Model 6.2.3

		Effects			Covariates					
Principal component		**Time of year**	**Region**	**Interaction**	**Depth**	**Start time**	**Prawn catch**	**Roughness**	**Hardness**	**Effort**
1	F	8.54	64.41	6.11	4.94	0.01	0.00	3.06	24.87	3.21
	P	*0.0038*	*< 0.0001*	*< 0.0001*	*0.0271*	*0.9247*	*0.9672*	*0.0814*	*< 0.0001*	*0.0744*
2	F	0.99	31.89	5.96	23.44	1.3	113.11	5.53	18.35	0.08
	P	*0.3198*	*< 0.0001*	*< 0.0001*	*< 0.0001*	*0.2544*	*< 0.0001*	*0.0194*	*< 0.0001*	*0.7709*
3	F	9.18	36.69	3.09	53.27	1.25	14.42	1.46	0.00	5.70
	P	*< 0.0001*	*< 0.0001*	*0.006*	*< 0.0001*	*0.2639*	*0.0002*	*0.2277*	*0.9888*	*0.0176*

Table 6.2.7 The number and percentage of species which showed a significant result for the effects and covariates from the ANOVAs and ANCOVAs.

		Effects			Covariates					
		Time of year	**Region**	**Interaction**	**Depth**	**Start time**	**Prawn catch**	**Roughness**	**Hardness**	**Effort**
Model 6.2.1	**Species (n)**	68	133	73						
	%	*50.37*	*98.52*	*54.07*						
Model 6.2.2	**Species (n)**	67	127	83	56	15	56	25	41	
	%	*49.63*	*94.07*	*61.48*	*41.48*	*11.11*	*41.48*	*18.52*	*30.37*	
Model 6.2.3	**Species (n)**	58	120	78	57	16	50	21	40	11
	%	*42.96*	*88.89*	*57.78*	*42.22*	*11.85*	*37.04*	*15.56*	*29.63*	*8.15*

Table 6.2.8 The species which showed significant correlations between their abundance in a trawl and the principal component score for the trawl from the ordination (Figure 6.2.3).

Principal component 1		**Principal component 2**		**Principal component 3**	
Species	**r**	**Species**	**r**	**Species**	**r**
Scolopsis taeniopterus	-0.744	*Nemipterus hexodon*	-0.698	*Gerres macracanthus*	0.401
Nemipterus furcosus	-0.667	*Saurida* sp. 2	-0.679	*Leiognathus* sp.	0.408
Selaroides leptolepis	-0.627	*Suggrundus macracanthus*	-0.664	*Leiognathus equulus*	0.418
Paramonacanthus choirocephalus	-0.599	*Priacanthus tayenus*	-0.647	*Nemipterus peronii*	0.439
Upeneus tragula	-0.586	*Saurida micropectoralis*	-0.605	*Leiognathus moretoniensis*	0.467
Pentapodus paradiseus	-0.564	*Pentaprion longimanus*	-0.570	*Sillago burrus*	0.467
Leiognathus sp.	-0.557	*Nemipterus nematopus*	-0.565	*Terapon theraps*	0.470
Nemipterus peronii	-0.496	*Apistus carinatus*	-0.564	*Gazza minuta*	0.482
Upeneus luzonius	-0.496	*Apogon ellioti*	-0.523	*Upeneus sundaicus*	0.490
Inegocia japonica	-0.479	*Elates ransonnetii*	-0.492	*Trixiphichthys weberi*	0.491
Lagocephalus sceleratus	-0.479	*Apogon poecilopterus*	-0.468	*Sardinella gibbosa*	0.499
Choerodon cephalotes	-0.467	*Paramonacanthus filicauda*	-0.456	*Polydactylus multiradiatus*	0.504
Lethrinus genivittatus	-0.461	*Pseudorhombus elevatus*	-0.453	*Upeneus asymmetricus*	0.521
Callionymus grossi	-0.459	*Apogon fasciatus*	-0.439	*Pelates quadrilineatus*	0.558
Choerodon sugillatum	-0.458	*Leiognathus moretoniensis*	-0.431	*Torquigener whitleyi*	0.563
Siganus canaliculatus	-0.423			*Caranx bucculentus*	0.570
Gerres macrosoma	-0.405			*Pomadasys maculatum*	0.625
Secutor insidiator	0.409			*Leiognathus leuciscus*	0.637
Leiognathus moretoniensis	0.415				
Pomadasys kaakan	0.426				
Setipinna tenuifilis	0.430				
Anodontostoma chacunda	0.452				
Upeneus sulphureus	0.454				
Bregmacerotidae	0.458				
Nemipterus marginatus	0.467				
Leiognathus splendens	0.520				
Pomadasys trifasciatus	0.566				
Apogon poecilopterus	0.628				

Table 6.2.9 The dominant families in the bycatch from each region and the percentage of the total numbers caught that they contributed.

'Meville'		'Cobourg'		'North Groote'		'South Groote'		'Vanderlins'	
Family	**%**	**Family**	**%**	**Family**	**%**	**Family**	**%**	**Family**	**%**
Leiognathidae	18	Leiognathidae	40	Leiognathidae	31	Leiognathidae	33	Gerridae	12
Nemipteridae	16	Polynemidae	14	Bathysauridae	15	Bathysauridae	13	Bathysauridae	11
Mullidae	14	Teraponidae	11	Gerridae	12	Nemipteridae	10	Leiognathidae	10
Haemullidae	8	Apogonidae	6	Neimpteridae	11	Mullidae	9	Nemipteridae	10
Clupeidae	6	Sciaenidae	5	Apogonidae	10	Gerridae	6	Carangidae	9

'West Mornington'		'North Mornington'		'East Mornington'		'Weipa'		'Torres Strait'	
Family	**%**	**Family**	**%**	**Family**	**%**	**Family**	**%**	**Family**	**%**
Leiognathidae	21	Nemipteridae	26	Haemullidae	28	Leiognathidae	53	Mullidae	16
Nemipteridae	17	Bathysauridae	17	Teraponidae	14	Haemullidae	12	Nemipteridae	16
Teraponidae	13	Mullidae	8	Leiognathidae	12	Apogonidae	7	Leiognathidae	13
Mullidae	9	Leiognathidae	8	Carangidae	7	Clupeidae	7	Carangidae	12
Haemullidae	7	Priacanthidae	6	Nemipteridae	6	Bathysauridae	5	Bathysauridae	11

Table 6.2.10 The mean catch rate of species in the groups of regions separated in the ordination (Figure 6.2.3).

		(Me We NG)		(SG Va EM NM WM)		TS	
		n h^{-1}		n h^{-1}		n h^{-1}	
Family	**Species**	**mean**	**se**	**mean**	**se**	**mean**	**se**
Apogonidae	*Apogon ellioti*	16.32	2.23	27.48	4.24	47.08	7.82
	Apogon fasciatus	19.73	3.44	13.32	3.84	5.06	1.29
	Apogon poecilopterus	184.59	18.04	21.07	2.50	1.65	0.57
Bathysauridae	*Synodus hoshinonis*	—	—	1.15	0.25	0.15	0.11
	Saurida longimanus	3.93	0.99	0.01	0.01	—	—
	Saurida micropectoralis	48.73	6.54	26.74	3.01	3.81	1.39
	Synodus sageneus	—	—	0.29	0.10	2.70	0.92
	Saurida sp. 2	161.11	15.81	148.26	10.76	240.11	41.94
Leiognathidae	*Gazza minuta*	14.48	4.94	6.08	1.30	—	—
	Leiognathus bindus	354.23	133.43	45.35	9.45	11.76	5.02
	Leiognathus decorus	25.05	8.06	18.31	12.36	—	—
	Leiognathus equulus	64.70	21.16	5.12	1.84	—	—
	Leiognathus leuciscus	37.17	11.16	36.08	6.97	1.80	1.06
	Leiognathus moretoniensis	139.30	19.82	198.10	27.16	—	—
	Leiognathus ruconius	54.67	33.64	0.03	0.03	—	—
	Leiognathus sp.	0.12	0.08	34.56	7.44	259.45	80.81
	Leiognathus splendens	380.87	137.59	0.54	0.39	—	—
	Secutor insidiator	35.56	15.32	2.12	0.60	0.15	0.15
Mullidae	*Upeneus asymmetricus*	0.03	0.03	50.68	12.48	20.79	6.19
	Upeneus luzonius	1.36	1.07	8.77	1.61	13.44	3.96
	Upeneus sp. 1	0.94	0.57	16.98	3.04	0.20	0.20
	Upeneus sulphureus	129.75	25.83	47.99	7.15	—	—
	Upeneus sundaicus	9.89	2.32	19.83	3.76	0.32	0.23
	Upeneus tragula	—	—	5.88	0.99	288.01	76.92
Nemipteridae	*Nemipterus furcosus*	0.01	0.01	27.51	5.19	79.65	19.67
	Nemipterus hexodon	101.77	19.96	52.60	6.85	5.93	2.51
	Nemipterus marginatus	91.70	21.40	—	—	—	—
	Nemipterus nematopus	0.31	0.16	60.27	7.77	0.05	0.05
	Nemipterus peronii	1.30	0.42	53.32	8.03	20.17	5.62
	Pentapodus paradiseus	0.55	0.40	5.84	1.22	76.54	20.55
	Scolopsis taeniopterus	2.12	0.87	54.75	8.20	144.40	29.15

The catch rates recorded in the present study are similar to those of previous work in the western NPF (127-234 kg h^{-1}) (Pender *et al,*. 1992) and in the Torres Strait (50.2-157 kg h^{-1}) (Harris and Poiner, 1990). Surveys undertaken in the south eastern area of the Gulf of Carpentaria in the '60s and '80s suggest a decrease in the catch rate of teleosts after 20 years of trawling (Harris and Poiner, 1991). In 1964 the average catch rate of teleosts was 897 ($\pm$ 144) n ha^{-1}, while in 1986 and 1998 Harris and Poiner (1991) reported catch rates of 422 ($\pm$ 103) and 283 ($\pm$ 32) n ha^{-1} respectively. The average catch rate of teleosts in this study from the research survey is the equivalent of 253 ($\pm$12.8) n ha^{-1}. If we look at the East Morning region alone, where the previous work was undertaken, the catch rates were 201 ($\pm$ 149.3) and 746.2 ($\pm$101.7) n ha^{-1} in February and October respectively. The catch rates must be compared with caution as there are significant differences in the gear and season between the previous and current studies. However, the amount of variation seen within the single year in this study is comparable to the variation seen over 20 years by Harris and Poiner (1991). Harris and Poiner (1991) restricted their comparison to a single time of year, April.

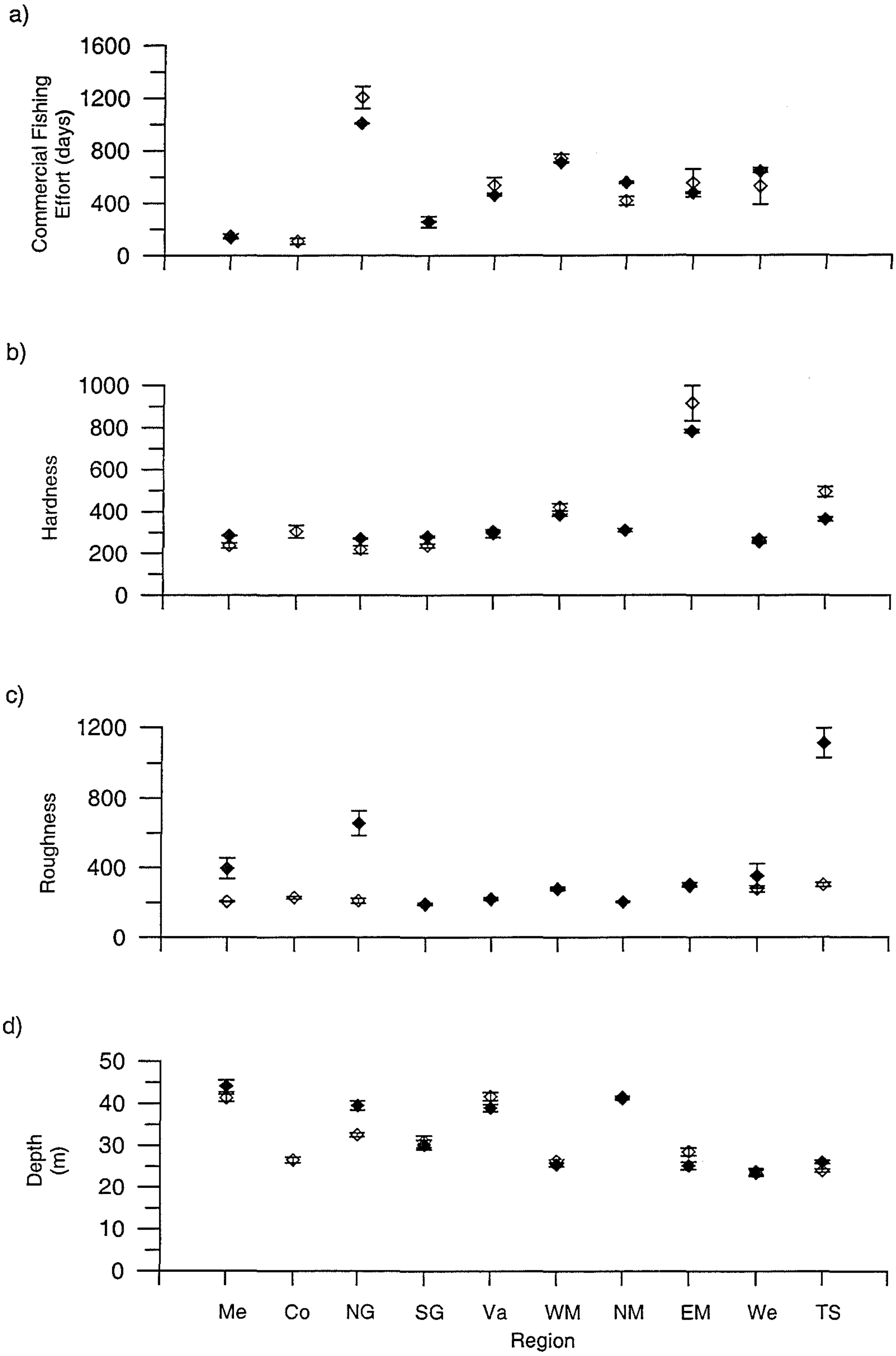

Figure 6.2.4 The mean (± se) (a) commercial fishing effort, (b) acoustic measure of hardness, (c) acoustic measure of roughness and (d) depth for trawls in each region at the two times of year. The labelling follows Figure 6.2.1., open symbols = February, closed symbols =October.

Table 6.2.11 The correlation coefficient between the covariates, the significance is shown in italics.

	Effort	Depth	Roughness	Hardness	Prawn catch
Start time	-0.035	0.007	0.084	0.089	0.026
	0.5033	*0.8826*	*0.1308*	*0.1108*	*0.6046*
Effort		-0.154	0.184	0.064	0.12
		0.0034	*0.0015*	*0.272*	*0.022*
Depth			-0.127	-0.356	-0.08
			0.0223	*< 0.0001*	*0.108*
Roughness				0.246	0.028
				< 0.0001	*0.6122*
Hardness					-0.338
					< 0.0001

Table 6.2.12 The results from the ANOVA (model 6.2.1) on the abiotic variables

Dependent Variable	Effects	df	F	P
Depth	Region	9,382	137.77	< 0.0001
	Time of Year	1,382	0.56	0.4528
	Interaction	8,382	6.43	< 0.0001
Roughness	Region	9,382	30.03	< 0.0001
	Time of Year	1,382	79.73	< 0.0001
	Interaction	7,382	20.96	< 0.0001
Hardness	Region	9,382	98.51	< 0.0001
	Time of Year	1,382	2.04	0.1541
	Interaction	7,382	5.75	< 0.0001
Effort	Region	8,345	55.93	< 0.0001
	Time of Year	1,345	0.39	0.5334
	Interaction	7,345	1.88	0.0703

The bycatch of tropical penaeid fisheries has been shown to be dominated by teleosts and elasmobranchs (Hall, 1999). In the present study 68 to 79% of the weight of the bycatch was made up by these two groups, with teleosts contributing the most to this percentage. This high proportion of teleosts is similar to records from previous work in the western NPF, where bycatch was estimated as 75 to 92% teleosts by weight (Pender *et al.*, 1992). The dominance of teleosts is also similar to the bycatch from prawn trawlers in the Gulf of Mexico (Nance and Scott-Denton, 1996) and on the north east coast of Australia (Poiner *et al.* 1998). However, the bycatch from temperate prawn fisheries appears different; crustaceans dominate the bycatch in Moreton Bay (southern Queensland) and the Gulf of St Vincent (South Australia) (Wassenberg and Hill, 1989, McShane, 1999). In the Moreton Bay fishery teleosts and elasmobranchs contributed only 23.8% of the weight of bycatch (Wassenberg and Hill, 1989).

The large proportion of teleosts and elasmobranchs in the bycatch of tropical penaeid fisheries has implications for understanding the ecological impact of trawling, because of differential survival among species (Wassenberg and Hill, 1989). The survival rate of teleosts species after capture by prawn trawls differs, but in general over 90% die (Wassenberg and Hill, 1989; Hill and Wassenberg, 1990). In contrast taxa such as crustaceans have a much lower mortality from trawling (Hill and Wassenberg, 1990). The survival rate of elasmobranchs is unknown but they are often killed for high value products, such as their fins, so survival of this group can be assumed to be low. The overwhelming majority of the discards from these tropical fisheries are, therefore, likely to be returned dead or dying to the ocean. This low likelihood of survival means that the capture of these species as bycatch results in direct fishing mortality that must be managed. The dead discards also provide a potential food source for scavengers in the ecosystem. The relative importance of the increased mortality of the bycatch species and the food available to scavengers must be understood in order to fully determine the impact on the ecosystem as a whole.

The dominant families in the bycatch by weight, were the Bathysauridae, Leiognathidae, Nemipteridae, Carangidae, Haemullidae and Mullidae (Table 6.2.1). This is similar to the dominance found by Pender *et al.* (1992) in the western NPF. The one major difference is the contribution of Monacanthidae. In Pender *et al.* (1992) this family contributed 6% by weight, while in the current study it made up only 0.34%. Although Pender *et al.* (1992) surveyed a more restricted area, in no single region survey within the present study did Monacanthidae contribute more than 0.43% of the bycatch by weight. In the 'Torres Strait' the Monacanthidae contributed 2.5%, but this is still lower than the contribution of 3.4-11.6% observed in this area by Harris & Poiner (1990).

These tropical fisheries also had a highly diverse (over 400 vertebrate species) bycatch, dominated by a high number of species which occurred in low abundance. Most species were caught rarely (in < 10% of trawls) and in numbers (< 10 n h^{-1}) and biomass (< 1 kg h^{-1}). While tropical prawn fisheries bycatch is often highly diverse, with hundreds of species (Kulbicki and Wantiez, 1990; Andrew and Pepperell, 1992; Pender *et al.*, 1992; Nance and Scott-Denton, 1996; Poiner *et al.*, 1998), in many fisheries a few dominant species contribute to the majority of the weight of the catch (Andrew and Pepperell, 1992). In the present study there were 9 species which accounted for 50% of the bycatch by numbers.

The high species diversity in the bycatch presents a challenge to monitoring and management. The high diversity means that monitoring programs focusing on bycatch composition require the taxonomic capability to identify a large number of taxa. It also means that evaluating the sustainability of the catch of each species using traditional stock assessment methods is impractical. The high diversity also presents a challenge with respect to devices which aim to reduce overall bycatch levels. Significant resources have been focused at bycatch reduction devices (reviewed by Andrew and Pepperell, 1992; Pascoe, 1997), often aimed primarily at reducing the catch of endangered or vulnerable species (Hall, 1999) or those important in other commercial fisheries (e.g. Gutherz and Pellegrin, 1988; Broadhurst *et al.*, 1997). Reduction of the overall amount bycatch is potentially more difficult, particularly in tropical fisheries of high diversity. Most bycatch species are the same size as prawns and they have an unpredictable response to the fishing gear. In fisheries, such as those examined here, it is probably unrealistic to expect that bycatch could be eliminated entirely, emphasising the need to determine which species can or cannot sustain this impact.

Assessing the impacts on species of their capture as bycatch requires reliable estimates of the numbers caught and their population sizes (Hall, 1999). The rarity of the majority of species in the bycatch could be due to natural rarity or the inefficiency of prawn trawls for catching fish. Prawn trawls do not sample all fish species present with equal efficiency (Wassenberg *et al.*, 1997). Some of the species that are rare in the bycatch may, therefore, be caught at rates which are negligible from the point of view of the population (Hall, 1994). Knowledge of the catchability of bycatch species by prawn trawls is therefore, critical to determining the impact. The low catch rates and high variances likely to be associated with rare species, makes the detection of changes in catch rates difficult until the magnitude of the change is large.

The significant spatial and temporal differences in bycatch composition have implications for monitoring strategies. The results suggest that spatial variation in bycatch composition was much stronger than variation due to the two times of year. The large variation among fishing regions is not surprising given the geographical scale of the fisheries, over 15° of latitude and 8° of longitude. The strong differences observed between the 'Torres Strait' region and the regions in the NPF are likely to reflect the fact that in the 'Torres Strait' trawling occurs in a coral reef region, in sandy inter-reef areas (Harris and Poiner, 1990). The NPF regions are likely to have stronger coastal or estuarine influences (Harris and Poiner, 1990). The separation of the regions within the NPF into two groups appears to parallel differences in the dominant target species, rather than the proximity of the regions. The 'Melville', 'Cobourg', 'Weipa' and 'North Groote' regions (Figure 6.2.3) are regions where the prawn catch is dominated by *Penaeus semisulcatus* while the other group (Figure 6.2.3) corresponds to regions where *P. esculentus* dominates. It is also clear that bycatch composition and individual abundance of species was influenced by factors such as depth, seabed characteristics, commercial effort and prawn catch. However, these covariates did not explain all the regional variation observed.

Future monitoring of the bycatch composition and catch rates within these fisheries must, therefore, take into account the spatial and temporal variation. Bycatch samples from a single region are unlikely to be representative of the entire fishery. Monitoring should be stratified with respect to the strong regional differences seen here. Our results provide a compromise solution that could save costs. Despite the large area of the fisheries, the bycatch composition fell into two groups within the NPF and a sampling regime based on two regions should result in a significant cost saving over sampling all regions. The monitoring should also take into account the significant temporal differences. A monitoring strategy should therefore, at a minimum, include regions within each of the major groups (Figure 6.2.3) and be restricted to the same times of year.

The importance of such stratification of sampling has been clearly recognised (Anderson and Pepperell, 1992). However, it requires prior knowledge of the fishing grounds and identification of the primary sources of variation. Initial descriptive surveys, such as those presented here, are crucial for the identification of the major sources of variation. Stratification of sampling for monitoring with respect to the primary sources of variation (in this case spatial and temporal) will reduce the variance around catch rate estimates. The lower the variance the greater the power to detect changes in catch rate which would trigger a management response. The collection of abiotic data (such as depth) was also clearly demonstrated to be important for partitioning the variation in bycatch, increasing the ability of monitoring strategies to detect changes in catch rates which are not due to environmental variables. It is clear, therefore, that in order to manage bycatch in a tropical penaeid fishery, particularly ones that occur over large geographic scales, the identification of the major sources of variation is crucial. If the major sources of variation are not identified and taken into account, the high diversity and rarity of species will limit the power of monitoring strategies.

Specifically, for the NPF, any monitoring strategy should take into account the spatial variation observed here. Sampling should cover at least two regions, representing the major groupings seen in this comparison (Figure 6.2.3). Comparisons between years must be restricted to samples within the same regions to avoid spatial variation confounding the results. The significant variation between the two times of year also suggests that any comparisons between years must also be restricted to samples collected at the same time of year. It would also be beneficial to record abiotic factors, such as depth during sampling, so that variation due to these can be factored out of the analysis.

6.2.5 Conclusions

- The bycatch from the NPF and TSPF is characterised by a high diversity, high proportion of teleosts, a predominance of species occurring at low abundance and significant spatial and temporal variation.

- The spatial variation in bycatch composition was contributed to but not completely explained by differences in abiotic factors; depth, start time of the trawl, acoustic measures of roughness and hardness of the seabed, catch rate of prawns or commercial fishing effort.

- The bycatch composition in the TSPF was distinct from the NPF regions.

- The regions within the NPF formed two groups, based on their bycatch composition, these groups appear to reflect differences in the dominant target penaeid species in the regions.

- Future monitoring strategies must take into account the significant spatial and temporal variation, within the NPF at least 2 regions should be monitored. Comparisons between years must be restricted to samples taken in the same region and at the same time of year.

References

Andrew, N.L., Pepperell, J.G., 1992. The by-catch of shrimp trawl fisheries. Oceanogr. Mar. Biol. Ann. Rev. 30, 527-565.

Broadhurst, M.K., Kennelly, S.J., Barker, D.T., 1997. Simulated escape of juvenile sand whiting (*Sillago ciliata*, Cuvier) through square-meshes: Effects on scale-loss and survival, Fish. Res. 31, 51-60.

Gutherz, E.J., Pellegrin, G.J., 1988. Estimate of the catch of red snapper, *Lutjanus campechanus,* by shrimp trawlers in the U.S. Gulf of Mexico. Mar. Fish. Rev. 50, 17-25.

Hall, S.J., 1999. The Effects of Fishing on Marine Ecosystems and Communities. Blackwell Science Ltd, Great Britain.

Harris, A.N., Poiner, I.R., 1990. By catch of the prawn fishery of Torres Strait: Composition and partitioning of the discards into components that float or sink. Aust. J. Mar. Freshwat. Res. 41, 37-52

Harris, A.N., Poiner, I.R., 1991. Changes in species composition of demersal fish fauna of southeast Gulf of Carpentaria, Australia, after 20 years of fishing. Mar. Biol. 111, 503-519.

Hill, B.J., Wassenberg, T.J., 1990. Fate of discards from prawn trawlers in Torres Strait. Aust. J. Mar. Freshwat. Res. 41, 53-64.

Kulbicki, M., Wantiesz, L., 1990. Variations in the fish catch composition in the bay of St Vincent, New Caledonia as determined by experimental trawling. Aust. J. Mar. Freshwat. Res. 41, 121-144.

McShane, P., 1999. Trophic consequences of prawn trawling: linking by-catch to benthos. In Buxton, E.D., Eayrs, S.E. (Eds), Establishing Meaningful Targets for Bycatch Reduction in Australian fisheries, Australian Society for Fish Biology Workshop Proceedings, Hobart, September 1998. Australian Society for Fish Biology, Sydney.

Nance J.M., Scott-Denton, E., 1996. Bycatch in the Gulf of Mexico Shrimp Fishery. In Hancock, D.A., Smith D.C., Grant, A., Beamer, J.P. (eds.) Developing and sustaining world fisheries resources: the state of science and management, 2nd World Fisheries Congress proceedings, CSIRO Publishing, Australia. pp. 98-102.

Pascoe, S., 1997. Bycatch management and the economics of discarding. FAO Fish. Tech. Paper 370, 137pp.

Pender, P.J., Willing, R.S., Ramm, D.C., 1992. Northern Prawn Fishery bycatch study: distribution, abundance, size and use of bycatch from the missed species fishery., Fishery Report No. 26 (Northern Territory Department of Primary Industry and Fisheries), 70pp.

Poiner, I., Glaister, J., Pitcher, R., Burridge, C., Wassenberg, T., Gribble, N., Hill, B., Blaber, S., Milton, D., Brewer, D., Ellis, N., 1998. Final report on effects of trawling in the Far Northern Section of the Great

Barrier Reef. CSIRO Division of Marine Research, Cleveland, Australia.

Robins, C., Sachse, M., 1994. A Creep Called Technology: Evolution of the Fleet In: Pownall, P.C. (Ed.), Australia's Northern Prawn Fishery. NPF25, Cleveland, Australia, pp 23-34.

Somers, I., 1994. No resource, no fishery: prawns and their habitat. In: Pownall, P.C. (Ed.), Australia's Northern Prawn Fishery. NPF25, Cleveland, Australia, pp.49-65.

Sokal, R.R., Rolf, F.J., 1996. Introduction to biostatistics, 2nd edition. Freeman and Company, New York.

Thresher, R.E., Sainsbury, K.J., Gunn, J.S., Whitelaw, A.W., 1986. Life history strategies and recent changes in population structure in the lizardfish genus, Saurida, on the Australian Northwest shelf. Copeia. 86 (4), 876-885.

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

Wassenberg, T.J., Blaber, S.J.M., Burridge, C.Y., Brewer, D.T., Salini, J.P., Gribble, N., 1997. The effectiveness of fish and shrimp trawls for sampling fish communities in tropical Australia. Fish. Res. 30, 241-251.

Wassenberg, T.J., Burridge, C.Y., Connell, M., Gribble, N., 1998. A validation of short duration scientific tows as a representation of long commercial length tows: comparing the catch rates, size composition and species composition of prawn trawler bycatch in the far northern Great Barrier Reef, Australia. Fish. Res.,36, 35-46.

Williams, W.T., 1976. Pattern analysis in agricultural science. CSIRO Publishing, Melbourne and Elsevier Scientific Publishing Company, Amsterdam.

7. THE SUSTAINABILITY OF VERTEBRATE BYCATCH SPECIES

To measure the impact of prawn trawling on the sustainability of important vertebrate bycatch species, particularly those that may be vulnerable or endangered and for those bycatch species for which no significant reductions can be achieved.

7.1 General introduction

The bycatch of the NPF, TSPF and QBTF is dominated by a high diversity of vertebrates (Section 6). This presents a challenge to fishery managers who are obliged to ensure the sustainability of all bycatch species in order to meet legislative requirements (Section 2). In most prawn trawl fisheries bycatch research and management has been driven by external pressures focusing on particular species. Concern from commercial and recreational fisheries about the impacts of trawling on their target species has resulted in studies focused on these species (e.g. Broadhurst and Kennelly, 1994; Nance and Scott-Denton, 1996). In addition, conservation agencies have focused attention on vulnerable or endangered species (e.g. CSTC, 1990; Poiner *et al.*, 1990). However, there is a need for a process by which prawn trawl fisheries can examine the sustainability of all bycatch species to identify potential problems, rather than being driven by external concerns.

The sustainability of the target species of fisheries is usually determined by stock assessments based on data collected over substantial time periods (e.g. Somers, 1994). This approach is not feasible for bycatch in fisheries such as the NPF where the bycatch consists of a large number of species and there is only limited historical and biological information available with little or no quantitative information. In this section we developed an approach to examine the likely impact of trawling on the vertebrate bycatch species. We applied this process to the NPF but it can be used in other fisheries with bycatch issues of a similar scale. The work focuses only on the vertebrate species that are currently captured as bycatch. It does not attempt to address the issue of whether some species may have already disappeared from the trawled area due to the impacts of fishing since trawling commenced in this area in the 1960s.

We decided that there were two overriding characteristics that determined the sustainability of bycatch species to trawling. These characteristics form two axes of a matrix (Figure 7.1.1):

Axis 1. The susceptibility of a species to capture and mortality due to a prawn trawl
Axis 2. The capacity of a species to recover once the population is depleted.

Each characteristic is composed of several criteria reflecting ecological and biological aspects that will influence either the species susceptibility or recovery capacity. The ranking of the species with respect to these two characteristics reflects their relative ability to sustain capture by trawlers and therefore their priority with respect to management, monitoring and research initiatives (Figure 7.1.1). This approach enables fishery managers to examine their bycatch and address potential problems.

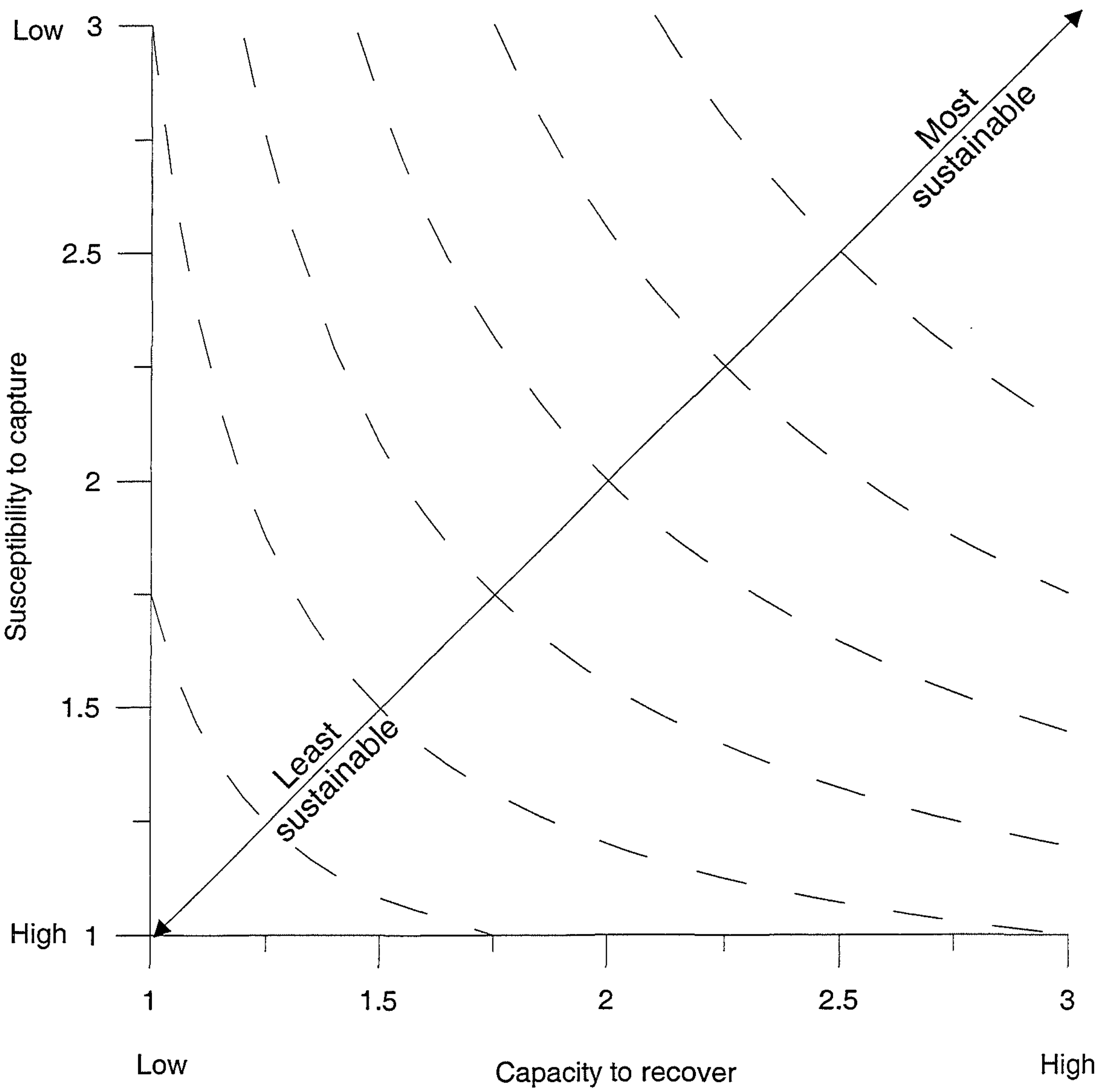

Figure 7.1.1. The axes on which species will be ranked in order to determine their relative priority with respect to management, monitoring and research. The Y axis includes criteria that represent the susceptibility of species to capture and mortality from prawn trawling. The X axis includes criteria that represent the capacity of species to recover after depletion. The contour lines group species that would be similar with respect to their sustainability, based on a multiplicative, symetrical relationship between these axes, explained in Section 7.2.2. The minimum rank species can get on each axis is 1 and the maximum is 3.

7.1 General introduction

This section focuses on the vertebrate bycatch species and their likely sustainability within the NPF. Turtles are excluded from this examination as they have been examined by previous (Poiner *et al.*, 1990) and ongoing research (FRDC project 98/202 "Monitoring the catch of turtles in the NPF"). Turtle catches are also expected to be largely reduced by the introduction of Turtle Excluder Devices (TEDs) in 2000. The teleosts (fishes), elasmobranchs (sharks, rays and sawfishes) and sea snakes are dealt with separately. This separation reflects the fundamental differences in the taxonomy and biology of these groups.

References

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

CSTC (Committee on Sea Turtle Conservation)., 1990 Decline of the sea turtles: Causes and prevention, National Research Council, National Academy Press, Washington D.C.

Nance J.M., Scott-Denton, E., 1996. Bycatch in the Gulf of Mexico Shrimp Fishery. In Hancock, D.A., Smith D.C., Grant, A., Beumer, J.P. (eds.) Developing and sustaining world fisheries resources: the state of science and management, 2nd World Fisheries Congress proceedings, CSIRO Publishing, Australia. pp. 98-102.

Poiner, I.R., Buckworth, R.C., Harris, A.N.M., 1990. Incidental capture and mortality of sea turtles in Australia's northern prawn fishery. Aust. J. Mar. Freshwat. Res. 41, 97-110.

Somers, I, 1994. No resources, no fishery: prawns and their habitat. In: Pownall, P.C. (Ed.), Australia's Northern Prawn Fishery. NPF25, Cleveland, Australia, pp. 49-65.

7.2 The sustainability of teleost bycatch

7.2.1 Introduction

Teleosts (bony fishes) dominate the bycatch of the NPF, contributing 73% of the bycatch weight (Section 6.2.3). However, currently nothing is known about the impact of trawling on the sustainability of any fish species. In many fisheries concern has focused on bycatch species that are the target of other commercial or recreational fisheries (e.g. Broadhurst and Kennelly, 1994; Graham, 1995; Nance and Scott-Denton, 1996). This has resulted in focused research to address the issue of the impact of trawling on specific species. In the region of the NPF there are relatively few other fisheries apart from small shark fisheries, that overlap with the NPF. There have been concerns raised by conservation groups about some fish species. Trawling was nominated under the *Endangered Species Protection Act 1992* as a threatening process for two fish species (*Paramonacanthus japonicus* and *P. filicauda*), but this nomination was not successful. There are also concerns regarding the impact of trawling on pipefishes and seahorses (Family Sygnathidae).

This section aims to assess the capacity of teleost bycatch species to sustain capture as bycatch, in order to identify species that may be an issue for management. The specific objectives of this section were to:

- examine the differences in catch rate of teleost bycatch species between day and night trawling
- develop a process for examining the sustainability of teleost bycatch species with respect to their take in the trawl fishery
- apply this process to teleost bycatch species in order to identify species of high priority with respect to management, monitoring and research.

7.2.2 Methods

Species captured in prawn trawl bycatch in the NPF

A list of the teleost species recorded in prawn trawl bycatch within the NPF was collated from three sources:

- research surveys and scientific observer collections undertaken within the NPF fishing grounds in the current project (Section 6.2.2),
- previous CSIRO research surveys (FRDC 93/179; 92/51) that collected bycatch samples with standard prawn trawl nets in the NPF, and
- bycatch surveys undertaken by the Northern Territory Department of Primary Industry and Fisheries (Pender *et al.,* 1992).

Night versus day catch rates

In order to assess the impact of trawling on the species populations we compared night and day catch rates of some species. Commercial trawling for tiger prawns is a night-time activity, with day-time trawling banned for the majority of the fishing season. A larger proportion of the populations of species with a higher night-time catchability is likely to be caught, than of species with a higher day-time catchability.

In October 1997, prawn trawls were conducted during the day and night in the fishing grounds in order to compare the relative catch rate of species. A two-way ANOVA was used to examine differences in the catch rate with time and region and any interaction between these effects. The catch rates were transformed (log (n h^{-1} + minimum n h^{-1}) prior to analysis to reduce heteroscedasticity. The results reported here focus on significant time or interaction effects only.

Process for assessing the sustainability of bycatch species

Relevant biological and ecological information was collated from the literature for each species (Druzhinin, 1977a; 1977b; Fishelson, 1975; Kartha, 1975; Kothare and Bal, 1975; Pillai and Devadoss, 1975; Hasse *et al.*, 1977; Senta, 1977; Beumer, 1978; Conacher *et al.*, 1979; Winterbottom, 1980; Dawson, 1981; FAO/UNDP Offshore Trawling Surv. Proj., 1981; Moyer and Zaiser, 1981; Collette and Nauer, 1983; Fricke, 1983; Murty, 1983; Said *et al.*, 1983; Compagno, 1984a; 1984b; Datta *et al.*, 1984; Gloerfelt-Tarp *et al.*, 1984; Houde, 1984; Sainsbury and Whitelaw, 1984; Sainsbury *et al.*, 1984; Venkataramani and Natarajan., 1984a; 1984b; Allen, 1985; Golani and Ben-Tuvia, 1985; Jayabalan *et al.*, 1985a; 1985b; Jones, 1985; Nakamura, 1985; Winterbottom, 1985a; 1985b; Jayabalan, 1986; Kailola, 1986; Moyer, 1986; Murty, 1986; Thresher *et al.,* 1986; Wongratana, 1986; Bawazeer, 1987; Naama and Yousif, 1987; Allen and Swainston, 1988; Ibrahim *et al.*, 1988; Jayabalan, 1988a; 1988b; McDowall, 1988; Munekiyo and Kuwahara, 1988; Rajaguru *et al.*, 1988; Whitehead *et al.*, 1988; Wijeyaratne and Costa, 1988; Withell and Wankowski, 1988; Bawazeer and Al-Baz, 1989; Carpenter and Allen, 1989; Menon *et al.*, 1989; Shaffer and Nakamura, 1989; Wassenberg and Hill, 1989; Das and Mishra, 1990; Hill and Wassenberg, 1990; Hussain, 1990; Marquez, 1990; Murty, 1990; Nagasawa, 1990; Randall *et al.*, 1990; Rao, 1990; Russell, 1990; Sumpton and Greenwood, 1990; Brewer *et al.*, 1991; Cyrus and Martin, 1991; Jayabalan, 1991; Kurup and Samuel., 1991; Barry and Fast, 1992; McKay, 1992; Park, 1992; Al-Ghais, 1993; Chapleau and Renard, 1993; Grant, 1993; Heemstra and Randall, 1993; Hill and Wassenberg, 1993; Nakamura and Parin, 1993; Randall and Goren, 1993; Arai, 1994; Blaber *et al.*, 1994a; 1994b; Brewer *et al.*, 1994; El-Sayed and Bary., 1994; Gladstone, 1994; Last and Stevens, 1994; Lieske and Myers, 1994; Nemeth, 1994; Render *et al.*, 1994; Salini *et al.*, 1994; Tanaka, 1994; Zavala Garcia and Flores-Coto, 1994a; 1994b; Clarke and Privitera, 1995; Ebisawa *et al.*, 1995; Ferreira, 1995; Kennelly, 1995; Krishnakumar and Blakrishnan., 1995; Venkataramani *et al.*, 1995; Clarke, 1996; Iwai *et al.*, 1996; Mohsin and Ambak, 1996; Pauly *et al.*, 1996; Reuben *et al.*, 1996; Allen, 1997; McKay, 1997; Sasaki, 1997; Froese and Pauly., 1999; Staunton-Smith *et al.*, 1999). This information was then used to rank the species along two axes, that described the overriding characteristics that would determine the sustainability of the species in bycatch:

Axis 1: The susceptibility of a species to capture and mortality due to a prawn trawl,
Axis 2: The capacity of a species to recover once the population is depleted.

Each characteristic (or axis) was derived from several criteria that summarised aspects of the biology and ecology of the species (7 criteria for axis 1 and 6 criteria for axis 2). Each species was given a rank from 1-3 for each criterion. A rank of 1 reflects the state of that criterion that would result in the species being highly susceptible to capture or having a low capacity to recover. A rank of 3 reflects the state of that criterion that would result in the species having a low susceptibility to capture or a high capacity to recover. Within each axis the rank for each criterion was multiplied by the criterion weighting score and then summed to produce a value for each species on the axis. The weighting score of the criteria was determined by the NPF Fishery Assessment Group (NPF FAG), through consensus. The weighting scores reflect the relative importance each criterion in determining the overall characteristic.

Where species specific information was not available, a species was given a rank based on the ranks for other species within its family, or a rank of 1.

Axis 1: The susceptibility of species to capture and mortality due to a prawn trawl
The criteria on this axis were:

Water column position (weight = 3)
The distribution of the species in the water column was determined from the literature. Prawn trawls fish close to the sea floor, resulting in demersal and benthic species having a higher susceptibility to capture than pelagic species.

Rank	Description
1	Demersal or benthic species, species that are closely associated with the sea floor or the water column just above the sea floor
2	Benthopelagic species, species that utilise the water column close to the sea floor but also the higher water column
3	Pelagic species, species that occur primarily in the higher water column

Preferred habitat (weight = 3)
This criterion is derived from the available literature on the primary habitat of a species and reflects the overlap of the species habitat with the habitat where trawling occurs.

Rank	Description
1	Species that primarily occur over soft or muddy sediments or specifically on prawn trawl grounds
2	Species known to occur in soft or muddy sediments or prawn trawl grounds but that also use other habitats such as reefs or estuaries
3	Species that primarily occur in habitats outside trawl grounds, such as reef associated species

Survival (weight = 3)
This ranking is based on information from studies of the survival of bycatch species after capture in a trawl (Wassenberg and Hill, 1989; Hill and Wassenberg, 1990; 1993). The data available for individual species was limited, covering only 17 species and so the values were extrapolated for families. The range of survival is from 0% to 100% and so this was divided into thirds for the ranks.

Rank	Description
1	Species with a probability of survival that is < 33% or for which there are no data
2	Species with a probability of survival that is between 33 % and 66 %
3	Species with a probability of survival that is > 66%

Range (weight = 2)

This criterion reflects the range of the distribution of the species within the NPF and was determined from the scientific surveys within the current project (Section 6.2). The presence/absence of each species was recorded in the 9 regions (Section 6.2). It was assumed that species with a restricted range could potentially be impacted more heavily by trawling than those with a broader range.

Rank	Description
1	Species occurred in ≤ 3 regions
2	3 regions < the number of regions a species occurred in ≤ 6 regions
3	Species occurred in > 6 regions

Day/night catchability (weight = 2)

This reflects the relative catch rate of species during night and day time trawling determined from the current study as outlined previously. The tiger prawn fishery is predominantly a night time fishery, with day time trawling banned for most of the season (AFMA). Species with a significantly higher mean catch rate during the night are, therefore, more susceptible to capture by trawls.

Rank	Description
1	Species that had a significantly higher mean catch rate during night-time trawling
2	Species that had no significant difference in catch rate between night and day-time trawling, or no data available for the species
3	Species that had a significantly higher mean catch rate during day-time trawling

Diet (weight = 2)

This criterion reflects whether the diet of the species would attract them to trawl grounds and whether they feed within the area of the water column that is swept by a prawn trawl. This information came from the literature that examined species' diets.

Rank	Description
1	Species that are known to or are capable of feeding on commercial prawns
2	Species that are not known to feed on commercial prawns, but which feed on other benthic or demersal organisms
3	Species that feed on pelagic organisms

Depth range (weight = 1)

Trawling occurs mainly at depths between 15 m and 40 m in the NPF (Somers, 1994). The overlap between these depths and the preferred depth distribution of species will influence their susceptibility to capture. The depth distribution of species was determined from the depths at which species were recorded in previous CSIRO surveys in the area of the NPF, and from species depth distributions in the literature. The coarse scale reflects the limitations of the available data.

Rank	Description
1	Species with a depth distribution that is limited to < 40 m
3	Species with a depth distribution that extends deeper than 40 m

Axis 2: The capacity of a species to recover once the population is depleted

The criteria on this axis were:

Breeding (weight = 3)

The probability that an individual of a species has bred before capture was determined from the mean length at capture of a species in comparison to the size at first maturity. A t-test (Sokal and Rohlf, 1996) was used to determine whether the mean length at capture was significantly different to the size at first maturity.

The mean length at capture of a species was determined from data collected in the present study. In each trawl on the research surveys, up to 20 randomly selected individuals of each species were measured and from this the mean length at capture calculated. The size at first maturity was determined from the available literature. This size is not known for most species. To overcome this lack of information, we calculated, within families, the ratio of size at first maturity to maximum size and this ratio was used to estimate the size at first maturity for those species where this was not known. For families in which there was no available information on the size at first maturity of any species, the ratio between size at first maturity and maximum size was estimated from the other families combined.

The species for which the average length at capture was not available were given a rank of 1.

Rank	Description
1	The mean length at capture is significantly less than the size at first maturity, suggesting that the probability an individual has bred before capture is less than 50%
2	The mean length at capture is not significantly different from the size at first maturity, suggesting that the probability an individual has bred before capture is 50%
3	The mean length at capture is significantly greater than the size at first maturity, suggesting that the probability an individual has bred before capture is greater than 50%

Maximum size (weight = 3)
The maximum size of a species was used as an estimate for the relative recovery rate for the species. In general, larger species tend to be longer lived and their populations recover more slowly (Roberts and Hawkins, 1999). The estimate of maximum size came from the literature. If no estimate was available the largest size captured in the present study was used as the estimate.

The range of the maximum sizes of species was calculated and divided into thirds for the ranks.

Rank	Description
1	A maximum size > 1300 mm
2	200 < maximum size ≤ 1300 mm
3	A maximum size ≤ 200 mm

Removal rate (weight = 3)
In general the higher the proportion of biomass removed the lower the ability of the population to recover.

Estimate of the removal rate and total biomass of species in the NPF
An estimate of the removal rate by the fishery was obtained using the catch rates from the present study. An estimate of the total biomass of bycatch species in the region of the fishery was also generated, so that the removal rate could be looked at as a proportion of total biomass.

The removal rate was generated from the catch rates of species from night-time prawn trawls from the research surveys as well as data collected by scientific observer surveys (Section 6.2.2) (Table 7.2.1). This assumes that the catch rates observed in the current study were representative of the catch rates in the commercial fishery. The trawls during the research surveys were shorter in duration than commercial trawls, which may affect catch rates. Comparisons conducted by Wassenberg *et al.* (1998) demonstrated that short duration trawls accurately reflected the species composition and size frequency of longer duration trawls, but that they may over-estimate catch rates. This suggests that the process used in the present study, where a combination of short duration research trawls and long duration commercial length trawls from the scientific observer were used to generate the removal rate may over-estimate the removal for some species. The fact that the removal rates were based on catch rates from several times of year is important. This results in an estimate that is less likely to be biased than one obtained from a single point in time.

Catch rates (n h^{-1} and kg h^{-1}) were converted into catch per swept area of the trawl (n km^{-2} and kg km^{-2}). This assumed that the prawn trawls had a spread of 0.66 of the headrope length (Bishop and Sterling, 1999).

In order to take into account the significant spatial variation within the fishery (Section 6.2), the fishery was stratified using the bioregions from the IMCRA process (Thackway and Cresswell, 1998) (Figure 7.2.1). An average catch rate for each species was calculated in each bioregion where commercial tiger prawn trawling occurs, but excluding the Joseph Bonaparte Gulf (JBG). The estimate of the annual removal rate by the commercial fishery (n y^{-1} and kg y^{-1}) was calculated by multiplying the catch rate by the 1997 commercial fishery effort in each bioregion (AFMA logbook information, Table 7.2.2). Commercial fishery effort is recorded in boat days. One boat day was assumed to be the equivalent of 14 h trawling with two nets with 14 fathom (25.48 m) headropes at a speed of 3.2 knots (5.9 km h^{-1}).

The estimate of the total removal rate for the fishery was obtained by summing the removal rates in each bioregion. This removal rate was then converted to a proportion of the estimated total biomass of the species present in the bioregions where commercial tiger prawn trawling occurs (excluding the JBG) of the NPF.

An estimate of the total biomass of each species in the bioregions where tiger prawn trawling occurs was generated from all research and scientific observer surveys conducted in the NPF during the 1990's (FRDC 88/77; 90/29; 92/51; 93/179; Blaber *et al.*, 1994a; Crocos and Coman, 1992; Milton *et al.*, 1995) including the work from the current study (Figure 7.2.2, Table 7.2.1). The gears used were prawn trawls and two types of fish trawls (Frank and Bryce trawls and Engel trawls). Both night and day-time trawling occurred. We did not limit ourselves to prawn trawl surveys because this would have restricted the areas sampled to the fishing grounds (Figure 7.2.1).

The catch rates (n h^{-1} and kg h^{-1}) were converted to the catch per swept area of the trawl (n km^{-2} and kg km^{-2}). The fish trawls were assumed to have a spread of 0.6 of the headrope length (Blaber *et al.*, 1994a).

The catch rates of the different gears were not converted to an estimate of catch rate with a standard gear because the relative catchability of species in the different gear types is unknown. We also did not try and convert day-time catch rates to a night-time equivalent as the relative catchability of most species at the two times is unknown. Some comparisons have been made between day-time Frank and Bryce trawls and night-time prawn trawls for some species (Wassenberg *et al.,* 1997). However, for most species the relative catchability is unknown. An average catch rate for each gear at each time (day or night) was calculated in each bioregion, resulting in up to 6 catch rate estimates for a species in a bioregion. The highest catch rate estimate was taken as the catch rate for the species in that bioregion. This catch rate was then multiplied by the area of the bioregion to give an estimate of total biomass (n and kg). Currently there are no robust estimates of the catchability coefficients for these gears and these species and so we assumed a catchability coefficient of 1 for all species. Such a high catchability coefficient is unlikely to be valid for most species and this means that we have underestimated of the total biomass.

There were 2 bioregions in which commercial tiger prawn trawling occurs for which no survey data were available to estimate catch rates (Arnhem Wessel and Arafura, Figure 7.2.1) The average catch rate across all other bioregions was taken as the estimate of catch rate in these bioregions.

Table 7.2.1 The time, type and gear used in the surveys that contributed to the estimate of the total biomass and removal rate (*) for teleost and elasmobranch species in the NPF. # only used for elasmobranchs (Section 7.3).

Year	Month	Type	Gear	Trawls (n)	Nets used (n)	
1990	November - December	Research survey	Frank and Bryce	128	1	
1991	November	Research survey	Frank and Bryce	62	1	
1993	January - February	Research survey	Engels, Frank and Bryce	71	1	
1993	August	Research survey	Florida Flyer	9	2	
1993	October	Research survey	Florida Flyer	5	2	
1993	November	Research survey	Florida Flyer	81	1	
1994	March	Research survey	Florida Flyer	5	2	
1994	May	Research survey	Florida Flyer	4	2	
1994	July	Research survey	Florida Flyer	7	2	
1994	November	Research survey	Florida Flyer	7	2	
1995	February - March	Research survey	Florida Flyer	39	1	
1995	June	Research survey	Florida Flyer	38	1	
1995	October - November	Research survey	Florida Flyer	39	1	
1996	September	Scientific observer	Florida Flyer	83	1 (2 #)	*
1997	May - June	Scientific observer	Florida Flyer	76	1	*
1997	August - October	Crew member observer	Florida Flyer	141	2	*#
1997	September - October	Scientific observer	Florida Flyer	60	1	*
1997	February - March	Research survey	Florida Flyer, Engels	248	1	*
1997	October	Research survey	Florida Flyer	424	1	*
1998	September - October	Research survey	Florida Flyer	366	1	*

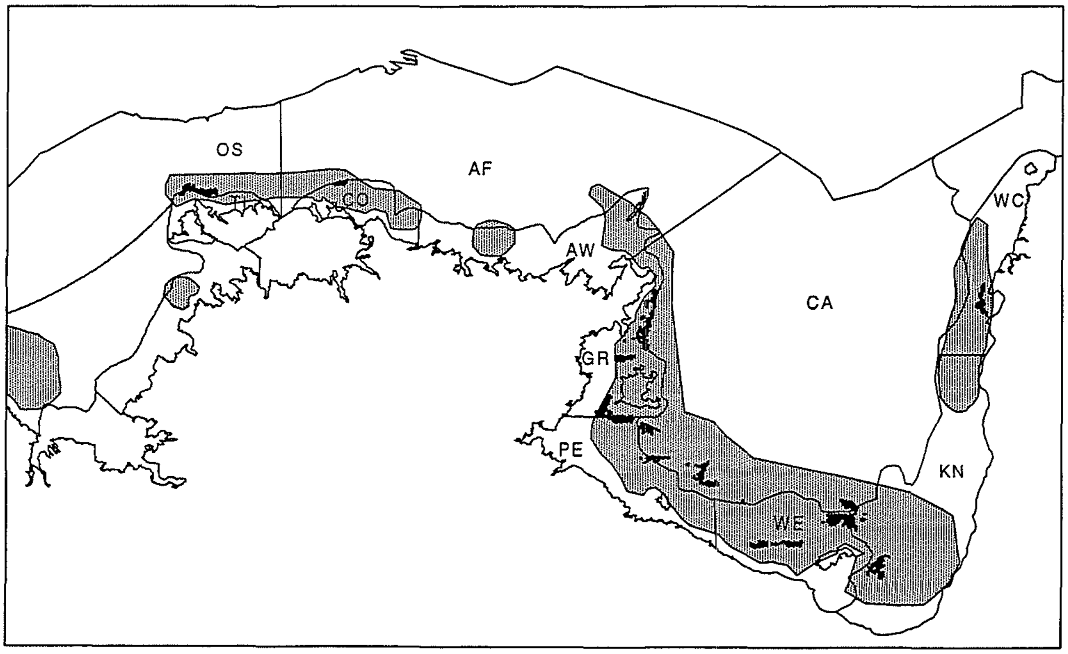

Figure 7.2.1 The bioregions defined in the NPF through the IMCRA process (Thackway and Cresswell, 1998). The shaded area represents the region fished by commercial prawn trawlers. The dots mark the positions of the trawls sampled in the present study, to estimate the removal rate of bycatch species. Bioregions; OS = Oceanic Shoals, TI = Tiwi, Co = Cobourg, AR = Arafura, AW = Arnhem Wessel, CA = Carpentaria, GR = Groote, PE = Pellew, WE = Wellesley, KN = Karumba-Nassau, WC = West Cape York.

Table 7.2.2 The area of the bioregions where commercial trawling for tiger prawns occurs in the NPF (excluding Joseph Bonaparte Gulf) as shown on Figure 7.2.1 and the amount of commercial fishing effort in each bioregion.

Bioregion	Total area km^2	Effort boat days
Anson Beagle	2026	42
Arafura	155081	92
Arnhem Wessel	27425	21
Carpentaria	229975	2349
Cobourg	10302	97
Groote	19435	2909
Karumba-Nassau	56477	1524
Oceanic Shoals	253344	198
Pellew	25507	558
Tiwi	5130	45
Wellesley	21931	2195
West Cape York	27369	2846

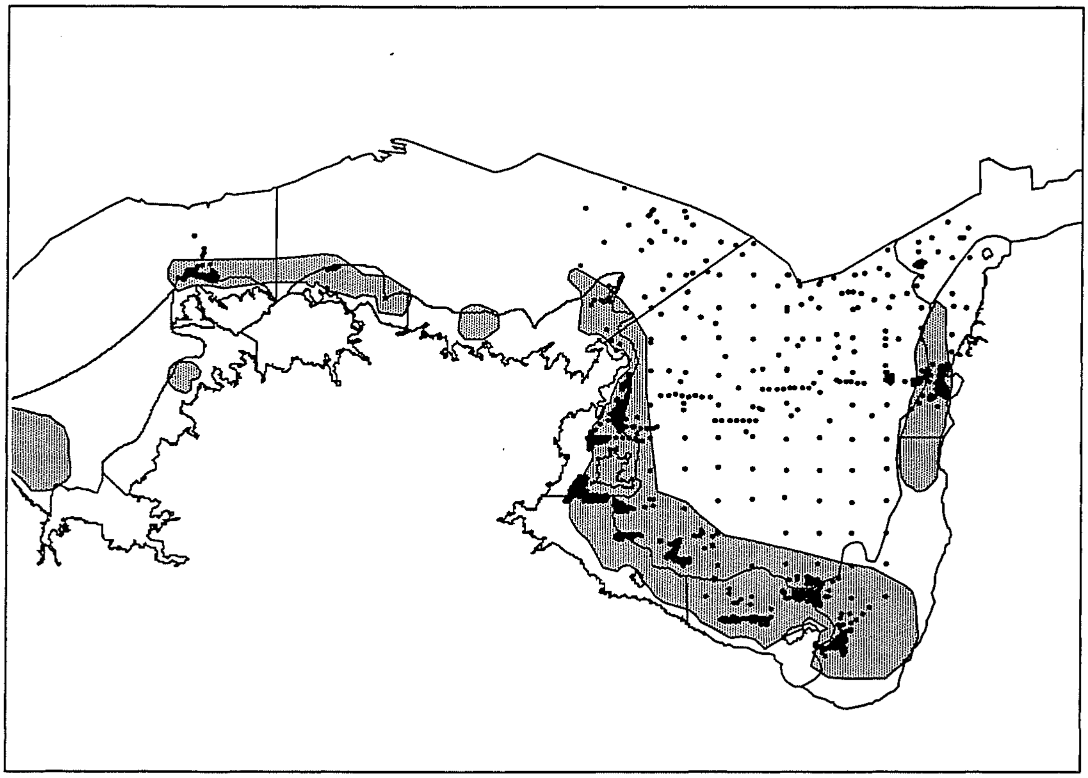

Figure 7.2.2 The bioregions and fishing grounds within the NPF (detailed in Figure 7.2.1.) and the location of sampling sites (dots) used to estimate the total biomass of bycatch species within these

The estimates of total biomass depend on several important assumptions. Species were assumed to be uniformly distributed within bioregions. This is unlikely given the size of the bioregions. However, little information is available that would enable stratification below the scale of bioregion, except perhaps with respect to depth. Stratification by bioregion and depth would be appropriate as depth has been shown to influence the abundance of the species (Section 6.2). If strata within bioregions were used the number of trawls available to estimate abundances within strata would have been very low, so the stratification was left at the level of bioregions. While not ideal, this stratification is better than assuming the region as a whole is uniform. Section 6.2 clearly shows that there is significant geographic variation within the NPF and stratification by bioregions takes this into account.

The distribution of samples used in the estimates of total biomass was not random or even within bioregions. In most bioregions the sampling did not cover the full extent of the bioregion and is unlikely to have covered all the available habitats. This may be particularly important in the coastal bioregions where none of the shallow coastal areas were sampled. However, the current process was not able to quantify the proportion of the population in the shallow coastal areas in comparison to the proportion in the prawn trawling grounds. This may have resulted in an underestimate of the total biomass for species with distributions that extend into the shallow coastal areas.

The different sampling gears used in the different surveys also introduce potential biases. Fish trawls have a larger codend mesh size and fish higher off the seabed than prawn trawls. They tend, therefore, to catch the larger and more pelagic species (Wassenberg *et al.*, 1997). The prawn trawls tend to catch smaller, demersal and benthic species (Wassenberg *et al.*, 1997). Wassenberg *et al.* (1997) showed that neither gear was effective at sampling the whole fish community in a region. The implication of this is that the abundance of the species most susceptible to prawn trawls is likely to be underestimated by fish trawl surveys. This could result in an over-estimate of the proportion of the population removed for these species, as the estimate of total biomass would be low. It would have been preferable to restrict the estimate of total biomass to samples solely using prawn trawls, removing any effect of gear type from the estimate of relative abundance inside and outside the fishing grounds. However, doing so would have restricted the data available from outside the fishing grounds, because this sampling was done primarily with fish trawls.

The estimates of total biomass are also restricted by the fact that the surveys were conducted over 8 years and in a range of seasons. This would have introduced significant sources of variation. The mean catch rate in different bioregions may have been generated by surveys from different times of year.

The removal rate should range from 0% to 100%, and this range was divided into thrirds for the divisions between the ranks.

Rank	Description
1	Proportion of biomass removed > 66 %
2	33 % < proportion of biomass removed $\leq$ 66 %
3	Proportion of biomass removed $\leq$ 33%

Reproductive strategy (weight = 2)
The reproductive strategy of the species was determined from the literature and provides a proxy for the relative fecundity of the species, the latter is not available for most of species. Species that are broadcast spawners have the capacity to produce more young than species that bear live young or brood their young. This means that broadcast spawners have the capacity to recover faster if their population size is reduced.

Rank	Description
1	Species that bear live young or brood their young
2	Species that guard their eggs and/or their young
3	Species that are broadcast spawners

Hermaphroditism (weight = 1)
It has been suggested that hermaphroditic species generally have a lower capacity to recover, as hermaphroditism is often associated with other characteristics that produce a lower recovery rate (Roberts and Hawkins, 1999).

Rank	Description
1	Species that display hermaphroditism
3	Species that are dioecious (separate sexes)

Mortality Index (weight = 1)
A measure of instantaneous mortality can be derived from the length frequency of a species and the von Bertelanffy growth parameters (Sparre and Venema, 1992). For the majority of species von Bertelanffy parameters are not available and so an a index of mortality was calculated

$$\text{Mortality Index} = (L_{max} - L_{ave}) / (L_{ave} - L_{min})$$

L_{max} is the maximum length, L_{ave} is the average length at capture and L_{min} is the length at first capture. The closer the average length of a species (L_{ave}) is to the maximum length (L_{max}) the lower the mortality the population is subject to. As mortality due to fishing increases, the average length of species in a population approaches the minimum length (L_{min}). This assumes constant catchability and mortality across the whole length range caught. The L_{ave} and L_{min} were calculated from data collected during the research surveys (Section 6.2.2), including both day and night time trawls.

The range of the mortality indices was calculated and divided into thirds for the ranks.

Rank	Description
1	mortality index > 2.7,
2	0.75 < mortality index $\leq$ 2.7,
3	mortality index $\leq$ 0.75.

Partial correlations (Sokal and Rohlf, 1996) were used to dtermine whether there was any redundancy in the criteria. Highly correlated criteria would suggest that they are explaining the same factors and therefore, one of the criteria should be removed.

The summed ranks of each criteria (after weighting) were then graphed to determine the species that were likely to be least sustainable in bycatch. Contour lines were drawn on the graph to group species that would be similar with respect to their sustainability. As neither susceptibility or recovery alone provide a complete index to the sustainability of species, the index is a combination of these. Recovery is likely to be conditionally important on susceptibility and therefore, a multiplicative relationship between the two axes is appropriate. We have assumed that this relationship was symmetrical and given this assumption the contour lines follow the equation;

$$16(y - 0.75)(x - 0.75) = 4, 9, 16, 25, 36, 49 \qquad \textbf{(Equation 6.2.1)}$$

7.2.3 Results

Species captured in the prawn trawl bycatch of the NPF

At least 411 species, from 99 families, have been recorded in the bycatch from the NPF from the sources outlined in Section 7.2.2 (Table 7.2.3). The current study detected 354 of these taxa in research surveys and scientific observer collections. Over 40% of the families were represented in the bycatch by a single species, but the number of species ranged up to 32 for the family Carangidae.

Table 7.2.3 The teleost species recorded in bycatch from the NPF, from the sources outlined in Section 7.2.2.

Family	Species	Family	Species
Acropomatidae	*Malakichthys* sp. 1	Bothidae	*Pseudorhombus spinosus*
Antennariidae	*Antennarius hispidus*	Bregmacerotidae	*Bregmaceros japonicus*
	Antennarius nummifer		*Bregmaceros mcclellandi*
	Antennarius pictus	Caesionidae	*Caesio caerulaurea*
	Antennarius striatus		*Caesio teres*
	Tathicarpus butleri		*Pterocaesio chrysozona*
	Tetrabrachium ocellatum		*Pterocaesio digramma*
Aploactinidae	*Adventor elongatus*	Callionymidae	*Callionymus belcheri*
Apogonidae	*Apogon albimaculosus*		*Callionymus goodladi*
	Apogon aureus		*Callionymus grossi*
	Apogon brevicaudata		*Callionymus japonicus*
	Apogon cavitiensis		*Callionymus meridionalis*
	Apogon ellioti		*Callionymus sublaevis*
	Apogon fasciatus		*Dactylopus dactylopus*
	Apogon melanopus		*Synchiropus rameus*
	Apogon nigripinnis	Carangidae	*Alectis ciliaris*
	Apogon nigrocincta		*Alectis indicus*
	Apogon notatus		*Alepes* sp.
	Apogon poecilopterus		*Atule mate*
	Apogon septemstriatus		*Carangoides caeruleopinnatus*
	Apogon sp. 2		*Carangoides chrysophrys*
	Cheilodipterus artus		*Carangoides fulvoguttatus*
	Pseudamia amblyuroptera		*Carangoides gymnostethus*
	Rhabdamia gracilis		*Carangoides hedlandensis*
	Siphamia argyrogaster		*Carangoides humerosus*
	Siphamia fuscolineata		*Carangoides malabaricus*
	Siphamia guttulatus		*Carangoides talamparoides*
	Siphamia majimai		*Caranx bucculentus*
	Siphamia roseigaster		*Caranx kleinii*
Ariidae	*Arius argyropleuron*		*Caranx melampygus*
	Arius bilineatus		*Decapterus macrosoma*
	Arius nella		*Decapterus russelli*
	Arius proximus		*Gnathanodon speciosus*
	Netuma thalassinus		*Megalaspis cordyla*
Ariommatidae	*Ariomma indica*		*Pantolabus radiatus*
Balistidae	*Abalistes stellaris*		*Parastromateus niger*
Bathysauridae	*Saurida longimanus*		*Scomberoides commersonnianus*
	Saurida micropectoralis		*Scomberoides tala*
	Saurida sp. 2		*Scomberoides tol*
	Saurida undosquamis		*Selar boops*
Batrachoididae	*Batrachomoeus trispinosus*		*Selar crumenophthalmus*
Bothidae	*Arnoglossus waitei*		*Selaroides leptolepis*
	Engyprosopon grandisquamum		*Seriolina nigrofasciata*
	Grammatobothus polyophthalmus		*Trachinotus cf mookalee*
	Laeops parviceps		*Ulua aurochs*
	Psettina gigantea		*Ulua mentalis*
	Psettina tosana		*Uraspis uraspis*
	Pseudorhombus argus	Carapidae	*Encheliophis gracilis*
	Pseudorhombus arsius		*Onuxodon margaritiferae*
	Pseudorhombus diplospilus	Centriscidae	*Centriscus scutatus*
	Pseudorhombus dupliciocellatus	Centrolophidae	*Psenopsis humerosa*

Table 7.2.3 The teleost species recorded in bycatch from the NPF, from the sources outlined in Section 7.2.2.

Family	Species
	Pseudorhombus elevatus
	Pseudorhombus jenynsii
Chaetodontidae	*Chelmon marginalis*
	Chelmon muelleri
	Chelmonops truncatus
	Coradion chrysozonus
	Heniochus diphreutes
	Parachaetodon ocellatus
Champsodontidae	*Champsodon nudivittis*
Chaunacidae	Chaunacidae
Chirocentridae	*Chirocentrus dorab*
Citharidae	*Brachypleura novaezeelandiae*
Clupeidae	
	Amblygaster sirm
	Anodontostoma chacunda
	Dussumieria elopsoides
	Escualosa thoracata
	Herklotsichthys koningsbergeri
	Herklotsichthys lippa
	Pellona ditchela
	Sardinella albella
	Sardinella gibbosa
Congridae	*Ariosoma anago*
	Conger cinereus
	Conger wilsoni
	Gnathophis sp.
	Lumiconger arafura
	Poeciloconger kapala
	Uroconger lepturus
Congrogadidae	*Congrogadus amplimaculatus*
Cynoglossidae	*Cynoglossus arel*
	Cynoglossus bilineatus
	Cynoglossus kopsii
	Cynoglossus macrophthalmus
	Cynoglossus maculipinnis
	Paraplagusia bilineata
	Paraplagusia longirostris
Dactylopteridae	*Dactyloptena macracanthus*
	Dactyloptena papilio
Diodontidae	*Cyclichthys hardenbergi*
	Cyclichthys orbicularis
	Lophodiodon calori
	Tragulichthys jaculiferus
Drepanidae	*Drepane punctata*
Echeneidae	*Echeneis naucrates*
Engraulididae	*Encrasicholina devisi*
	Encrasicholina heteroloba
	Setipinna tenuifilis
	Stolephorus carpentariae
	Stolephorus indicus
	Stolephorus waitei
	Thryssa hamiltonii
Cepolidae	*Acanthocepola abbreviata*
Chaetodontidae	*Chaetodon flavirostris*
Ephippidae	*Platax batavianus*
	Platax teira
	Zabidius novaemaculatus
Exocoetidae	Exocoetidae
Fistulariidae	*Fistularia commersonii*
	Fistularia petimba
Gerreidae	*Gerres baconensis*
	Gerres erythrourus
	Gerres filamentosus
	Gerres macracanthus
	Gerres macrosoma
	Gerres oyena
	Gerres subfasciatus
	Pentaprion longimanus
Glaucosomatidae	*Glaucosoma magnificum*
Gobiidae	*Acentrogobius caninus*
	Acentrogobius viridipunctatus
	Ctenotrypauchen microcephalus
	Drombus globiceps
	Oxyurichthys papuanus
	Oxyurichthys sp.
	Parachaeturichthys polynema
	Trimma taylori
	Yongeichthys nebulosus
Haemulidae	*Diagramma pictum*
	Plectorhinchus gibbosus
	Pomadasys argenteus
	Pomadasys kaakan
	Pomadasys maculatus
	Pomadasys trifasciatus
Harpadontidae	*Harpadon translucens*
Hemiramphidae	*Euleptorhamphus viridis*
	Hemiramphus robustus
	Hyporhamphus affinis
Holocentridae	*Myripristis botche*
	Myripristis hexagona
	Myripristis murdjan
	Sargocentron rubrum
Labridae	*Choerodon cephalotes*
	Choerodon monostigma
	Choerodon sugillatum
	Leptojulis cyanopleura
	Xiphocheilus typus
Lactariidae	*Lactarius lactarius*
Leiognathidae	*Gazza minuta*
	Leiognathus aureus
	Leiognathus bindus
	Leiognathus blochii
	Leiognathus decorus
	Leiognathus elongatus
	Leiognathus equulus

Table 7.2.3 The teleost species recorded in bycatch from the NPF, from the sources outlined in Section 7.2.2.

Family	Species	Family	Species
	Thryssa marasriae		*Leiognathus fasciatus*
	Thryssa setirostris		*Leiognathus leuciscus*
Leiognathidae	*Leiognathus moretoniensis*	Nemipteridae	*Pentapodus paradiseus*
	Leiognathus ruconius		*Pentapodus porosus*
	Leiognathus smithursti		*Scolopsis affinis*
	Leiognathus sp.		*Scolopsis monogramma*
	Leiognathus splendens		*Scolopsis taeniopterus*
	Secutor insidiator		*Scolopsis vosmeri*
Lethrinidae	*Lethrinus genivittatus*	Nettastomatidae	*Nettastoma parviceps*
	Lethrinus laticaudis	Ogcocephalidae	*Ogcocephalidae*
	Lethrinus lentjan	Ophichthidae	*Ophichthidae*
Lutjanidae	*Lutjanus argentimaculatus*	Ophidiidae	*Sirembo imberbis*
	Lutjanus carponotatus	Opisthognathidae	*Opistognathus latitabundus*
	Lutjanus erythropterus	Ostraciidae	*Ostracion nasus*
	Lutjanus johnii		*Tetrosomus gibbosus*
	Lutjanus lutjanus	Pegasidae	*Eurypegasus draconis*
	Lutjanus malabaricus		*Pegasus volitans*
	Lutjanus quinquelineatus	Pempherididae	*Leptobrama mulleri*
	Lutjanus russelli		*Pempheris analis*
	Lutjanus sebae	Pinguipedidae	*Parapercis nebulosa*
	Lutjanus vitta		*Parapercis xanthozona*
	Symphorus nematophorus	Platycephalidae	*Cociella hutchinsi*
Megalopidae	*Megalops cyprinoides*		*Cymbacephalus nematophthalmus*
Melanostomiidae	*Bathophilus nigerrimus*		*Elates ransonnetii*
	Eustomias multifilis		*Inegocia harrisii*
Menidae	*Mene maculata*		*Inegocia japonica*
Microdesmidae	*Microdesmidae*		*Onigocia macrolepis*
Monacanthidae	*Aluterus monoceros*		*Onigocia spinosa*
	Anacanthus barbatus		*Papilloculiceps bosschei*
	Chaetodermis penicilligera		*Platycephalus arenarius*
	Monacanthus chinensis		*Platycephalus endrachtensis*
	Paramonacanthus choirocephalus		*Platycephalus indicus*
	Paramonacanthus filicauda		*Rogadius asper*
	Paramonacanthus japonicus		*Sorsogona tuberculata*
	Pseudomonacanthus peroni		*Suggrundus macracanthus*
Mugilidae	*Mugil cephalus*		*Suggrundus rodericensis*
	Valamugil cunnesius	Pleuronectidae	*Samaris cristatus*
	Parupeneus barberinoides	Plotosidae	*Euristhmus lepturus*
	Parupeneus heptacanthus		*Euristhmus nudiceps*
	Upeneus asymmetricus		*Plotosus lineatus*
	Upeneus luzonius	Polynemidae	*Polydactylus multiradiatus*
	Upeneus moluccensis		*Polydactylus nigripinnis*
	Upeneus sp. 1	Pomacanthidae	*Chaetodontoplus duboulayi*
	Upeneus sulphureus		*Pomacanthus sexstriatus*
	Upeneus sundaicus	Pomacentridae	*Pristotis jerdoni*
	Upeneus tragula	Priacanthidae	*Priacanthus tayenus*
Muraenesocidae	*Muraenesox cinereus*	Psettodidae	*Psettodes erumei*
Muraenidae	*Gymnothorax reticularis*	Pseudochromidae	*Pseudochromis quinquedentatus*
Myctophidae	Myctophidae	Rachycentridae	*Rachycentron canadum*
Nemipteridae	*Nemipterus celebicus*	Rhinoprenidae	*Rhinoprenes pentanemus*
	Nemipterus furcosus	Scaridae	*Scarus ghobban*
	Nemipterus hexodon	Scatophagidae	*Scatophagus argus*
	Nemipterus marginatus		*Scatophagus multifasciatus*

Table 7.2.3 The teleost species recorded in bycatch from the NPF, from the sources outlined in Section 7.2.2.

Family	Species	Family	Species
	Nemipterus nematopus	Soleidae	*Pardachirus pavoninus*
	Nemipterus peronii		*Strabozebrias cancellatus*
			Zebrias quagga
Sciaenidae	*Austronibea oedogenys*	Sciaenidae	*Atractoscion aequidens*
	Johnius amblycephalus		*Atrobucca brevis*
	Johnius borneensis		
	Johnius laevis	Sparidae	*Argyrops spinifer*
	Otolithes ruber	Sphyraenidae	*Sphyraena barracuda*
	Protonibea diacanthus		*Sphyraena flavicauda*
Scombridae	*Rastrelliger brachysoma*		*Sphyraena forsteri*
	Rastrelliger kanagurta		*Sphyraena jello*
	Scomberomorus commerson		*Sphyraena obtusata*
	Scomberomorus munroi		*Sphyraena putnamiae*
	Scomberomorus queenslandicus		*Sphyraena qenie*
	Scomberomorus semifasciatus	Sternoptychidae	*Polyipnus elongatus*
Scorpaenidae	*Brachypterois serrulatus*		*Polyipnus tridentifer*
	Cottapistus cottoides	Syngnathidae	*Trachyrhamphus longirostris*
	Cottapistus praepositus	Synodontidae	*Synodus hoshinonis*
	Dendrochirus brachypterus		*Synodus macrops*
	Dendrochirus zebra		*Synodus sageneus*
	Erosa erosa		*Trachinocephalus myops*
	Apistus carinatus	Terapontidae	*Pelates quadrilineatus*
	Inimicus sinensis		*Pelates sexlineatus*
	Minous trachycephalus		*Terapon jarbua*
	Minous versicolor		*Terapon puta*
	Neomerinthe amplisquamiceps		*Terapon theraps*
	Neomerinthe megalepis	Tetraodontidae	*Arothron manilensis*
	Paracentropogon longispinus		*Arothron stellatus*
	Pterois russelli		*Chelonodon patoca*
	Pterois volitans		*Feroxodon multistriatus*
	Richardsonichthys leucogaster		*Lagocephalus inermis*
	Scorpaena neglecta		*Lagocephalus lunaris*
	Scorpaenopsis diabolus		*Lagocephalus sceleratus*
	Scorpaenopsis venosa		*Lagocephalus spadiceus*
Serranidae	*Cephalopholis boenack*		*Torquigener hicksi*
	Epinephelus areolatus		*Torquigener pallimaculatus*
	Epinephelus coioides		*Torquigener tuberculiferus*
	Epinephelus heniochus		*Torquigener whitleyi*
	Epinephelus malabaricus	Triacanthidae	*Triacanthus biaculeatus*
	Epinephelus quoyanus		*Trixiphichthys weberi*
	Epinephelus sexfasciatus	Trichiuridae	*Trichiurus lepturus*
	Plectropomus leopardus	Triglidae	*Lepidotrigla argus*
	Plectropomus maculatus		*Lepidotrigla* sp. 2
Siganidae	*Siganus argenteus*		*Lepidotrigla spiloptera*
	Siganus canaliculatus	Uranoscopidae	*Ichthyscopus fasciatus*
	Siganus fuscescens		*Uranoscopus cognatus*
	Siganus lineatus		*Uranoscopus* sp. 1
Sillaginidae	*Sillago analis*	Veliferidae	*Velifer hypselopterus*
	Sillago burrus		
	Sillago ingenuua		
	Sillago lutea		
	Sillago sihama		
Soleidae	*Dexillus muelleri*		

Night versus day catch rates

Data were available to compare the catch rate of 129 species between day and night-time trawls and the majority (82%) showed a significant time effect or interaction (Table 7.2.4). Only 23 species showed no significant effect of the time of trawls (day *versus* night). Twenty eight species showed a significant time effect and no interaction with region, of these 25 had a higher catch rate at night and 3 during the day. There were 78 species with a significant time effect and a significant interaction or only a significant interaction. Of these, 20 species had a significantly higher catch rate during the day and 41 during the night. The interaction for these species indicated differences in the magnitude of the difference between day and night, but the direction was consistent. Seventeen of the species had significant interactions that indicated that the time of highest catch rate was not consistent among the regions (Table 7.2.4). The magnitude of the difference between day and night catch rates ranged up to 100%.

Table 7.2.4 The summary of results from two way ANOVAs examining the effect of region and time (day or night) on catch rate of species. Where time or the interaction were significant the time of highest catch rate is shown.

		Effect			
Family	**Species**	**Region P**	**Time P**	**Inter. P**	**Highest catch rate**
Apogonidae	*Apogon ellioti*	0.0000	0.0000	0.0085	night
	Apogon fasciatus	0.0000	0.0006	0.0091	night
	Apogon poecilopterus	0.0000	0.0000	0.0000	night
Ariidae	*Netuma thalassinus*	0.0000	0.0000	0.0010	night
	Euristhmus nudiceps	0.0000	0.0000	0.0359	night
Balistidae	*Abalistes stellaris*	0.0000	0.5961	0.5968	
Bathysauridae	*Saurida longimanus*	0.0000	0.7174	0.8520	
	Saurida micropectoralis	0.0000	0.0000	0.0082	night
	Saurida sp. 2	0.0000	0.0000	0.0516	night
Bothidae	*Arnoglossus waitei*	0.0000	0.0041	0.8535	night
	Grammatobothus polyophthalmus	0.0000	0.0000	0.0553	night
	Pseudorhombus argus	0.0000	0.0000	0.0147	night
	Pseudorhombus arsius	0.0000	0.0000	0.0226	night
	Pseudorhombus diplospilus	0.0170	0.0000	0.5176	night
	Pseudorhombus elevatus	0.0000	0.0011	0.0018	night
	Pseudorhombus spinosus	0.0000	0.0243	0.0001	night
Bregmacerotidae	*Bregmaceros mcclellandi*	0.0001	0.6514	.	
	Bregmacerotidae	0.0000	0.0000	0.0000	night
Callionymidae	*Callionymus goodladi*	0.0000	0.0000	0.0038	night
	Callionymus grossi	0.0000	0.0000	0.0000	night
	Callionymus japonicus	0.0000	0.8131	0.8184	
	Callionymus meridionalis	0.0002	0.0000	0.0004	night
Carangidae	*Alepes* sp.	0.0005	0.5483	0.0828	
	Atule mate	0.0000	0.0001	0.0000	neither
	Carangoides caeruleopinnatus	0.0000	0.3484	0.4431	
	Carangoides chrysophrys	0.0000	0.0001	0.0000	neither
	Carangoides hedlandensis	0.0000	0.0024	0.0010	neither
	Carangoides humerosus	0.0000	0.5621	0.0238	neither
	Carangoides malabaricus	0.0000	0.5006	0.3015	
	Carangoides talamparoides	0.0000	0.0251	0.0079	day
	Caranx bucculentus	0.0000	0.7151	0.0000	neither

Table 7.2.4 The summary of results from two way ANOVAs examining the effect of region and time (day or night) on catch rate of species. Where time or the interaction were significant the time of highest catch rate is shown.

		Effect			
		Region	Time	Inter.	Highest
Family	**Species**	**P**	**P**	**P**	**catch rate**
	Pantolabus radiatus	0.0000	0.0000	0.0000	day
	Parastromateus niger	0.0000	0.0000	0.0000	day
	Scomberoides tala	0.0000	0.0000	0.0000	day
	Selar boops	0.0000	0.2925	0.5081	
	Selar crumenophthalmus	0.0042	0.0005	0.0057	day
	Selaroides leptolepis	0.0000	0.0000	0.0458	day
	Ulua aurochs	0.0000	0.0002	0.0000	day
Centriscidae	*Centriscus scutatus*	0.0000	0.0001	0.0000	night
Champsodontidae	Champsodontidae	0.0000	0.0032	.	night
Clupeidae	*Anodontostoma chacunda*	0.5507	0.1121	0.7995	
	Dussumieria elopsoides	0.0000	0.0000	0.0014	neither
	Herklotsichthys lippa	0.0000	0.4156	0.0000	day
	Pellona ditchela	0.0000	0.5730	0.0000	day
	Sardinella gibbosa	0.0000	0.7767	0.0274	neither
Dactylopteridae	*Dactyloptena papilio*	0.0000	0.0000	0.0023	neither
Echeneidae	*Echeneis naucrates*	0.0000	0.0982	0.0002	neither
Engraulididae	Engraulididae	0.0000	0.0267	0.0000	night
	Thryssa setirostris	0.0000	0.0674	0.0000	neither
Fistulariidae	*Fistularia petimba*	0.0000	0.8569	0.0000	neither
Gerreidae	*Gerres macracanthus*	0.0000	0.6367	0.3465	
	Gerres macrosoma	0.0000	0.0178	0.0686	night
	Pentaprion longimanus	0.0000	0.0015	0.0000	neither
Haemulidae	*Diagramma pictum*	0.0782	0.2286	0.4232	
	Pomadasys kaakan	0.8489	0.0002	0.0246	day
	Pomadasys maculatus	0.0000	0.6866	0.0000	night
	Pomadasys trifasciatus	0.0000	0.3742	0.0000	night
Labridae	*Choerodon cephalotes*	0.6162	0.0000	0.0618	night
	Choerodon monostigma	0.0000	0.0000	0.0029	night
	Choerodon sugillatum	0.0007	0.0309	0.0001	night
Lactariidae	*Lactarius lactarius*	0.0000	0.0176	0.0001	day
Leiognathidae	*Gazza minuta*	0.0000	0.0023	0.0014	day
	Leiognathus bindus	0.0004	0.0000	0.0000	day
	Leiognathus equulus	0.0000	0.9440	0.0175	day
	Leiognathus leuciscus	0.0000	0.1491	0.0107	neither
	Leiognathus moretoniensis	0.0000	0.0000	0.0008	night
	Leiognathus sp.	0.0000	0.0000	0.0594	day
	Leiognathus splendens	0.0000	0.0017	0.0008	day
	Secutor insidiator	0.0000	0.0000	0.4941	day
Lethrinidae	*Lethrinus genivittatus*	0.0027	0.0936	0.0958	
	Lethrinus laticaudis	0.0003	0.0016	0.2686	night
	Lethrinus lentjan	0.0000	0.1369	0.0313	neither
Lutjanidae	*Lutjanus malabaricus*	0.0000	0.1988	0.0203	neither
	Lutjanus russelli	0.0292	0.0019	0.0265	night
	Lutjanus sebae	0.0011	0.1984	0.6286	
	Lutjanus vitta	0.0000	0.0411	0.5870	night
Menidae	*Mene maculata*	0.0000	0.0000	0.0000	day
Monacanthidae	*Paramonacanthus choirocephalus*	0.0000	0.0000	0.0003	night
	Paramonacanthus filicauda	0.0000	0.0844	0.0790	

Table 7.2.4 The summary of results from two way ANOVAs examining the effect of region and time (day or night) on catch rate of species. Where time or the interaction were significant the time of highest catch rate is shown.

		Effect			
		Region	Time	Inter.	Highest
Family	**Species**	**P**	**P**	**P**	**catch rate**
Mullidae	*Upeneus asymmetricus*	0.0000	0.0538	0.3893	
	Upeneus luzonius	0.0137	0.0001	0.2189	night
	Upeneus sp. 1	0.0000	0.0064	0.6287	night
	Upeneus sulphureus	0.0000	0.2368	0.2535	
	Upeneus sundaicus	0.0000	0.0109	0.1470	night
	Upeneus tragula	0.0000	0.0000	0.0009	night
Nemipteridae	*Nemipterus furcosus*	0.0000	0.0011	0.0162	night
	Nemipterus hexodon	0.0000	0.0000	0.0001	night
	Nemipterus nematopus	0.0000	0.0000	0.0888	night
	Nemipterus peronii	0.0000	0.0000	0.0000	night
	Pentapodus paradiseus	0.3219	0.0223	0.0820	night
	Scolopsis taeniopterus	0.0000	0.0000	0.0000	night
Ophidiidae	*Sirembo imberbis*	0.0012	0.0000	0.2157	night
Ostraciidae	*Ostracion nasus*	0.0000	0.0000	0.0008	night
Pinguipedidae	*Parapercis nebulosa*	0.0000	0.0017	0.0941	night
Platycephalidae	*Elates ransonnetii*	0.0000	0.0002	0.0000	night
	Inegocia japonica	0.0000	0.0000	0.0000	night
	Rogadius asper	0.0000	0.0000	0.0031	night
	Suggrundus macracanthus	0.0000	0.0000	0.4704	night
	Suggrundus rodericensis	0.0000	0.0287	0.4279	night
Polynemidae	*Polydactylus multiradiatus*	0.0002	0.1234	0.0003	night
Pomacentridae	*Pristotis jerdoni*	0.0001	0.0200	0.7665	night
Priacanthidae	*Priacanthus tayenus*	0.0000	0.0000	0.7904	night
Psettodidae	*Psettodes erumei*	0.0000	0.0001	0.0001	night
Sciaenidae	*Johnius amblycephalus*	0.1195	0.1746	0.8890	
	Johnius borneensis	0.0000	0.4498	0.1267	
Scombridae	*Rastrelliger kanagurta*	0.0000	0.0000	0.0000	day
	Scomberomorus queenslandicus	0.0000	0.0000	0.0005	day
Scorpaenidae	*Brachypterois serrulatus*	0.0004	0.0144	0.3793	night
	Apistus carinatus	0.2198	0.0000	0.0393	night
	Minous trachycephalus	0.0000	0.0000	0.0075	night
Serranidae	*Epinephelus sexfasciatus*	0.0001	0.0135	0.0049	night
Siganidae	*Siganus canaliculatus*	0.1152	0.2067	0.2430	
Sillaginidae	*Sillago burrus*	0.0000	0.9825	0.0000	neither
	Sillago ingenuua	0.0000	0.0159	0.4908	night
Sphyraenidae	*Sphyraena forsteri*	0.0000	0.0000	0.0000	day
	Sphyraena obtusata	0.0000	0.0000	0.0000	day
Synodontidae	*Synodus sageneus*	0.0000	0.0000	0.0002	night
Terapontidae	*Pelates quadrilineatus*	0.0000	0.3439	0.6939	
	Terapon jarbua	0.0001	0.1950	0.4261	
	Terapon theraps	0.0000	0.4121	0.0003	neither
Tetraodontidae	*Chelonodon patoca*	0.0000	0.0000	0.0001	night
	Lagocephalus sceleratus	0.0001	0.0000	0.0783	night
	Lagocephalus spadiceus	0.0000	0.6187	0.0006	neither
	Torquigener pallimaculatus	0.0004	0.0183	0.0844	night
	Torquigener whitleyi	0.0000	0.0000	0.9005	night
Triacanthidae	*Trixiphichthys weberi*	0.0000	0.5462	0.2109	
Trichiuridae	*Trichiurus lepturus*	0.0000	0.0322	0.1924	day

Table 7.2.4 The summary of results from two way ANOVAs examining the effect of region and time (day or night) on catch rate of species. Where time or the interaction were significant the time of highest catch rate is shown.

		Effect			
Family	Species	Region P	Time P	Inter. P	Highest catch rate
Triglidae	*Lepidotrigla* sp. C	0.0001	0.0191	0.3875	night
Uranoscopidae	*Uranoscopus cognatus*	0.0000	0.4574	0.2916	

Process for assessing the sustainability of bycatch species

The 411 taxa recorded in bycatch were ranked on each criterion on the two axes (Tables 7.2.5 and 7.2.6) and plotted in Figure 7.2.3. The proportion of species for which the ranking was based on species specific information varied among the criteria (Table 7.2.7). While some of the correlations between the criteria were significant, they were not strong and so all criteria were retained (Table 7.2.8).

On the susceptibility axis (Figure 7.2.3, Table 7.2.5) the species *Antennarius hispidus* (Antennariidae), *Brachypleura novaezeelandiae* (Citharidae), *Engyprosopon grandisquamum* (Bothidae), *Grammatobothus polyophthalmus* (Bothidae), *Lumiconger arafura* (Congridae), *Saurida micropectoralis* (Bathysauridae), *Saurida undosquamis* (Bathysauridae) and *Siphamia roseigaster* (Apogonidae) had the lowest ranks (1.13). These were the most susceptible species to capture and mortality. The least susceptible species were *Polyipnus elongatus* (Sternoptychidae), *Sphyraena flavicauda,* (Sphyraenidae), *Sphyraena forsteri* (Sphyraenidae), *Sphyraena jello* (Sphyraenidae), *Sphyraena obtusata* (Sphyraenidae), *Sphyraena putnamiae* (Sphyraenidae) and *Sphyraena qenie* (Sphyraenidae) with the highest ranks (≥ 2.38) (Figure 7.2.3, Table 7.2.5).

The families most susceptible to capture, with mean ranks ≤ 1.4, included: Antennariidae, Aploactinidae, Ariidae, Balistidae, Bathysauridae, Bothidae, Centriscidae, Citharidae, Ophidiidae, Opisthognathidae and Polynemidae (Figure 7.2.4). The families that were the least susceptible to capture, with mean ranks > 2.1, included: Caesionidae, Carangidae, Echeneidae, Megalopidae, Melanostomiidae, Scatophagidae, Sphyraenidae, Sternoptychidae and Trichiuridae (Figure 7.2.4).

On the recovery axis, the species with the lowest recovery capacity were *Arius bilineatus* (Ariidae), *A. proximus* (Ariidae), *Euleptorhamphus viridis* (Hemiramphidae), *Euristhmus lepturus* (Plotosidae) and *Rhabdamia gracilis* (Apogonidae), with ranks 1.53 (Figure 7.2.3, Table 7.2.6). There were 42 species with high capacities to recover, ranks of 3 (Figure 7.2.3, Table 7.2.6).

The families with the lowest capacity to recover included: Ariidae, Chaunacidae, Hemiramphidae, Microdesmidae, Opisthognathidae, Pleuronectidae, Scatophagidae, Sternoptychidae and Syngnathidae with mean ranks of < 2 (Figure 7.2.4). Families with a higher capacity to recover, with mean ranks > 2.6, included: Drepanidae, Glaucosomatidae, Lactariidae, Menidae, Psettodidae, Pomacentridae, Teraponidae and Veliferidae (Figure 7.2.4).

The ranks of the species on both axes are shown in Figure 7.2.3. The species that are the least likely to be sustainable, based on this ranking are *Antennarius hispidus* (Antennaridae), *Arius bilineatus* (Ariidae), *Arius nella* (Ariidae), *Arius proximus* (Ariidae), *Brachypleura novaezeelandiae* (Bothidae), *Engyprosondon grandisqaumus* (Bothidae), *Grammatobothus polyophthalmus* (Bothidae), *Lumiconger arafura* (Congridae), *Paramonacanthus japonicus* (Monacanthidae), *Poeciloconger kapala* (Congridae), *Saurida micropectoralis* (Bathysauridae), *Saurida undosquamis* (Bathysauridae), *Siphamia roseigaster* (Apogonidae) (Figure 7.2.3. Table 7.2.11).

The species that are most likely to be sustainable are *Lethrinus laticaudis* (Lethrinidae), *Lutjanus russelli* (Lutjanidae) *Pelates quadrilineatus* (Teraponidae), *Pellona ditchela* (Clupeidae), *Rastrelliger kanagurta* (Scombridae), *Sphyraena flavicauda* (Sphyraenidae) *Sphyraena forsteri* (Sphyraenidae), *Sphyraena obtusa* (Sphyraenidae), *Terapon jarbua* (Teraponidae) and *Trachinocephalus myops* (Synodontidae) (Figure 7.2.3, Table 7.2.12).

Table 7.2.5 The ranking of bycatch species with respect to criteria that reflect their susceptibility to capture and mortality due to prawn trawls. The weighting scores of the criteria are shown in parentheses; * indicates where species specific information was not available.

		Criteria													
Family	**Species**	**Water column position (3)**		**Preferred habitat (3)**		**Survival (3)**		**Range (2)**		**Day/night catchability (2)**		**Diet (2)**	**Depth range (1)**		**Susceptibility rank**
Bathysauridae	*Saurida micropectoralis*	1		1		1	*	1	*	1	*	1	3		1.13
Bathysauridae	*Saurida undosquamis*	1		1		1	*	1	*	1	*	1	3		1.13
Apogonidae	*Siphamia roseigaster*	1		1		1	*	1	*	1	*	1	3		1.13
Antennariidae	*Antennarius hispidus*	1	*	1		1	*	1	*	2	*	1	1	*	1.13
Bothidae	*Engyprosopon grandisquamum*	1		1		1	*	1	*	1	*	1	3		1.13
Bothidae	*Grammatobothus polyophthalmus*	1		1		1	*	1	*	1	*	1	3		1.13
Citharidae	*Brachypleura novaezeelandiae*	1		1		1	*	1	*	2	*	1	1		1.13
Congridae	*Lumiconger arafura*	1		1		1	*	1	*	1	*	1	3		1.13
Centriscidae	*Centriscus scutatus*	1		1		1	*	2		1		1	3		1.25
Antennariidae	*Tathicarpus butleri*	1	*	1		1	*	1	*	1	*	2	3		1.25
Antennariidae	*Tetrabrachium ocellatum*	1	*	1		1	*	1	*	2	*	1	3		1.25
Aploactinidae	*Adventor elongatus*	1		1		1	*	1	*	2	*	1	3		1.25
Apogonidae	*Apogon poecilopterus*	1		1		1	*	1	*	1	*	2	3		1.25
Callionymidae	*Synchiropus rameus*	1		1		1	*	1	*	1	*	2	3		1.25
Leiognathidae	*Leiognathus elongatus*	1		1	*	1	*	1	*	1	*	2	3		1.25
Bathysauridae	*Saurida* sp. 2	1	*	2		1	*	1	*	1	*	1	3		1.31
Apogonidae	*Siphamia majimai*	1		2		1	*	1	*	1	*	1	3		1.31
Ariidae	*Arius argyropleuron*	1	*	2		1	*	1	*	1	*	2	1		1.31
Ariidae	*Arius bilineatus*	1	*	2		1	*	1	*	1	*	2	1		1.31
Monacanthidae	*Paramonacanthus japonicus*	1	*	2		1	*	1	*	1	*	1	3		1.31
Mugilidae	*Valamugil cunnesius*	1		2		1	*	1	*	1	*	1	3		1.31
Mullidae	*Parupeneus heptacanthus*	1	*	2		1	*	1	*	1	*	1	3		1.31
Congridae	*Poeciloconger kapala*	1	*	2		1	*	1	*	1	*	1	3		1.31
Balistidae	*Abalistes stellaris*	1	*	2		1	*	1	*	1	*	2	1		1.31
Monacanthidae	*Pseudomonacanthus peroni*	1		2		1	*	1	*	1	*	1	3		1.31
Apogonidae	*Siphamia guttulatus*	2		1		1	*	1	*	1	*	1	3		1.31
Apogonidae	*Siphamia fuscolineata*	1	*	2		1	*	1	*	2	*	1	1	*	1.31
Ariidae	*Arius nella*	1	*	2		1	*	1	*	2	*	1	1		1.31
Ariidae	*Arius proximus*	1		2		1	*	1		1		2	1		1.31
Ariidae	*Netuma thalassinus*	1	*	2		1	*	1	*	1	*	2	1		1.31
Bathysauridae	*Saurida longimanus*	1		2		1	*	1	*	1	*	2	1		1.31
Bothidae	*Arnoglossus waitei*	1		2		1	*	2		1		1	1		1.31
Bothidae	*Laeops parviceps*	1		2		1	*	1	*	1	*	1	3		1.31

Table 7.2.5 The ranking of bycatch species with respect to criteria that reflect their susceptibility to capture and mortality due to prawn trawls. The weighting scores of the criteria are shown in parentheses; * indicates where species specific information was not available.

		Criteria												
Family	Species	Water column position (3)		Preferred habitat (3)	Survival (3)		Range (2)		Day/night catchability (2)		Diet (2)	Depth range (1)		Susceptibility rank
Platycephalidae	*Rogadius asper*	1		1	2	*	1	*	2	*	1	1		1.31
Platycephalidae	*Sorsogona tuberculata*	1		1	2	*	1	*	2	*	1	1		1.31
Bothidae	*Pseudorhombus argus*	1		1	1	*	1	*	2	*	2	3		1.38
Bothidae	*Pseudorhombus arsius*	1		1	1	*	1	*	2	*	2	3		1.38
Nemipteridae	*Scolopsis taeniopterus*	1		1	1	*	1	*	2	*	2	3		1.38
Opisthognathidae	*Opistognathus latitabundus*	1		1	1		3		1		1	3		1.38
Bothidae	*Pseudorhombus dupliciocellatus*	1		1	1	*	3		1		2	1		1.38
Bothidae	*Pseudorhombus elevatus*	1		1	1	*	3		1		2	1		1.38
Bothidae	*Pseudorhombus jenynsii*	1		1	1	*	1		2		2	3		1.38
Nemipteridae	*Nemipterus celebicus*	1		1	1	*	1	*	1	*	3	3		1.38
Polynemidae	*Polydactylus nigripinnis*	1		1	1	*	1	*	2	*	2	3		1.38
Callionymidae	*Callionymus japonicus*	1		1	1	*	1	*	2	*	2	3		1.38
Bothidae	*Psettina gigantea*	1		1	1	*	1	*	2	*	2	3		1.38
Bothidae	*Pseudorhombus diplospilus*	1		1	1	*	3		1		1	3		1.38
Cynoglossidae	*Cynoglossus bilineatus*	1		1	1	*	3		1		1	3		1.38
Diodontidae	*Cyclichthys hardenbergi*	1	*	1	1	*	1	*	2	*	2	3		1.38
Antennariidae	*Antennarius nummifer*	1	*	3	1	*	1	*	1	*	1	1		1.38
Bothidae	*Pseudorhombus spinosus*	1		1	1	*	1	*	2	*	2	3		1.38
Callionymidae	*Callionymus goodladi*	1		1	3	*	1	*	1	*	1	1	*	1.38
Callionymidae	*Callionymus grossi*	1		1	3	*	1	*	1	*	1	1	*	1.38
Callionymidae	*Callionymus meridionalis*	1		1	1	*	1	*	2	*	2	3		1.38
Diodontidae	*Cyclichthys orbicularis*	1	*	1	1	*	1	*	2	*	2	3		1.38
Gerreidae	*Pentaprion longimanus*	1	*	1	1	*	2		1		2	3		1.38
Haemulidae	*Pomadasys maculatus*	1	*	1	1	*	1	*	2	*	2	3		1.38
Nemipteridae	*Nemipterus furcosus*	1		1	1	*	3		1		1	3		1.38
Nemipteridae	*Nemipterus hexodon*	1		1	1	*	1	*	2	*	2	3		1.38
Nemipteridae	*Nemipterus marginatus*	1		1	1	*	1	*	2	*	3	1		1.38
Nemipteridae	*Nemipterus nematopus*	1	*	1	1	*	1	*	2	*	2	3		1.38
Nemipteridae	*Nemipterus peronii*	1		1	1	*	1	*	2	*	2	3		1.38
Ophidiidae	*Sirembo imberbis*	1		1	1	*	1	*	2	*	3	1	*	1.38
Polynemidae	*Polydactylus multiradiatus*	1		1	1	*	1	*	2	*	3	1	*	1.38
Labridae	*Choerodon monostigma*	1		2	1	*	1	*	2	*	2	1		1.44
Apogonidae	*Apogon ellioti*	1	*	2	1	*	1	*	1	*	2	3		1.44

Table 7.2.5 The ranking of bycatch species with respect to criteria that reflect their susceptibility to capture and mortality due to prawn trawls. The weighting scores of the criteria are shown in parentheses; * indicates where species specific information was not available.

Family	Species	Criteria: Water column position (3)		Preferred habitat (3)		Survival (3)		Range (2)		Day/night catchability (2)		Diet (2)	Depth range (1)		Susceptibility rank
Apogonidae	*Apogon fasciatus*	1	*	2		1	*	1		1	*	2	3		1.44
Leiognathidae	*Leiognathus ruconius*	1		2		1	*	1	*	2	*	1	3		1.44
Platycephalidae	*Inegocia japonica*	1		1		2	*	1	*	2		1	3		1.44
Platycephalidae	*Onigocia macrolepis*	1		1		2	*	3		1		1	1		1.44
Scorpaenidae	*Apistus carinatus*	1		1		2	*	1	*	2	*	1	3		1.44
Scorpaenidae	*Brachypterois serrulatus*	1		1		2	*	1	*	2	*	1	3		1.44
Carapidae	*Encheliophis gracilis*	1		2		1	*	1	*	2	*	2	1		1.44
Pegasidae	*Pegasus volitans*	1	*	2		1	*	1	*	2	*	2	1	*	1.44
Leiognathidae	*Leiognathus bindus*	1	*	2		1	*	1	*	1	*	2	3		1.44
Apogonidae	*Apogon albimaculosus*	1		2		1	*	1	*	2	*	1	3		1.44
Apogonidae	*Apogon melanopus*	2		1		1	*	2		1		1	3		1.44
Apogonidae	*Apogon nigripinnis*	1	*	2		1	*	1	*	2	*	1	3		1.44
Apogonidae	*Apogon septemstriatus*	1		2		1	*	1	*	1	*	2	3		1.44
Apogonidae	*Apogon* sp. 2	1	*	2		1	*	1	*	2	*	2	1		1.44
Apogonidae	*Pseudamia amblyuroptera*	1	*	2		1	*	1	*	1	*	2	3		1.44
Callionymidae	*Dactylopus dactylopus*	1		2		1	*	1	*	1	*	2	3		1.44
Carangidae	*Caranx kleinii*	1		2	*	1	*	1	*	2	*	2	1		1.44
Carangidae	*Trachinotus cf mookalee*	1		2	*	1	*	1	*	1	*	2	3	*	1.44
Cepolidae	*Acanthocepola abbreviata*	2		1		1	*	2		1	*	1	3		1.44
Holocentridae	*Myripristis botche*	1	*	2		1	*	1	*	1	*	2	3		1.44
Labridae	*Choerodon sugillatum*	1	*	2		1	*	1	*	2	*	1	3		1.44
Leiognathidae	*Gazza minuta*	1	*	2		1	*	1	*	1	*	2	3		1.44
Leiognathidae	*Leiognathus blochii*	1		2		1	*	1	*	1		2	3		1.44
Leiognathidae	*Leiognathus decorus*	1	*	2		1	*	1	*	1	*	2	3		1.44
Leiognathidae	*Leiognathus equulus*	1	*	2		1	*	1	*	1	*	2	3		1.44
Leiognathidae	*Leiognathus fasciatus*	1		2		1	*	1	*	2	*	2	1		1.44
Leiognathidae	*Leiognathus leuciscus*	1		2		1	*	1	*	2	*	1	3		1.44
Leiognathidae	*Leiognathus moretoniensis*	1		2		1	*	1	*	2	*	2	1	*	1.44
Pegasidae	*Eurypegasus draconis*	1		2		1	*	1	*	2	*	2	1		1.44
Platycephalidae	*Inegocia harrisii*	1		1		2	*	1	*	2	*	1	3		1.44
Scorpaenidae	*Cottapistus praepositus*	1	*	1		2	*	1	*	2	*	2	1		1.44
Scorpaenidae	*Richardsonichthys leucogaster*	1	*	1		1	*	1	*	2	*	3	3		1.50
Congridae	*Conger wilsoni*	1		3		1	*	1	*	1	*	1	3		1.50

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		Criteria													
Family	Species	Water column position (3)		Preferred habitat (3)		Survival (3)		Range (2)		Day/night catchability (2)		Diet (2)	Depth range (1)		Susceptibility rank
Mugilidae	*Mugil cephalus*	2		2		1	*	1	*	1	*	1	3		1.50
Mullidae	*Parupeneus barberinoides*	1	*	3		1	*	1	*	1	*	1	3		1.50
Scorpaenidae	*Minous versicolor*	1		1		1	*	1	*	2	*	3	3		1.50
Congridae	*Gnathophis* sp.	1	*	1	*	1	*	3		2		2	1		1.50
Chaetodontidae	*Parachaetodon ocellatus*	2	*	2		1	*	1	*	2	*	1	1		1.50
Apogonidae	*Siphamia argyrogaster*	2		2		1	*	1	*	1	*	2	1		1.50
Ariommatidae	*Ariomma indica*	2		2		1	*	1	*	2	*	1	1		1.50
Batrachoididae	*Batrachomoeus trispinosus*	1	*	3		1	*	1	*	1	*	1	3		1.50
Chaetodontidae	*Coradion chrysozonus*	2	*	2		1	*	1	*	1	*	2	1		1.50
Congridae	*Ariosoma anago*	1		1		3	*	2		1		1	1	*	1.50
Congridae	*Uroconger lepturus*	1		1		1	*	2		2		2	3		1.50
Monacanthidae	*Paramonacanthus filicauda*	1		1		3	*	1	*	1	*	1	3		1.50
Mullidae	*Upeneus asymmetricus*	1	*	1		1	*	3		2		1	3		1.50
Platycephalidae	*Suggrundus rodericensis*	1		1		1	*	1	*	2	*	3	3		1.50
Pleuronectidae	*Samaris cristatus*	1		1		1	*	2		2		2	3		1.50
Mullidae	*Upeneus luzonius*	1	*	2		1	*	1	*	2	*	2	3		1.56
Mullidae	*Upeneus moluccensis*	1	*	2		1	*	1	*	2	*	2	3		1.56
Gobiidae	*Yongeichthys nebulosus*	1	*	2		1	*	3		1		1	3		1.56
Nemipteridae	*Pentapodus paradiseus*	1		2		1	*	1	*	2	*	2	3		1.56
Cynoglossidae	*Paraplagusia longirostris*	1		2		1	*	2		1	*	2	3		1.56
Cynoglossidae	*Cynoglossus maculipinnis*	1		1	*	2	*	2		1		2	3		1.56
Rhinoprenidae	*Rhinoprenes pentanemus*	1	*	2		1	*	1	*	2	*	2	3		1.56
Cynoglossidae	*Cynoglossus kopsii*	1		2		1	*	2		2		1	3		1.56
Gobiidae	*Ctenotrypauchen microcephalus*	1	*	2		1	*	2		1		2	3		1.56
Bothidae	*Psettina tosana*	1		2		1	*	1	*	2	*	2	3		1.56
Cynoglossidae	*Cynoglossus macrophthalmus*	1		2		1	*	3		1		1	3		1.56
Sillaginidae	*Sillago burrus*	1	*	1		2	*	2		1		2	3		1.56
Gerreidae	*Gerres filamentosus*	1	*	2		1	*	1	*	2	*	3	1		1.56
Haemulidae	*Pomadasys argenteus*	1	*	2		1	*	2		1		2	3		1.56
Pomacentridae	*Pristotis jerdoni*	2		1		1	*	1		2		2	3		1.56
Gobiidae	*Acentrogobius viridipunctatus*	1		2		1	*	1	*	2	*	2	3		1.56
Haemulidae	*Pomadasys trifasciatus*	1		2		1	*	1	*	2	*	2	3		1.56
Mullidae	*Upeneus* sp. 1	1	*	2		1	*	1	*	2	*	2	3		1.56

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		Criteria											
Family	Species	Water column position (3)		Preferred habitat (3)	Survival (3)		Range (2)		Day/night catchability (2)		Diet (2)	Depth range (1)	Susceptibility rank
Callionymidae	*Callionymus belcheri*	1		2	1	*	1	*	1	*	3	3	1.56
Callionymidae	*Callionymus sublaevis*	1		2	1	*	2		1	*	2	3	1.56
Cynoglossidae	*Cynoglossus arel*	1		2	1	*	2		1	*	2	3	1.56
Dactylopteridae	*Dactyloptena macracanthus*	1		2	1	*	1	*	2	*	2	3	1.56
Dactylopteridae	*Dactyloptena papilio*	1		2	1	*	1	*	2	*	2	3	1.56
Diodontidae	*Lophodiodon calori*	1		2	1	*	1	*	2	*	2	3	1.56
Diodontidae	*Tragulichthys jaculiferus*	1	*	2	1	*	1	*	2	*	2	3	1.56
Fistulariidae	*Fistularia petimba*	1		2	1	*	3		1		1	3	1.56
Gerreidae	*Gerres baconensis*	1		2	1	*	1	*	2	*	3	1	1.56
Gerreidae	*Gerres erythrourus*	1		2	1	*	1	*	2	*	3	1	1.56
Gerreidae	*Gerres macracanthus*	1		2	1	*	1	*	2	*	2	3	1.56
Gerreidae	*Gerres macrosoma*	1		2	1	*	1	*	2	*	2	3	1.56
Gerreidae	*Gerres oyena*	1	*	2	1	*	1	*	2	*	2	3	1.56
Gerreidae	*Gerres subfasciatus*	1	*	2	1	*	1	*	2	*	2	3	1.56
Gobiidae	*Acentrogobius caninus*	1	*	2	1	*	1	*	2	*	2	3	1.56
Gobiidae	*Drombus globiceps*	1		2	1	*	1	*	2	*	2	3	1.56
Gobiidae	*Oxyurichthys papuanus*	1	*	2	1	*	1	*	2	*	2	3	1.56
Gobiidae	*Oxyurichthys* sp.	1	*	2	1	*	1	*	2	*	2	3	1.56
Gobiidae	*Parachaeturichthys polynema*	1	*	2	1	*	1	*	2	*	2	3	1.56
Haemulidae	*Diagramma pictum*	1	*	2	1	*	1	*	2	*	2	3	1.56
Haemulidae	*Pomadasys kaakan*	1	*	2	1	*	1	*	2	*	2	3	1.56
Harpadontidae	*Harpadon translucens*	1		2	1	*	3		1	*	1	3	1.56
Mullidae	*Upeneus tragula*	1	*	2	1	*	1	*	2	*	2	3	1.56
Muraenesocidae	*Muraenesox cinereus*	1		2	1	*	1	*	2	*	2	3	1.56
Muraenidae	*Gymnothorax reticularis*	1		2	1	*	1	*	2	*	2	3	1.56
Nemipteridae	*Pentapodus porosus*	1		2	1	*	1	*	2	*	2	3	1.56
Nemipteridae	*Scolopsis affinis*	1	*	2	1	*	1	*	2	*	2	3	1.56
Nemipteridae	*Scolopsis monogramma*	1		2	1	*	1	*	2	*	2	3	1.56
Nettastomatidae	*Nettastoma parviceps*	1	*	2	3	*	1	*	1	*	1	1	1.56
Ogcocephalidae	Ogcocephalidae	1	*	2	3	*	1	*	1	*	1	1	1.56
Ophichthidae	Ophichthidae	1	*	2	3	*	1	*	1	*	1	1	1.56
Psettodidae	*Psettodes erumei*	1		2	1	*	1		2	*	2	3	1.56
Sillaginidae	*Sillago analis*	1	*	2	1	*	1	*	2	*	3	1	1.56

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		Criteria													
Family	**Species**	**Water column position (3)**		**Preferred habitat (3)**		**Survival (3)**		**Range (2)**		**Day/night catchability (2)**		**Diet (2)**	**Depth range (1)**		**Susceptibility rank**
Sillaginidae	*Sillago lutea*	1	*	1		2	*	1	*	2	*	2	3		1.56
Sillaginidae	*Sillago sihama*	1	*	2		1	*	1	*	3	*	1	3		1.56
Antennariidae	*Antennarius striatus*	1	*	3		1	*	1		1		2	3		1.63
Apogonidae	*Apogon brevicaudata*	2		2		1	*	1	*	2	*	2	1	*	1.63
Ostraciidae	*Ostracion nasus*	2	*	2		1	*	1	*	2	*	2	1		1.63
Soleidae	*Strabozebrias cancellatus*	1		1		1	*	2		2		3	3		1.63
Ostraciidae	*Tetrosomus gibbosus*	2	*	2		1	*	1	*	1	*	3	1	*	1.63
Antennariidae	*Antennarius pictus*	1	*	3		1	*	1	*	1	*	2	3		1.63
Platycephalidae	*Papilloculiceps bosschei*	1		3		1	*	1	*	2	*	1	3		1.63
Carapidae	*Onuxodon margaritiferae*	1	*	3		1	*	1	*	2	*	2	1		1.63
Pempherididae	*Leptobrama mulleri*	2		2		1	*	1	*	2	*	2	1		1.63
Soleidae	*Zebrias quagga*	1		2		2	*	1	*	2	*	1	3		1.63
Platycephalidae	*Onigocia spinosa*	1		1		1		3		2		2	3		1.63
Apogonidae	*Apogon aureus*	1	*	3		1	*	1	*	2	*	2	1	*	1.63
Apogonidae	*Apogon cavitiensis*	1	*	3		1	*	1	*	2	*	2	1		1.63
Apogonidae	*Apogon nigrocincta*	2		2		1	*	1	*	1	*	2	3		1.63
Apogonidae	*Apogon notatus*	1	*	3		1	*	1	*	1	*	2	3		1.63
Apogonidae	*Cheilodipterus artus*	1	*	3		1	*	2		1	*	1	3		1.63
Apogonidae	*Rhabdamia gracilis*	1	*	3		1	*	1	*	1		2	3		1.63
Carangidae	*Parastromateus niger*	2	*	2		1	*	2		1		2	1		1.63
Carangidae	*Selaroides leptolepis*	3	*	1		1	*	1	*	1	*	2	3		1.63
Chaetodontidae	*Chelmon marginalis*	2	*	2		1	*	1	*	2	*	2	1		1.63
Holocentridae	*Myripristis hexagona*	1	*	3		1	*	1	*	1	*	2	3		1.63
Holocentridae	*Myripristis murdjan*	1	*	3		1	*	1	*	1	*	2	3		1.63
Holocentridae	*Sargocentron rubrum*	1	*	3		1	*	1	*	1	*	2	3		1.63
Labridae	*Xiphocheilus typus*	1	*	3		1	*	1	*	1	*	3	1		1.63
Pempherididae	*Pempheris analis*	1	*	3		1	*	1	*	2	*	2	1		1.63
Pinguipedidae	*Parapercis nebulosa*	1		3		1	*	1	*	2	*	2	1		1.63
Triglidae	*Lepidotrigla argus*	1	*	1		1	*	3		2	*	3	1		1.63
Triglidae	*Lepidotrigla* sp. 2	1	*	1	*	1	*	1	*	3	*	3	3		1.63
Tetraodontidae	*Torquigener whitleyi*	1		2		1	*	1	*	3	*	2	3		1.69
Clupeidae	*Sardinella gibbosa*	3	*	2		1	*	1	*	2	*	1	1		1.69
Scorpaenidae	*Neomerinthe amplisquamiceps*	1		2		1	*	1	*	2	*	3	3		1.69

Table 7.2.5 The ranking of bycatch species with respect to criteria that reflect their susceptibility to capture and mortality due to prawn trawls. The weighting scores of the criteria are shown in parentheses; * indicates where species specific information was not available.

		Criteria													
Family	**Species**	**Water column position (3)**		**Preferred habitat (3)**		**Survival (3)**		**Range (2)**		**Day/night catchability (2)**		**Diet (2)**	**Depth range (1)**		**Susceptibility rank**
Leiognathidae	*Leiognathus* sp.	1	*	2		1	*	3		1		2	3		1.69
Lutjanidae	*Lutjanus johnii*	2	*	3		1	*	1	*	2	*	1	1		1.69
Tetraodontidae	*Torquigener tuberculiferus*	1		2		1	*	1	*	3		2	3		1.69
Platycephalidae	*Platycephalus endrachtensis*	1		2		1	*	1	*	2	*	3	3		1.69
Serranidae	*Epinephelus heniochus*	2	*	1		1	*	1	*	3		2	3		1.69
Tetraodontidae	*Torquigener pallimaculatus*	1		2		1	*	1	*	3		2	3		1.69
Acropomatidae	*Malakichthys* sp. 1	3	*	2	*	1	*	1	*	1	*	1	3		1.69
Chaetodontidae	*Chelmon muelleri*	2	*	3		1	*	1	*	1	*	2	1		1.69
Chaetodontidae	*Heniochus diphreutes*	3		2		1	*	1	*	1	*	2	1		1.69
Chaunacidae	Chaunacidae	1		2		1	*	3		1		2	3		1.69
Chirocentridae	*Chirocentrus dorab*	3		2		1	*	1	*	2	*	1	1		1.69
Congrogadidae	*Congrogadus amplimaculatus*	1		2		1	*	1	*	2	*	3	3		1.69
Leiognathidae	*Leiognathus smithursti*	1		2		1	*	3		1		2	3		1.69
Lutjanidae	*Lutjanus carponotatus*	2	*	3		1	*	1	*	1		2	1	*	1.69
Lutjanidae	*Lutjanus sebae*	2	*	2		2	*	1	*	2	*	1	1		1.69
Menidae	*Mene maculata*	1		2		3	*	1	*	1	*	1	3		1.69
Microdesmidae	*Microdesmidae*	1	*	2	*	3	*	1	*	1	*	1	3		1.69
Monacanthidae	*Aluterus monoceros*	1	*	2		3	*	1	*	1	*	1	3		1.69
Monacanthidae	*Anacanthus barbatus*	1	*	2		3	*	1	*	1		1	3		1.69
Monacanthidae	*Chaetodermis penicilligera*	1	*	2		3	*	1	*	1	*	1	3		1.69
Monacanthidae	*Monacanthus chinensis*	1	*	2		3	*	1	*	1	*	1	3		1.69
Monacanthidae	*Paramonacanthus choirocephalus*	1	*	2		3	*	1	*	1	*	1	3		1.69
Platycephalidae	*Suggrundus macracanthus*	1		2		1	*	1	*	2	*	3	3		1.69
Plotosidae	*Euristhmus lepturus*	1	*	2		1	*	2		2		2	3		1.69
Plotosidae	*Euristhmus nudiceps*	1	*	2		3	*	1	*	1	*	1	3		1.69
Plotosidae	*Plotosus lineatus*	1	*	2		1	*	1	*	2	*	3	3		1.69
Scorpaenidae	*Erosa erosa*	1		2		1	*	1	*	2	*	3	3		1.69
Scorpaenidae	*Minous trachycephalus*	1		2		1	*	1	*	2	*	3	3		1.69
Scorpaenidae	*Neomerinthe megalepis*	1		2		1	*	1	*	2	*	3	3		1.69
Scorpaenidae	*Paracentropogon longispinus*	1		2		1	*	1	*	2	*	3	3		1.69
Syngnathidae	*Trachyrhamphus longirostris*	1		2		1	*	1	*	2	*	3	3		1.69
Synodontidae	*Synodus hoshinonis*	1		1		2	*	3		2		1	3		1.69
Tetraodontidae	*Feroxodon multistriatus*	1	*	2		1	*	1	*	2		3	3		1.69

Table 7.2.5 The ranking of bycatch species with respect to criteria that reflect their susceptibility to capture and mortality due to prawn trawls. The weighting scores of the criteria are shown in parentheses; * indicates where species specific information was not available.

		Criteria												
Family	**Species**	**Water column position (3)**		**Preferred habitat (3)**	**Survival (3)**		**Range (2)**		**Day/night catchability (2)**		**Diet (2)**	**Depth range (1)**		**Susceptibility rank**
Tetraodontidae	*Lagocephalus lunaris*	1		2	1	*	1	*	2	*	3	3		1.69
Tetraodontidae	*Lagocephalus spadiceus*	1	*	2	1	*	1	*	2	*	3	3		1.69
Tetraodontidae	*Torquigener hicksi*	1		2	1	*	1	*	3	*	2	3		1.69
Uranoscopidae	*Uranoscopus cognatus*	1		1	2	*	1	*	2	*	3	3		1.69
Gobiidae	*Trimma taylori*	1	*	3	1	*	3		1		1	3		1.75
Scaridae	*Scarus ghobban*	1	*	3	1	*	1		3		1	3		1.75
Cynoglossidae	*Paraplagusia bilineata*	1		2	2	*	2		1		2	3		1.75
Mullidae	*Upeneus sulphureus*	1	*	2	2	*	2	*	1	*	2	3		1.75
Pomacanthidae	*Pomacanthus sexstriatus*	2	*	2	1	*	1	*	2	*	2	3		1.75
Haemulidae	*Plectorhinchus gibbosus*	1	*	3	1	*	3		1		1	3		1.75
Sillaginidae	*Sillago ingenuua*	1	*	2	2	*	3		1		1	3		1.75
Soleidae	*Pardachirus pavoninus*	1		1	3	*	1	*	2	*	2	3		1.75
Mullidae	*Upeneus sundaicus*	1	*	2	2	*	1	*	2	*	3	1	*	1.75
Pomacanthidae	*Chaetodontoplus duboulayi*	2		2	1	*	1	*	2	*	2	3		1.75
Pseudochromidae	*Pseudochromis quinquedentatus*	2	*	2	1	*	1	*	2	*	2	3		1.75
Sciaenidae	*Otolithes ruber*	2	*	2	1	*	1	*	2	*	3	1	*	1.75
Sciaenidae	*Protonibea diacanthus*	2	*	2	1	*	1	*	3	*	1	3		1.75
Serranidae	*Epinephelus sexfasciatus*	2	*	1	2	*	1	*	3		1	3		1.75
Siganidae	*Siganus canaliculatus*	2	*	1	2	*	1	*	3		1	3		1.75
Siganidae	*Siganus fuscescens*	2	*	2	1	*	1	*	2	*	3	1		1.75
Carangidae	*Megalaspis cordyla*	3	*	2	1	*	1	*	1	*	2	3		1.81
Lactariidae	*Lactarius lactarius*	3		2	1	*	1	*	1	*	2	3		1.81
Triglidae	*Lepidotrigla spiloptera*	1		1	2		3		2		2	3		1.81
Labridae	*Choerodon cephalotes*	1	*	3	2	*	1	*	1	*	2	3		1.81
Carangidae	*Carangoides chrysophrys*	3	*	2	1	*	1		2		1	3		1.81
Carangidae	*Pantolabus radiatus*	3	*	2	1	*	1	*	1	*	2	3		1.81
Sparidae	*Argyrops spinifer*	2	*	2	2	*	1	*	2	*	1	3		1.81
Carangidae	*Scomberoides tala*	3	*	2	1	*	1	*	1	*	2	3		1.81
Carangidae	*Scomberoides tol*	3	*	2	1	*	1	*	1	*	2	3		1.81
Carangidae	*Selar boops*	3	*	2	1	*	1	*	1	*	2	3		1.81
Pinguipedidae	*Parapercis xanthozona*	1		2	1	*	3		2		2	3		1.81
Platycephalidae	*Elates ransonnetii*	1		2	1	*	2		3		2	3		1.81
Labridae	*Leptojulis cyanopleura*	1	*	2	1	*	3		2		2	3		1.81

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		Criteria							
Family	Species	Water column position (3)	Preferred habitat (3)	Survival (3)	Range (2)	Day/night catchability (2)	Diet (2)	Depth range (1)	Susceptibility rank
Carangidae	*Alepes* sp.	3 *	2	1 *	1 *	1 *	2	3	1.81
Carangidae	*Atule mate*	3 *	2	1 *	1 *	1 *	2	3	1.81
Carangidae	*Carangoides caeruleopinnatus*	3 *	2	1 *	1 *	1 *	2	3	1.81
Carangidae	*Carangoides malabaricus*	3 *	2	1 *	1 *	2 *	2	1 *	1.81
Carangidae	*Carangoides talamparoides*	3 *	2	1 *	1 *	1 *	2	3	1.81
Carangidae	*Caranx bucculentus*	3 *	2	1 *	1 *	2 *	2	1	1.81
Carangidae	*Decapterus macrosoma*	3 *	2	1 *	2	1	1	3	1.81
Carangidae	*Decapterus russelli*	3 *	2	1 *	1 *	2 *	1	3	1.81
Carangidae	*Gnathanodon speciosus*	3 *	2	1 *	1 *	2 *	2	1 *	1.81
Carangidae	*Scomberoides commersonnianus*	3 *	2	1 *	1 *	2 *	1	3	1.81
Carangidae	*Selar crumenophthalmus*	3 *	2	1 *	1 *	2 *	1	3	1.81
Carangidae	*Seriolina nigrofasciata*	3 *	2	1 *	1 *	1 *	2	3	1.81
Carangidae	*Ulua aurochs*	3 *	2	1 *	1 *	1 *	2	3	1.81
Carangidae	*Ulua mentalis*	3 *	2	1 *	1 *	1 *	2	3	1.81
Carangidae	*Uraspis uraspis*	3 *	2	1 *	1 *	1	2	3	1.81
Centrolophidae	*Psenopsis humerosa*	3	2	1 *	2	1	1	3	1.81
Chaetodontidae	*Chaetodon flavirostris*	2 *	3	1 *	2	1	1	3	1.81
Leiognathidae	*Leiognathus aureus*	1	2	1 *	3	2	2	3	1.81
Platycephalidae	*Cociella hutchinsi*	1 *	2	1 *	3	2 *	2	3	1.81
Platycephalidae	*Cymbacephalus nematophthalmus*	1	2	1 *	3	1	3	3	1.81
Platycephalidae	*Platycephalus arenarius*	1	2	1 *	3	2	2	3	1.81
Scorpaenidae	*Cottapistus cottoides*	1	2	3 *	1 *	1 *	2	3	1.81
Scorpaenidae	*Dendrochirus zebra*	1 *	3	1 *	1 *	2 *	3	3	1.88
Leiognathidae	*Leiognathus splendens*	1	2	2 *	3	1	2	3	1.88
Leiognathidae	*Secutor insidiator*	1 *	2	2	3	1	2	3	1.88
Platycephalidae	*Platycephalus indicus*	1	2	2 *	3	1	2	3	1.88
Lutjanidae	*Lutjanus quinquelineatus*	2 *	2	1 *	2	2 *	3	1	1.88
Synodontidae	*Synodus sageneus*	1	2	2	3	2	1	3	1.88
Veliferidae	*Velifer hypselopterus*	1	1	1 *	3	3	3	3	1.88
Lutjanidae	*Lutjanus vitta*	2 *	2	1 *	3	1	2	3	1.88
Tetraodontidae	*Lagocephalus inermis*	1	2	2 *	3	2	1	3	1.88
Terapontidae	*Terapon theraps*	1	2	2	3	2	1	3	1.88
Scorpaenidae	*Inimicus sinensis*	1 *	2	2	3	3	1	1	1.88

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		Criteria												
		Water column position		Preferred habitat	Survival		Range		Day/night catchability		Diet	Depth range		Susceptibility
Family	Species	(3)		(3)	(3)		(2)		(2)		(2)	(1)		rank
Lutjanidae	*Lutjanus lutjanus*	2	*	2	1	*	3		2		1	3		1.88
Champsodontidae	*Champsodon nudivittis*	3		2	2	*	1	*	2	*	1	1	*	1.88
Congridae	*Conger cinereus*	1	*	3	3	*	1	*	1	*	1	3		1.88
Lethrinidae	*Lethrinus lentjan*	2	*	2	1	*	3		1		2	3		1.88
Lutjanidae	*Lutjanus argentimaculatus*	2	*	2	1	*	3		2	*	2	1		1.88
Lutjanidae	*Lutjanus erythropterus*	2	*	2	1	*	3		2		2	1	*	1.88
Scorpaenidae	*Pterois russelli*	1	*	3	1	*	1	*	2	*	3	3		1.88
Serranidae	*Epinephelus malabaricus*	2	*	2	1	*	1	*	3	*	2	3		1.88
Sternoptychidae	*Polyipnus tridentifer*	2		2	1	*	1	*	2	*	3	3		1.88
Synodontidae	*Synodus macrops*	1		2	2	*	3		2		1	3		1.88
Tetraodontidae	*Arothron manilensis*	1	*	2	2	*	1	*	2	*	3	3		1.88
Tetraodontidae	*Chelonodon patoca*	1	*	2	2	*	1	*	2	*	3	3		1.88
Tetraodontidae	*Lagocephalus sceleratus*	1	*	3	1	*	1	*	2	*	3	3		1.88
Rachycentridae	*Rachycentron canadum*	3		2	1	*	1	*	2	*	2	3		1.94
Sciaenidae	*Johnius amblycephalus*	2	*	2	2	*	1	*	2	*	2	3		1.94
Priacanthidae	*Priacanthus tayenus*	2	*	3	1	*	1	*	2	*	2	3		1.94
Bregmacerotidae	*Bregmaceros japonicus*	3	*	2	1	*	1	*	2	*	2	3		1.94
Bregmacerotidae	*Bregmaceros mcclellandi*	3	*	2	1	*	1	*	2	*	2	3		1.94
Caesionidae	*Pterocaesio chrysozona*	3		2	1	*	2		1		2	3		1.94
Drepanidae	*Drepane punctata*	3	*	2	1	*	1	*	2	*	2	3		1.94
Engraulididae	*Encrasicholina devisi*	3	*	2	1	*	1	*	2	*	2	3		1.94
Engraulididae	*Encrasicholina heteroloba*	3		2	1	*	1	*	2	*	2	3		1.94
Engraulididae	*Setipinna tenuifilis*	3		2	1	*	2		1		2	3		1.94
Engraulididae	*Stolephorus indicus*	3		2	1	*	1	*	2	*	2	3		1.94
Engraulididae	*Stolephorus waitei*	3		2	1	*	1	*	2	*	2	3		1.94
Engraulididae	*Thryssa hamiltonii*	3		2	1	*	1	*	2	*	2	3		1.94
Engraulididae	*Thryssa marasriae*	3		2	1	*	1	*	2	*	2	3		1.94
Engraulididae	*Thryssa setirostris*	3		2	1	*	1	*	2	*	2	3		1.94
Ephippidae	*Platax batavianus*	3	*	2	1	*	1	*	2	*	2	3		1.94
Exocoetidae	Exocoetidae	3		2	1	*	2		2		1	3		1.94
Fistulariidae	*Fistularia commersonii*	2	*	3	1	*	1	*	1	*	3	3		1.94
Glaucosomatidae	*Glaucosoma magnificum*	2	*	3	1	*	1	*	2	*	2	3		1.94
Hemiramphidae	*Euleptorhamphus viridis*	3		2	1	*	1	*	2	*	2	3		1.94

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		Criteria												
Family	**Species**	**Water column position (3)**		**Preferred habitat (3)**		**Survival (3)**		**Range (2)**		**Day/night catchability (2)**		**Diet (2)**	**Depth range (1)**	**Susceptibility rank**
Hemiramphidae	*Hemiramphus robustus*	3		2		1	*	1	*	2	*	2	3	1.94
Myctophidae	Myctophidae	3	*	2	*	1	*	1	*	2	*	2	3	1.94
Nemipteridae	*Scolopsis vosmeri*	1		2		3	*	3		1	*	1	3	1.94
Sciaenidae	*Johnius borneensis*	2	*	2		2	*	2		2	*	1	3	1.94
Scombridae	*Rastrelliger brachysoma*	3		2		3	*	1	*	1	*	1	1	1.94
Serranidae	*Epinephelus quoyanus*	2	*	3		1	*	1	*	2	*	3	1	1.94
Siganidae	*Siganus lineatus*	2	*	3		1	*	1	*	2	*	3	1	1.94
Soleidae	*Dexillus muelleri*	1		2		3	*	1	*	2	*	2	3	1.94
Carangidae	*Caranx melampygus*	3		3		1	*	1	*	2	*	1	3	2.00
Carangidae	*Carangoides fulvoguttatus*	3	*	2		2	*	1	*	1	*	2	3	2.00
Carangidae	*Carangoides hedlandensis*	3	*	2		2	*	1	*	1	*	2	3	2.00
Sphyraenidae	*Sphyraena barracuda*	3		2		2	*	1	*	2	*	1	3	2.00
Scombridae	*Scomberomorus munroi*	3	*	2		2	*	1	*	3		1	1	2.00
Triacanthidae	*Trixiphichthys weberi*	2	*	1		2	*	3		3		1	3	2.00
Carangidae	*Carangoides humerosus*	3	*	2		2	*	1	*	1	*	2	3	2.00
Scombridae	*Scomberomorus commerson*	3		2		2	*	1	*	2	*	1	3	2.00
Carangidae	*Alectis ciliaris*	3	*	3		1	*	1	*	1	*	2	3	2.00
Carangidae	*Alectis indicus*	3	*	3		1	*	1	*	1	*	2	3	2.00
Hemiramphidae	*Hyporhamphus affinis*	3	*	3		1	*	1	*	1	*	2	3	2.00
Scombridae	*Scomberomorus queenslandicus*	3	*	2		2	*	1	*	2	*	1	3	2.00
Scombridae	*Scomberomorus semifasciatus*	3	*	2		2	*	1	*	2	*	1	3	2.00
Scorpaenidae	*Scorpaenopsis diabolus*	1	*	3		2	*	3		2		1	3	2.06
Lethrinidae	*Lethrinus genivittatus*	2	*	2		2	*	3		1		2	3	2.06
Triacanthidae	*Triacanthus biaculeatus*	2	*	1		1	*	3		3		3	3	2.06
Clupeidae	*Herklotsichthys koningsbergeri*	3		2		1	*	3		1		2	3	2.06
Lutjanidae	*Lutjanus russelli*	2	*	3		1	*	2		3	*	2	1	2.06
Clupeidae	*Sardinella albella*	3		2		1	*	2		1		3	3	2.06
Uranoscopidae	*Uranoscopus* sp. 1	1	*	2		1	*	3		3		3	3	2.06
Clupeidae	*Amblygaster sirm*	3		2		1	*	2		2		2	3	2.06
Terapontidae	*Terapon jarbua*	2	*	2		2	*	3		2		1	3	2.06
Terapontidae	*Terapon puta*	2		2		2	*	3		2		1	3	2.06
Serranidae	*Epinephelus areolatus*	2	*	3		1	*	1	*	3	*	2	3	2.06
Synodontidae	*Trachinocephalus myops*	1	*	3		2	*	3		2		1	3	2.06

Table 7.2.5 The ranking of bycatch species with respect to criteria that reflect their susceptibility to capture and mortality due to prawn trawls. The weighting scores of the criteria are shown in parentheses; * indicates where species specific information was not available.

		Criteria												
Family	Species	Water column position (3)		Preferred habitat (3)		Survival (3)		Range (2)		Day/night catchability (2)		Diet (2)	Depth range (1)	Susceptibility rank
Clupeidae	*Anodontostoma chacunda*	3		2		1		3		1		2	3	2.06
Clupeidae	*Dussumieria elopsoides*	3		2		1	*	3		1		2	3	2.06
Clupeidae	*Escualosa thoracata*	3		2		1	*	3		1		2	3	2.06
Scorpaenidae	*Scorpaenopsis venosa*	1	*	3		2	*	2		2		2	3	2.06
Serranidae	*Cephalopholis boenack*	2	*	3		1	*	3		1		2	3	2.06
Chaetodontidae	*Chelmonops truncatus*	2	*	3		1	*	3		1		2	3	2.06
Clupeidae	*Herklotsichthys lippa*	3		2		1	*	3		1		2	3	2.06
Clupeidae	*Pellona ditchela*	3		2		1	*	3		1		2	3	2.06
Lutjanidae	*Lutjanus malabaricus*	2	*	3		1	*	1	*	2	*	3	3	2.06
Lutjanidae	*Symphorus nematophorus*	2	*	3		1	*	3		1		2	3	2.06
Scorpaenidae	*Pterois volitans*	2	*	3		1	*	1	*	2	*	3	3	2.06
Scorpaenidae	*Scorpaena neglecta*	1		2		1	*	3		3		3	3	2.06
Serranidae	*Epinephelus coioides*	2	*	3		1	*	1	*	3	*	2	3	2.06
Terapontidae	*Pelates sexlineatus*	2		2		2	*	2		3		1	3	2.06
Tetraodontidae	*Arothron stellatus*	1	*	3		2	*	1	*	2	*	3	3	2.06
Serranidae	*Plectropomus leopardus*	2	*	3		2	*	1	*	2	*	3	1	2.13
Sciaenidae	*Austronibea oedogenys*	2	*	2		1	*	3		3		2	3	2.13
Caesionidae	*Caesio caerulaurea*	3		3		1	*	3		1		1	3	2.13
Sciaenidae	*Atractoscion aequidens*	2		2		1	*	3		3		2	3	2.13
Sciaenidae	*Atrobucca brevis*	2		2	*	1		3		2		3	3	2.13
Scatophagidae	*Scatophagus argus*	2	*	2		1	*	3		3		2	3	2.13
Scatophagidae	*Scatophagus multifasciatus*	2	*	2		1	*	3		3		2	3	2.13
Caesionidae	*Caesio teres*	3		3		1	*	2		1		2	3	2.13
Caesionidae	*Pterocaesio digramma*	3		3		1	*	2	*	1	*	2	3	2.13
Echeneidae	*Echeneis naucrates*	3		3		1	*	1	*	2	*	2	3	2.13
Engraulididae	*Stolephorus carpentariae*	3		3		1	*	1	*	2	*	2	3	2.13
Ephippidae	*Platax teira*	3	*	3		1	*	1	*	2	*	2	3	2.13
Ephippidae	*Zabidius novaemaculatus*	3	*	3		1	*	1	*	2	*	2	3	2.13
Sciaenidae	*Johnius laevis*	2	*	2		1	*	3		3		2	3	2.13
Scombridae	*Rastrelliger kanagurta*	3	*	2		2	*	1	*	2	*	2	3	2.13
Serranidae	*Plectropomus maculatus*	2	*	3		2	*	2		2		1	3	2.13
Siganidae	*Siganus argenteus*	2	*	3		2	*	1	*	3		1	3	2.13
Scorpaenidae	*Dendrochirus brachypterus*	1	*	3		2		3		2		2	3	2.19

Table 7.2.5 The ranking of bycatch species with respect to criteria that reflect their susceptibility to capture and mortality due to prawn trawls. The weighting scores of the criteria are shown in parentheses; * indicates where species specific information was not available.

		Criteria												
Family	**Species**	**Water column position (3)**		**Preferred habitat (3)**		**Survival (3)**		**Range (2)**		**Day/night catchability (2)**		**Diet (2)**	**Depth range (1)**	**Susceptibility rank**
Carangidae	*Carangoides gymnostethus*	3	*	3		2	*	1	*	1	*	2	3	2.19
Trichiuridae	*Trichiurus lepturus*	2	*	2		2	*	2		2	*	3	3	2.19
Uranoscopidae	*Ichthyscopus fasciatus*	2		1		3	*	3		2		2	3	2.19
Megalopidae	*Megalops cyprinoides*	3		3	*	1		3		1		2	3	2.25
Lethrinidae	*Lethrinus laticaudis*	2	*	3		2	*	3		1		2	3	2.25
Melanostomiidae	*Eustomias multifilis*	3		3	*	1	*	3		1		2	3	2.25
Terapontidae	*Pelates quadrilineatus*	3		2		2	*	1	*	2	*	3	3	2.25
Melanostomiidae	*Bathophilus nigerrimus*	3		3	*	1	*	3		1		2	3	2.25
Sphyraenidae	*Sphyraena forsteri*	3	*	3		1	*	3		2		3	1	2.38
Sphyraenidae	*Sphyraena jello*	3	*	3		1	*	3		2	*	2	3	2.38
Sphyraenidae	*Sphyraena obtusata*	3	*	3		1	*	3		2		2	3	2.38
Sphyraenidae	*Sphyraena putnamiae*	3	*	3		1	*	1	*	3	*	3	3	2.38
Sphyraenidae	*Sphyraena qenie*	3	*	3		1	*	3		3		1	3	2.38
Sternoptychidae	*Polyipnus elongatus*	2	*	2		3		3		2		2	3	2.38
Sphyraenidae	*Sphyraena flavicauda*	3	*	3		2	*	3		3		1	3	2.56

Table 7.2.6 The ranking of teleost species with respect to criteria that reflect their capacity to recover. The weighting of the criteria are shown in parentheses; * indicates where species specific information was not available.

Family	Species	Probability of breeding (3)	Maximum size (3)	Removal rate (3)	Reproductive stratey (2)	Hermaphrotism (1)	Mortality Index (1)	Recovery rank
		Criteria						
Plotosidae	*Euristhmus lepturus*	1 *	3	1 *	1 *	3 *	1 *	1.62
Ariidae	*Arius proximus*	1 *	3	1 *	1 *	3 *	1 *	1.62
Ariidae	*Arius bilineatus*	1 *	3	1 *	1	3	1 *	1.62
Apogonidae	*Rhabdamia gracilis*	1 *	3	1 *	1 *	3 *	1 *	1.62
Hemiramphidae	*Euleptorhamphus viridis*	1 *	3	1 *	1 *	3 *	1 *	1.62
Serranidae	*Epinephelus malabaricus*	1 *	1	2	3	3	1 *	1.69
Mugilidae	*Mugil cephalus*	1 *	2	1 *	3	3	1 *	1.69
Bothidae	*Psettina tosana*	1 *	2	1 *	3 *	3 *	1 *	1.69
Carangidae	*Alectis ciliaris*	1 *	2	1 *	3 *	3 *	1 *	1.69
Carangidae	*Caranx melampygus*	1 *	2	1 *	3	3	1 *	1.69
Congridae	*Conger wilsoni*	1 *	2	1 *	3 *	3 *	1 *	1.69
Sciaenidae	*Atractoscion aequidens*	1 *	2	1 *	3	3	1 *	1.69
Sphyraenidae	*Sphyraena jello*	1 *	2	1 *	3	3	1 *	1.69
Sternoptychidae	*Polyipnus tridentifer*	1 *	3	1 *	3 *	1 *	1 *	1.77
Gobiidae	*Acentrogobius viridipunctatus*	1 *	3	1 *	2 *	3 *	1 *	1.77
Gobiidae	*Ctenotrypauchen microcephalus*	1 *	3	1 *	2 *	3 *	1 *	1.77
Gobiidae	*Drombus globiceps*	1 *	3	1 *	2 *	3 *	1 *	1.77
Monacanthidae	*Chaetodermis penicilligera*	1 *	3	1 *	2	3	1 *	1.77
Apogonidae	*Apogon brevicaudata*	1	3	1 *	1 *	3 *	3	1.77
Ariidae	*Arius nella*	1 *	3	2	1 *	3 *	1 *	1.85
Apogonidae	*Apogon aureus*	1 *	3	2	1 *	3 *	1 *	1.85
Monacanthidae	*Paramonacanthus japonicus*	1	3	1 *	2	3	2	1.85
Callionymidae	*Callionymus belcheri*	1 *	3	1 *	3 *	3 *	1 *	1.92
Callionymidae	*Callionymus sublaevis*	1 *	3	1 *	3 *	3 *	1 *	1.92
Tetraodontidae	*Arothron manilensis*	1 *	3	1 *	3 *	3 *	1 *	1.92

Table 7.2.6 The ranking of teleost species with respect to criteria that reflect their capacity to recover. The weighting of the criteria are shown in parentheses; * indicates where species specific information was not available.

		Criteria										
		Probability of breeding		Maximum size	Removal rate		Reproductive stratey		Hermaphrotism		Mortality Index	Recovery
Family	***Species***	(3)		(3)	(3)		(2)		(1)		(1)	rank
Haemulidae	*Plectorhinchus gibbosus*	1	*	3	1	*	3	*	3	*	1	* 1.92
Bothidae	*Psettina gigantea*	1	*	3	1	*	3	*	3	*	1	* 1.92
Caesionidae	*Pterocaesio chrysozona*	1	*	3	1	*	3	*	3	*	1	* 1.92
Carangidae	*Trachinotus cf mookalee*	1	*	3	1	*	3	*	3	*	1	* 1.92
Carapidae	*Encheliophis gracilis*	1	*	3	1	*	3	*	3	*	1	* 1.92
Chaetodontidae	*Chaetodon flavirostris*	1	*	3	1	*	3	*	3	*	1	* 1.92
Chaetodontidae	*Heniochus diphreutes*	1	*	3	1	*	3	*	3	*	1	* 1.92
Chaunacidae	unidentified Chaunacidae	1	*	3	1	*	3		3		1	* 1.92
Congridae	*Poeciloconger kapala*	1	*	3	1	*	3	*	3	*	1	* 1.92
Diodontidae	*Cyclichthys orbicularis*	1	*	3	1		3	*	3	*	1	* 1.92
Engraulididae	*Encrasicholina devisi*	1	*	3	1	*	3		3		1	* 1.92
Engraulididae	*Stolephorus carpentariae*	1	*	3	1	*	3	*	3	*	1	* 1.92
Gerreidae	*Gerres erythrourus*	1	*	3	1	*	3	*	3	*	1	* 1.92
Labridae	*Leptojulis cyanopleura*	1	*	3	1	*	3	*	3	*	1	* 1.92
Leiognathidae	*Leiognathus blochii*	1	*	3	1	*	3	*	3	*	1	* 1.92
Microdesmidae	unidentified Microdesmidae	1	*	3	1	*	3	*	3	*	1	* 1.92
Mullidae	*Parupeneus barberinoides*	1	*	3	1	*	3		3		1	* 1.92
Platycephalidae	*Platycephalus arenarius*	1	*	3	1	*	3	*	3	*	1	* 1.92
Pleuronectidae	*Samaris cristatus*	1	*	3	1	*	3	*	3	*	1	* 1.92
Scatophagidae	*Scatophagus multifasciatus*	1	*	3	1	*	3	*	3	*	1	* 1.92
Scorpaenidae	*Paracentropogon longispinus*	1	*	3	1	*	3	*	3	*	1	* 1.92
Scorpaenidae	*Pterois volitans*	1	*	3	1	*	3	*	3	*	1	* 1.92
Scorpaenidae	*Richardsonichthys leucogaster*	1	*	3	1	*	3	*	3	*	1	* 1.92
Scorpaenidae	*Scorpaena neglecta*	1	*	3	1	*	3		3		1	* 1.92
Sphyraenidae	*Sphyraena barracuda*	1	*	1	3		3		3		1	* 1.92

Table 7.2.6 The ranking of teleost species with respect to criteria that reflect their capacity to recover. The weighting of the criteria are shown in parentheses; * indicates where species specific information was not available.

		Criteria											
Family	***Species***	**Probability of breeding (3)**		**Maximum size (3)**	**Removal rate (3)**		**Reproductive stratey (2)**		**Hermaphrotism (1)**		**Mortality Index (1)**		**Recovery rank**
Synodontidae	*Synodus macrops*	1	*	3	1	*	3	*	3	*	1	*	1.92
Triacanthidae	*Triacanthus biaculeatus*	1	*	3	1	*	3		3		1	*	1.92
Uranoscopidae	*Ichthyscopus fasciatus*	1	*	3	1	*	3		3		1	*	1.92
Bathysauridae	*Saurida undosquamis*	1	*	3	1	*	3	*	3	*	1	*	1.92
Scombridae	*Rastrelliger brachysoma*	1		3	1	*	3		3		2		2.00
Gerreidae	*Gerres filamentosus*	1		3	1	*	3	*	3	*	2		2.00
Carangidae	*Ulua mentalis*	2		2	1	*	3	*	3	*	2		2.00
Pinguipedidae	*Parapercis xanthozona*	1	*	3	2		3		1		1	*	2.00
Hemiramphidae	*Hemiramphus robustus*	1	*	3	3		1	*	3	*	1	*	2.08
Scombridae	*Scomberomorus commerson*	1	*	1	3		3		3		3		2.08
Syngnathidae	*Trachyrhamphus longirostris*	1	*	3	3		1	*	3	*	1	*	2.08
Bregmacerotidae	*Bregmaceros japonicus*	1		3	1	*	3	*	3	*	3		2.08
Fistulariidae	*Fistularia commersonii*	1	*	1	3		3		3		3		2.08
Ariidae	*Netuma thalassinus*	3		1	3		1		3		1		2.08
Apogonidae	*Apogon cavitiensis*	1	*	3	3		1	*	3	*	1	*	2.08
Apogonidae	*Apogon nigrocincta*	1	*	3	3		1	*	3	*	1	*	2.08
Apogonidae	*Cheilodipterus artus*	1	*	3	3		1	*	3	*	1	*	2.08
Apogonidae	*Siphamia fuscolineata*	1	*	3	3		1	*	3	*	1	*	2.08
Apogonidae	*Siphamia guttulatus*	1	*	3	3		1	*	3	*	1	*	2.08
Hemiramphidae	*Hyporhamphus affinis*	1	*	3	3		1	*	3	*	1	*	2.08
Opisthognathidae	*Opistognathus latitabundus*	1	*	3	3		1	*	3	*	1	*	2.08
Scatophagidae	*Scatophagus argus*	1	*	3	1		3	*	3	*	3		2.08
Scorpaenidae	*Dendrochirus brachypterus*	1		3	1	*	3		3		3		2.08
Apogonidae	*Apogon nigripinnis*	1	*	3	3		1	*	3	*	2		2.15
Apogonidae	*Pseudamia amblyuroptera*	1		3	3		1	*	3	*	2		2.15

Table 7.2.6 The ranking of teleost species with respect to criteria that reflect their capacity to recover. The weighting of the criteria are shown in parentheses; * indicates where species specific information was not available.

		Criteria										
Family	***Species***	**Probability of breeding (3)**		**Maximum size (3)**	**Removal rate (3)**	**Reproductive stratey (2)**		**Hermaphrotism (1)**		**Mortality Index (1)**		**Recovery rank**
Ariidae	*Arius argyropleuron*	1	*	3	3	1	*	3	*	2		2.15
Megalopidae	*Megalops cyprinoides*	1	*	2	3	3		3		1	*	2.15
Rachycentridae	*Rachycentron canadum*	2		1	3	3		3		1		2.15
Serranidae	*Plectropomus leopardus*	1	*	2	3	3		3		1	*	2.15
Clupeidae	*Escualosa thoracata*	1	*	3	2	3		3		1	*	2.15
Carangidae	*Carangoides gymnostethus*	1	*	2	3	3	*	3	*	1	*	2.15
Chaetodontidae	*Chelmonops truncatus*	1	*	3	2	3	*	3	*	1	*	2.15
Congridae	*Ariosoma anago*	1	*	3	2	3	*	3	*	1	*	2.15
Congridae	*Conger cinereus*	1	*	2	3	3	*	3	*	1	*	2.15
Nemipteridae	*Scolopsis vosmeri*	1	*	3	2	3	*	3	*	1	*	2.15
Nettastomatidae	*Nettastoma parviceps*	1	*	2	3	3		3		1	*	2.15
Platycephalidae	*Papilloculiceps bosschei*	1	*	3	2	3	*	3	*	1	*	2.15
Sciaenidae	*Otolithes ruber*	1	*	2	3	3	*	3	*	1	*	2.15
Siganidae	*Siganus argenteus*	1	*	3	2	3		3		1	*	2.15
Siganidae	*Siganus lineatus*	1	*	3	2	3		3		1	*	2.15
Plotosidae	*Euristhmus nudiceps*	1		3	3	1	*	3	*	3		2.23
Apogonidae	*Apogon albimaculosus*	1		3	3	1	*	3	*	3		2.23
Apogonidae	*Apogon melanopus*	1		3	3	1	*	3	*	3		2.23
Apogonidae	*Apogon poecilopterus*	1		3	3	1	*	3	*	3		2.23
Gobiidae	*Acentrogobius caninus*	1	*	3	3	2	*	3	*	1	*	2.23
Monacanthidae	*Aluterus monoceros*	1	*	3	3	2		3		1	*	2.23
Pseudochromidae	*Pseudochromis quinquedentatus*	1	*	3	3	1	*	3	*	3		2.23
Muraenidae	*Gymnothorax reticularis*	1	*	3	2	3		3		2		2.23
Melanostomiidae	*Bathophilus nigerrimus*	1	*	3	3	3	*	1	*	1	*	2.23
Melanostomiidae	*Eustomias multifilis*	1	*	3	3	3	*	1	*	1	*	2.23

Table 7.2.6 The ranking of teleost species with respect to criteria that reflect their capacity to recover. The weighting of the criteria are shown in parentheses; * indicates where species specific information was not available.

		Criteria											
Family	***Species***	**Probability of breeding (3)**		**Maximum size (3)**	**Removal rate (3)**		**Reproductive stratey (2)**		**Hermaphrotism (1)**		**Mortality Index (1)**		**Recovery rank**
Serranidae	*Cephalopholis boenack*	1	*	3	3		3		1		1	*	2.23
Serranidae	*Epinephelus heniochus*	1	*	3	3		3		1		1	*	2.23
Sternoptychidae	*Polyipnus elongatus*	1	*	3	3		3	*	1	*	1	*	2.23
Sciaenidae	*Protonibea diacanthus*	1	*	2	3		3	*	3	*	3		2.31
Scombridae	*Scomberomorus semifasciatus*	1	*	2	3		3	*	3	*	3		2.31
Clupeidae	*Sardinella albella*	2		3	1	*	3		3		3		2.31
Serranidae	*Plectropomus maculatus*	1	*	2	3		3		3		3		2.31
Caesionidae	*Caesio teres*	1	*	3	2		3		3		3		2.31
Carangidae	*Carangoides fulvoguttatus*	1	*	2	3		3	*	3	*	3		2.31
Champsodontidae	*Champsodon nudivittis*	2		3	1	*	3		3		3		2.31
Engraulididae	*Stolephorus waitei*	2		3	1	*	3		3		3		2.31
Gerreidae	*Gerres oyena*	3		3			3	*	3	*	3		2.31
Serranidae	*Epinephelus coioides*	1	*	2	3		3		3		3		2.31
Tetraodontidae	*Lagocephalus inermis*	1	*	2	3		3		3		3		2.31
Batrachoididae	*Batrachomoeus trispinosus*	1	*	3	3		2	*	3	*	3		2.38
Gobiidae	*Parachaeturichthys polynema*	1		3	3		2	*	3	*	3		2.38
Monacanthidae	*Paramonacanthus choirocephalus*	1		3	3		2		3		3		2.38
Apogonidae	*Siphamia majimai*	2		3	3		1	*	3	*	2		2.38
Scaridae	*Scarus ghobban*	2		2	3		3		1		3		2.38
Pinguipedidae	*Parapercis nebulosa*	1		3	3		3		1		3		2.38
Serranidae	*Epinephelus quoyanus*	1	*	3	3		3		1		3		2.38
Lutjanidae	*Lutjanus quinquelineatus*	1	*	3	3		3		3		1	*	2.38
Antennariidae	*Antennarius pictus*	1	*	3	3		3	*	3	*	1	*	2.38
Callionymidae	*Callionymus meridionalis*	1		3	3		3	*	3	*	1	*	2.38
Sphyraenidae	*Sphyraena putnamiae*	2		2	3		3		3		1		2.38
Nemipteridae	*Nemipterus celebicus*	1	*	3	3		3	*	3	*	1	*	2.38

Table 7.2.6 The ranking of teleost species with respect to criteria that reflect their capacity to recover. The weighting of the criteria are shown in parentheses; * indicates where species specific information was not available.

		Criteria									
		Probability of breeding		Maximum size	Removal rate	Reproductive stratey		Hermaphrotism		Mortality Index		Recovery
Family	***Species***	(3)		(3)	(3)	(2)		(1)		(1)		rank
Nemipteridae	*Pentapodus porosus*	1	*	3	3	3	*	3	*	1	*	2.38
Nemipteridae	*Scolopsis affinis*	1	*	3	3	3	*	3	*	1	*	2.38
Sciaenidae	*Johnius laevis*	1	*	3	3	3		3		1	*	2.38
Acropomatidae	*Malakichthys* sp. 1	1	*	3	3	3	*	3	*	1	*	2.38
Antennariidae	*Antennarius hispidus*	1	*	3	3	3	*	3	*	1	*	2.38
Antennariidae	*Antennarius striatus*	1	*	3	3	3	*	3	*	1	*	2.38
Congrogadidae	*Congrogadus amplimaculatus*	1	*	3	3	3		3		1	*	2.38
Apogonidae	*Apogon notatus*	1	*	3	3	3	*	3	*	1	*	2.38
Ariommatidae	*Ariomma indica*	1	*	3	3	3		3		1	*	2.38
Bothidae	*Pseudorhombus dupliciocellatus*	1	*	3	3	3	*	3	*	1	*	2.38
Caesionidae	*Caesio caerulaurea*	1	*	3	3	3	*	3	*	1	*	2.38
Caesionidae	*Pterocaesio digramma*	1	*	3	3	3	*	3	*	1	*	2.38
Carangidae	*Decapterus macrosoma*	1	*	3	3	3		3		1	*	2.38
Carapidae	*Onuxodon margaritiferae*	1	*	3	3	3	*	3	*	1	*	2.38
Congridae	*Lumiconger arafura*	1	*	3	3	3	*	3	*	1	*	2.38
Congridae	*Uroconger lepturus*	1	*	3	3	3	*	3	*	1	*	2.38
Cynoglossidae	*Cynoglossus bilineatus*	1	*	3	3	3	*	3	*	1	*	2.38
Cynoglossidae	*Cynoglossus macrophthalmus*	1	*	3	3	3	*	3	*	1	*	2.38
Dactylopteridae	*Dactyloptena macracanthus*	1	*	3	3	3	*	3	*	1	*	2.38
Diodontidae	*Lophodiodon calori*	1	*	3	3	3	*	3	*	1	*	2.38
Engraulididae	*Thryssa marasriae*	1	*	3	3	3	*	3	*	1	*	2.38
Holocentridae	*Myripristis botche*	1	*	3	3	3	*	3	*	1	*	2.38
Holocentridae	*Myripristis murdjan*	1	*	3	3	3	*	3	*	1	*	2.38
Leiognathidae	*Leiognathus aureus*	1	*	3	3	3	*	3	*	1	*	2.38
Leiognathidae	*Leiognathus elongatus*	1	*	3	3	3	*	3	*	1	*	2.38
Muraenesocidae	*Muraenesox cinereus*	3		1	3	3		3		1	*	2.38

Table 7.2.6 The ranking of teleost species with respect to criteria that reflect their capacity to recover. The weighting of the criteria are shown in parentheses; * indicates where species specific information was not available.

		Criteria						
Family	***Species***	**Probability of breeding (3)**	**Maximum size (3)**	**Removal rate (3)**	**Reproductive stratey (2)**	**Hermaphrotism (1)**	**Mortality Index (1)**	**Recovery rank**
Myctophidae	unidentified Myctophidae	1 *	3	3	3 *	3 *	1 *	2.38
Ogcocephalidae	unidentified Ogcocephalidae	1 *	3	3	3 *	3 *	1 *	2.38
Ophichthidae	unidentified Ophichthidae	1 *	3	3	3 *	3 *	1 *	2.38
Pegasidae	*Eurypegasus draconis*	1 *	3	3	3	3	1 *	2.38
Pempherididae	*Leptobrama mulleri*	1 *	3	3	3 *	3 *	1 *	2.38
Platycephalidae	*Inegocia harrisii*	1 *	3	3	3 *	3 *	1 *	2.38
Platycephalidae	*Onigocia spinosa*	1 *	3	3	3 *	3 *	1 *	2.38
Pomacanthidae	*Pomacanthus sexstriatus*	1 *	3	3	3 *	3 *	1 *	2.38
Sciaenidae	*Atrobucca brevis*	1 *	3	3	3	3	1 *	2.38
Scorpaenidae	*Dendrochirus zebra*	1 *	3	3	3	3	1 *	2.38
Scorpaenidae	*Erosa erosa*	1 *	3	3	3 *	3 *	1 *	2.38
Scorpaenidae	*Scorpaenopsis diabolus*	1 *	3	3	3 *	3 *	1 *	2.38
Scorpaenidae	*Scorpaenopsis venosa*	1 *	3	3	3 *	3 *	1 *	2.38
Soleidae	*Strabozebrias cancellatus*	1 *	3	3	3 *	3 *	1 *	2.38
Sphyraenidae	*Sphyraena qenie*	3	1	3	3	3	1	2.38
Scombridae	*Scomberomorus munroi*	2	2	3	3	3	2	2.46
Cynoglossidae	*Cynoglossus maculipinnis*	1 *	3	3	3 *	3 *	2	2.46
Engraulididae	*Setipinna tenuifilis*	1 *	3	3	3	3	2	2.46
Engraulididae	*Stolephorus indicus*	3	3	1 *	3	3	2	2.46
Exocoetidae	unidentified Exocoetidae	2	3	2	3 *	3 *	2	2.46
Haemulidae	*Diagramma pictum*	2	2	3	3	3	2	2.46
Labridae	*Choerodon monostigma*	1	3	3	3 *	3 *	2	2.46
Platycephalidae	*Cociella hutchinsi*	1 *	3	3	3 *	3 *	2	2.46
Platycephalidae	*Rogadius asper*	1	3	3	3 *	3 *	2	2.46
Scorpaenidae	*Cottapistus praepositus*	1	3	3	3 *	3 *	2	2.46

Table 7.2.6 The ranking of teleost species with respect to criteria that reflect their capacity to recover. The weighting of the criteria are shown in parentheses; * indicates where species specific information was not available.

		Criteria									
Family	***Species***	**Probability of breeding (3)**		**Maximum size (3)**	**Removal rate (3)**	**Reproductive stratey (2)**		**Hermaphrotism (1)**		**Mortality Index (1)**	**Recovery rank**
Apogonidae	*Apogon fasciatus*	2		3	3	1	*	3	*	3	2.46
Apogonidae	*Apogon septemstriatus*	2		3	3	1	*	3	*	3	2.46
Apogonidae	*Apogon* sp. 2	2		3	3	1	*	3	*	3	2.46
Apogonidae	*Siphamia argyrogaster*	2		3	3	1	*	3	*	3	2.46
Apogonidae	*Siphamia roseigaster*	2		3	3	1	*	3	*	3	2.46
Lethrinidae	*Lethrinus genivittatus*	2		3	3	3	*	1	*	2	2.54
Lutjanidae	*Lutjanus argentimaculatus*	2		2	3	3		3		3	2.54
Lutjanidae	*Lutjanus johnii*	1		3	3	3		3		3	2.54
Lutjanidae	*Symphorus nematophorus*	2		2	3	3	*	3	*	3	2.54
Callionymidae	*Callionymus grossi*	1		3	3	3	*	3	*	3	2.54
Callionymidae	*Synchiropus rameus*	1	*	3	3	3	*	3	*	3	2.54
Holocentridae	*Sargocentron rubrum*	1		3	3	3	*	3	*	3	2.54
Gerreidae	*Pentaprion longimanus*	1		3	3	3	*	3	*	3	2.54
Sphyraenidae	*Sphyraena obtusata*	1		3	3	3		3		3	2.54
Tetraodontidae	*Arothron stellatus*	2		2	3	3	*	3	*	3	2.54
Trichiuridae	*Trichiurus lepturus*	3		1	3	3		3		3	2.54
Scorpaenidae	*Minous trachycephalus*	1		3	3	3	*	3	*	3	2.54
Tetraodontidae	*Torquigener whitleyi*	1		3	3	3		3		3	2.54
Sillaginidae	*Sillago ingenuua*	1		3	3	3	*	3	*	3	2.54
Sillaginidae	*Sillago lutea*	1		3	3	3		3		3	2.54
Bathysauridae	*Saurida longimanus*	1		3	3	3	*	3	*	3	2.54
Bathysauridae	*Saurida* sp. 2	1		3	3	3	*	3	*	3	2.54
Carangidae	*Selaroides leptolepis*	1		3	3	3	*	3	*	3	2.54
Clupeidae	*Anodontostoma chacunda*	1		3	3	3		3		3	2.54
Clupeidae	*Dussumieria elopsoides*	1		3	3	3	*	3	*	3	2.54

Table 7.2.6 The ranking of teleost species with respect to criteria that reflect their capacity to recover. The weighting of the criteria are shown in parentheses; * indicates where species specific information was not available.

		Criteria						
		Probability of breeding	Maximum size	Removal rate	Reproductive stratey	Hermaphrotism	Mortality Index	Recovery
Family	***Species***	(3)	(3)	(3)	(2)	(1)	(1)	rank
Clupeidae	*Herklotsichthys koningsbergeri*	1	3	3	3	3	3	2.54
Clupeidae	*Herklotsichthys lippa*	1	3	3	3 *	3 *	3	2.54
Clupeidae	*Sardinella gibbosa*	1	3	3	3	3	3	2.54
Carangidae	*Caranx bucculentus*	1	3	3	3 *	3 *	3	2.54
Fistulariidae	*Fistularia petimba*	3	1	3	3	3	3	2.54
Bregmacerotidae	*Bregmaceros mcclellandi*	1	3	3	3	3	3	2.54
Carangidae	*Scomberoides commersonnianus*	2	2	3	3 *	3 *	3	2.54
Bathysauridae	*Saurida micropectoralis*	1	3	3	3 *	3 *	3	2.54
Bothidae	*Arnoglossus waitei*	1	3	3	3 *	3 *	3	2.54
Bothidae	*Engyprosopon grandisquamum*	1	3	3	3 *	3 *	3	2.54
Bothidae	*Grammatobothus polyophthalmus*	1	3	3	3 *	3 *	3	2.54
Bothidae	*Pseudorhombus argus*	1	3	3	3 *	3 *	3	2.54
Bothidae	*Pseudorhombus diplospilus*	1	3	3	3 *	3 *	3	2.54
Bothidae	*Pseudorhombus elevatus*	1	3	3	3 *	3 *	3	2.54
Bothidae	*Pseudorhombus jenynsii*	1	3	3	3	3	3	2.54
Bothidae	*Pseudorhombus spinosus*	1	3	3	3 *	3 *	3	2.54
Carangidae	*Alectis indicus*	3	1	3	3 *	3 *	3	2.54
Carangidae	*Alepes* sp.	1	3	3	3 *	3 *	3	2.54
Carangidae	*Carangoides hedlandensis*	1	3	3	3 *	3 *	3	2.54
Carangidae	*Carangoides humerosus*	1	3	3	3 *	3 *	3	2.54
Carangidae	*Caranx kleinii*	1	3	3	3 *	3 *	3	2.54
Carangidae	*Decapterus russelli*	1	3	3	3	3	3	2.54
Carangidae	*Selar boops*	1	3	3	3 *	3 *	3	2.54
Carangidae	*Uraspis uraspis*	1	3	3	3 *	3 *	3	2.54
Centriscidae	*Centriscus scutatus*	1	3	3	3	3	3	2.54
Citharidae	*Brachypleura novaezeelandiae*	1	3	3	3 *	3 *	3	2.54

Table 7.2.6 The ranking of teleost species with respect to criteria that reflect their capacity to recover. The weighting of the criteria are shown in parentheses; * indicates where species specific information was not available.

		Criteria						
Family	***Species***	**Probability of breeding (3)**	**Maximum size (3)**	**Removal rate (3)**	**Reproductive stratey (2)**	**Hermaphrotism (1)**	**Mortality Index (1)**	**Recovery rank**
Cynoglossidae	*Cynoglossus arel*	1 *	3	3	3 *	3 *	3	2.54
Engraulididae	*Encrasicholina heteroloba*	3	3	1 *	3	3	3	2.54
Engraulididae	*Thryssa hamiltonii*	1	3	3	3	3	3	2.54
Engraulididae	*Thryssa setirostris*	1	3	3	3	3	3	2.54
Ephippidae	*Platax batavianus*	1 *	3	3	3 *	3 *	3	2.54
Gerreidae	*Gerres macracanthus*	1	3	3	3 *	3 *	3	2.54
Gerreidae	*Gerres macrosoma*	1	3	3	3 *	3 *	3	2.54
Gerreidae	*Gerres subfasciatus*	1 *	3	3	3 *	3 *	3	2.54
Haemulidae	*Pomadasys argenteus*	1 *	3	3	3 *	3 *	3	2.54
Haemulidae	*Pomadasys trifasciatus*	1	3	3	3 *	3 *	3	2.54
Labridae	*Xiphocheilus typus*	1	3	3	3 *	3 *	3	2.54
Leiognathidae	*Leiognathus equulus*	1	3	3	3 *	3 *	3	2.54
Leiognathidae	*Leiognathus leuciscus*	1	3	3	3 *	3 *	3	2.54
Leiognathidae	*Leiognathus moretoniensis*	1	3	3	3 *	3 *	3	2.54
Leiognathidae	*Leiognathus ruconius*	1	3	3	3	3	3	2.54
Leiognathidae	*Leiognathus* sp.	1	3	3	3 *	3 *	3	2.54
Mullidae	*Upeneus luzonius*	1	3	3	3	3	3	2.54
Mullidae	*Upeneus* sp. 1	1	3	3	3	3	3	2.54
Mullidae	*Upeneus sulphureus*	1	3	3	3	3	3	2.54
Mullidae	*Upeneus sundaicus*	1	3	3	3	3	3	2.54
Ophidiidae	*Sirembo imberbis*	1	3	3	3 *	3 *	3	2.54
Pegasidae	*Pegasus volitans*	1	3	3	3	3	3	2.54
Pempherididae	*Pempheris analis*	1 *	3	3	3 *	3 *	3	2.54
Platycephalidae	*Elates ransonnetii*	1	3	3	3 *	3 *	3	2.54
Platycephalidae	*Inegocia japonica*	1	3	3	3 *	3 *	3	2.54
Platycephalidae	*Platycephalus endrachtensis*	1	3	3	3 *	3 *	3	2.54

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		Criteria									
Family	***Species***	**Probability of breeding (3)**		**Maximum size (3)**	**Removal rate (3)**	**Reproductive stratey (2)**		**Hermaphrotism (1)**		**Mortality Index (1)**	**Recovery rank**
Platycephalidae	*Sorsogona tuberculata*	1		3	3	3	*	3	*	3	2.54
Platycephalidae	*Suggrundus macracanthus*	1		3	3	3	*	3	*	3	2.54
Polynemidae	*Polydactylus multiradiatus*	1		3	3	3	*	3	*	3	2.54
Polynemidae	*Polydactylus nigripinnis*	1	*	3	3	3	*	3	*	3	2.54
Rhinoprenidae	*Rhinoprenes pentanemus*	1	*	3	3	3	*	3	*	3	2.54
Sciaenidae	*Austronibea oedogenys*	1	*	3	3	3	*	3	*	3	2.54
Sciaenidae	*Johnius amblycephalus*	1		3	3	3		3		3	2.54
Sciaenidae	*Johnius borneensis*	1		3	3	3		3		3	2.54
Scorpaenidae	*Apistus carinatus*	1		3	3	3	*	3	*	3	2.54
Scorpaenidae	*Brachypterois serrulatus*	1		3	3	3	*	3	*	3	2.54
Scorpaenidae	*Minous versicolor*	1		3	3	3	*	3	*	3	2.54
Scorpaenidae	*Neomerinthe megalepis*	1		3	3	3	*	3	*	3	2.54
Soleidae	*Dexillus muelleri*	1		3	3	3	*	3	*	3	2.54
Soleidae	*Zebrias quagga*	1		3	3	3	*	3	*	3	2.54
Sparidae	*Argyrops spinifer*	1	*	3	3	3	*	3	*	3	2.54
Sphyraenidae	*Sphyraena flavicauda*	1		3	3	3		3		3	2.54
Synodontidae	*Synodus sageneus*	1		3	3	3	*	3	*	3	2.54
Terapontidae	*Terapon puta*	1		3	3	3	*	3	*	3	2.54
Tetraodontidae	*Lagocephalus spadiceus*	1		3	3	3		3		3	2.54
Tetraodontidae	*Torquigener pallimaculatus*	1		3	3	3		3		3	2.54
Tetraodontidae	*Torquigener tuberculiferus*	1		3	3	3		3		3	2.54
Triglidae	*Lepidotrigla* sp. 2	1		3	3	3	*	3	*	3	2.54
Lutjanidae	*Lutjanus sebae*	3		2	3	3		3		1	2.62
Nemipteridae	*Nemipterus furcosus*	2		3	3	3		1		3	2.62
Nemipteridae	*Scolopsis monogramma*	2		3	3	3		1		3	2.62

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		Criteria								
		Probability of breeding	Maximum size	Removal rate	Reproductive stratey		Hermaphrotism		Mortality Index	Recovery
Family	***Species***	(3)	(3)	(3)	(2)		(1)		(1)	rank
Balistidae	*Abalistes stellaris*	2	3	3	2	*	3	*	3	2.62
Gobiidae	*Oxyurichthys papuanus*	2	3	3	2	*	3	*	3	2.62
Gobiidae	*Oxyurichthys* sp.	2	3	3	2	*	3	*	3	2.62
Gobiidae	*Trimma taylori*	2	3	3	2	*	3	*	3	2.62
Monacanthidae	*Anacanthus barbatus*	2	3	3	2		3		3	2.62
Monacanthidae	*Pseudomonacanthus peroni*	2	3	3	2		3		3	2.62
Serranidae	*Epinephelus areolatus*	2	3	3	3		1		3	2.62
Lutjanidae	*Lutjanus malabaricus*	3	2	3	3		3		2	2.69
Callionymidae	*Callionymus japonicus*	2	3	3	3	*	3	*	2	2.69
Apogonidae	*Apogon ellioti*	3	3	3	1	*	3	*	3	2.69
Carangidae	*Megalaspis cordyla*	3	2	3	3	*	3	*	2	2.69
Cynoglossidae	*Paraplagusia longirostris*	2	3	3	3	*	3	*	2	2.69
Diodontidae	*Cyclichthys hardenbergi*	2	3	3	3	*	3	*	2	2.69
Ephippidae	*Zabidius novaemaculatus*	2	3	3	3	*	3	*	2	2.69
Holocentridae	*Myripristis hexagona*	2	3	3	3	*	3	*	2	2.69
Labridae	*Choerodon cephalotes*	2	3	3	3	*	3	*	2	2.69
Leiognathidae	*Leiognathus smithursti*	2	3	3	3	*	3	*	2	2.69
Ostraciidae	*Tetrosomus gibbosus*	2	3	3	3	*	3	*	2	2.69
Platycephalidae	*Platycephalus indicus*	3	2	3	3	*	3	*	2	2.69
Scorpaenidae	*Cottapistus cottoides*	2	3	3	3	*	3	*	2	2.69
Soleidae	*Pardachirus pavoninus*	2	3	3	3	*	3	*	2	2.69
Tetraodontidae	*Feroxodon multistriatus*	2	3	3	3	*	3	*	2	2.69
Tetraodontidae	*Torquigener hicksi*	2	3	3	3		3		2	2.69
Uranoscopidae	*Uranoscopus* sp. 1	2	3	3	3		3		2	2.69
Monacanthidae	*Monacanthus chinensis*	3	3	3	2		3		2	2.77

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		Criteria								
Family	***Species***	**Probability of breeding (3)**	**Maximum size (3)**	**Removal rate (3)**	**Reproductive stratey (2)**		**Hermaphrotism (1)**		**Mortality Index (1)**	**Recovery rank**
Monacanthidae	*Paramonacanthus filicauda*	3	3	3	2		3		2	2.77
Lutjanidae	*Lutjanus carponotatus*	2	3	3	3	*	3	*	3	2.77
Lutjanidae	*Lutjanus erythropterus*	3	2	3	3		3		3	2.77
Lutjanidae	*Lutjanus lutjanus*	2	3	3	3		3		3	2.77
Antennariidae	*Antennarius nummifer*	2	3	3	3	*	3	*	3	2.77
Antennariidae	*Tetrabrachium ocellatum*	2	3	3	3	*	3	*	3	2.77
Aploactinidae	*Adventor elongatus*	2	3	3	3	*	3	*	3	2.77
Pomacanthidae	*Chaetodontoplus duboulayi*	2	3	3	3	*	3	*	3	2.77
Scombridae	*Scomberomorus queenslandicus*	3	2	3	3	*	3	*	3	2.77
Leiognathidae	*Leiognathus decorus*	2	3	3	3		3		3	2.77
Diodontidae	*Tragulichthys jaculiferus*	2	3	3	3	*	3	*	3	2.77
Serranidae	*Epinephelus sexfasciatus*	2	3	3	3		3		3	2.77
Nemipteridae	*Nemipterus marginatus*	2	3	3	3	*	3	*	3	2.77
Antennariidae	*Tathicarpus butleri*	2	3	3	3	*	3	*	3	2.77
Priacanthidae	*Priacanthus tayenus*	2	3	3	3	*	3	*	3	2.77
Sillaginidae	*Sillago sihama*	2	3	3	3		3		3	2.77
Clupeidae	*Amblygaster sirm*	2	3	3	3		3		3	2.77
Terapontidae	*Pelates sexlineatus*	2	3	3	3	*	3	*	3	2.77
Leiognathidae	*Secutor insidiator*	2	3	3	3	*	3	*	3	2.77
Bothidae	*Pseudorhombus arsius*	2	3	3	3	*	3	*	3	2.77
Bothidae	*Laeops parviceps*	2	3	3	3	*	3	*	3	2.77
Carangidae	*Carangoides chrysophrys*	2	3	3	3	*	3	*	3	2.77
Carangidae	*Carangoides talamparoides*	2	3	3	3	*	3	*	3	2.77
Carangidae	*Gnathanodon speciosus*	3	2	3	3	*	3	*	3	2.77
Carangidae	*Pantolabus radiatus*	2	3	3	3	*	3	*	3	2.77

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		Criteria						
		Probability of breeding	Maximum size	Removal rate	Reproductive stratey	Hermaphrotism	Mortality Index	Recovery
Family	***Species***	(3)	(3)	(3)	(2)	(1)	(1)	rank
Carangidae	*Seriolina nigrofasciata*	2	3	3	3 *	3 *	3	2.77
Centrolophidae	*Psenopsis humerosa*	2	3	3	3	3	3	2.77
Cepolidae	*Acanthocepola abbreviata*	2	3	3	3 *	3 *	3	2.77
Chaetodontidae	*Chelmon marginalis*	2	3	3	3 *	3 *	3	2.77
Chaetodontidae	*Coradion chrysozonus*	2	3	3	3 *	3 *	3	2.77
Chirocentridae	*Chirocentrus dorab*	3	2	3	3	3	3	2.77
Congridae	*Gnathophis* sp.	2	3	3	3 *	3 *	3	2.77
Cynoglossidae	*Cynoglossus kopsii*	2	3	3	3 *	3 *	3	2.77
Cynoglossidae	*Paraplagusia bilineata*	2	3	3	3 *	3 *	3	2.77
Dactylopteridae	*Dactyloptena papilio*	2	3	3	3 *	3 *	3	2.77
Echeneidae	*Echeneis naucrates*	3	2	3	3 *	3 *	3	2.77
Ephippidae	*Platax teira*	2	3	3	3 *	3 *	3	2.77
Gerreidae	*Gerres baconensis*	2	3	3	3 *	3 *	3	2.77
Haemulidae	*Pomadasys kaakan*	3	2	3	3 *	3 *	3	2.77
Harpadontidae	*Harpadon translucens*	2	3	3	3 *	3 *	3	2.77
Mullidae	*Parupeneus heptacanthus*	2	3	3	3	3	3	2.77
Mullidae	*Upeneus asymmetricus*	2	3	3	3	3	3	2.77
Platycephalidae	*Cymbacephalus nematophthalmus*	2	3	3	3 *	3 *	3	2.77
Platycephalidae	*Onigocia macrolepis*	2	3	3	3 *	3 *	3	2.77
Platycephalidae	*Suggrundus rodericensis*	2	3	3	3 *	3 *	3	2.77
Scorpaenidae	*Inimicus sinensis*	2	3	3	3	3	3	2.77
Scorpaenidae	*Neomerinthe amplisquamiceps*	2	3	3	3 *	3 *	3	2.77
Scorpaenidae	*Pterois russelli*	2	3	3	3	3	3	2.77
Siganidae	*Siganus fuscescens*	2	3	3	3 *	3 *	3	2.77
Synodontidae	*Synodus hoshinonis*	2	3	3	3 *	3 *	3	2.77
Tetraodontidae	*Lagocephalus lunaris*	2	3	3	3	3	3	2.77

Table 7.2.6 The ranking of teleost species with respect to criteria that reflect their capacity to recover. The weighting of the criteria are shown in parentheses; * indicates where species specific information was not available.

		Criteria						
Family	***Species***	**Probability of breeding (3)**	**Maximum size (3)**	**Removal rate (3)**	**Reproductive stratey (2)**	**Hermaphrotism (1)**	**Mortality Index (1)**	**Recovery rank**
Tetraodontidae	*Lagocephalus sceleratus*	3	2	3	3	3	3	2.77
Triglidae	*Lepidotrigla argus*	2	3	3	3	3	3	2.77
Triglidae	*Lepidotrigla spiloptera*	2	3	3	3	* 3	* 3	2.77
Sillaginidae	*Sillago analis*	3	3	2	3	3	3	2.77
Gobiidae	*Yongeichthys nebulosus*	3	3	3	2	* 3	* 3	2.85
Lethrinidae	*Lethrinus laticaudis*	3	3	3	3	* 1	* 3	2.85
Lethrinidae	*Lethrinus lentjan*	3	3	3	3	1	3	2.85
Nemipteridae	*Scolopsis taeniopterus*	3	3	3	3	1	3	2.85
Lactariidae	*Lactarius lactarius*	3	3	3	3	* 3	* 2	2.92
Nemipteridae	*Nemipterus nematopus*	3	3	3	3	* 3	* 2	2.92
Nemipteridae	*Pentapodus paradiseus*	3	3	3	3	* 3	* 2	2.92
Labridae	*Choerodon sugillatum*	3	3	3	3	* 3	* 2	2.92
Ostraciidae	*Ostracion nasus*	3	3	3	3	3	2	2.92
Veliferidae	*Velifer hypselopterus*	3	3	3	3	* 3	* 2	2.92
Leiognathidae	*Leiognathus bindus*	3	3	3	3	3	3	3.00
Haemulidae	*Pomadasys maculatus*	3	3	3	3	* 3	* 3	3.00
Lutjanidae	*Lutjanus russelli*	3	3	3	3	3	3	3.00
Lutjanidae	*Lutjanus vitta*	3	3	3	3	3	3	3.00
Plotosidae	*Plotosus lineatus*	3	3	3	3	3	3	3.00
Terapontidae	*Pelates quadrilineatus*	3	3	3	3	* 3	* 3	3.00
Triacanthidae	*Trixiphichthys weberi*	3	3	3	3	* 3	* 3	3.00
Uranoscopidae	*Uranoscopus cognatus*	3	3	3	3	3	3	3.00
Scombridae	*Rastrelliger kanagurta*	3	3	3	3	3	3	3.00
Callionymidae	*Callionymus goodladi*	3	3	3	3	* 3	* 3	3.00
Callionymidae	*Dactylopus dactylopus*	3	3	3	3	* 3	* 3	3.00

Table 7.2.6 The ranking of teleost species with respect to criteria that reflect their capacity to recover. The weighting of the criteria are shown in parentheses; * indicates where species specific information was not available.

		Criteria						
Family	***Species***	**Probability of breeding (3)**	**Maximum size (3)**	**Removal rate (3)**	**Reproductive stratey (2)**	**Hermaphrotism (1)**	**Mortality Index (1)**	**Recovery rank**
Carangidae	*Selar crumenophthalmus*	3	3	3	3	3	3	3.00
Sphyraenidae	*Sphyraena forsteri*	3	3	3	3	3	3	3.00
Glaucosomatidae	*Glaucosoma magnificum*	3	3	3	3	* 3	* 3	3.00
Terapontidae	*Terapon jarbua*	3	3	3	3	3	3	3.00
Nemipteridae	*Nemipterus hexodon*	3	3	3	3	3	3	3.00
Sillaginidae	*Sillago burrus*	3	3	3	3	3	3	3.00
Carangidae	*Carangoides malabaricus*	3	3	3	3	* 3	* 3	3.00
Clupeidae	*Pellona ditchela*	3	3	3	3	3	3	3.00
Carangidae	*Atule mate*	3	3	3	3	* 3	* 3	3.00
Psettodidae	*Psettodes erumei*	3	3	3	3	3	3	3.00
Siganidae	*Siganus canaliculatus*	3	3	3	3	* 3	* 3	3.00
Leiognathidae	*Leiognathus splendens*	3	3	3	3	3	3	3.00
Leiognathidae	*Gazza minuta*	3	3	3	3	* 3	* 3	3.00
Drepanidae	*Drepane punctata*	3	3	3	3	* 3	* 3	3.00
Nemipteridae	*Nemipterus peronii*	3	3	3	3	3	3	3.00
Carangidae	*Scomberoides tala*	3	3	3	3	* 3	* 3	3.00
Carangidae	*Carangoides caeruleopinnatus*	3	3	3	3	* 3	* 3	3.00
Carangidae	*Parastromateus niger*	3	3	3	3	3	3	3.00
Carangidae	*Scomberoides tol*	3	3	3	3	* 3	* 3	3.00
Carangidae	*Ulua aurochs*	3	3	3	3	* 3	* 3	3.00
Chaetodontidae	*Chelmon muelleri*	3	3	3	3	* 3	* 3	3.00
Chaetodontidae	*Parachaetodon ocellatus*	3	3	3	3	* 3	* 3	3.00
Leiognathidae	*Leiognathus fasciatus*	3	3	3	3	* 3	* 3	3.00
Menidae	*Mene maculata*	3	3	3	3	* 3	* 3	3.00
Mugilidae	*Valamugil cunnesius*	3	3	3	3	3	3	3.00

Table 7.2.6 The ranking of teleost species with respect to criteria that reflect their capacity to recover. The weighting of the criteria are shown in parentheses; * indicates where species specific information was not available.

		Criteria								
Family	***Species***	**Probability of breeding (3)**	**Maximum size (3)**	**Removal rate (3)**	**Reproductive stratey (2)**		**Hermaphrotism (1)**		**Mortality Index (1)**	**Recovery rank**
Mullidae	*Upeneus moluccensis*	3	3	3	3		3		3	3.00
Mullidae	*Upeneus tragula*	3	3	3	3	*	3	*	3	3.00
Pomacentridae	*Pristotis jerdoni*	3	3	3	3	*	3	*	3	3.00
Synodontidae	*Trachinocephalus myops*	3	3	3	3	*	3	*	3	3.00
Terapontidae	*Terapon theraps*	3	3	3	3	*	3	*	3	3.00
Tetraodontidae	*Chelonodon patoca*	3	3	3	3	*	3	*	3	3.00

Table 7.2.7 The percentage of species for which the information used to rank a criterion was species specific.

Axis	Criteria	%
Susceptibility	Water column position	47
	Preferred habitat	97
	Survival	3
	Range	31
	Day/Night catchability	30
	Depth	95
Recovery	Probability of breeding	63
	Maximum size	100
	Removal rate	87
	Reproductive strategy	24
	Total biomass	95
	Hermaphroditism	24
	Mortality index	69

Table 7.2.8 The correlations between criteria on each axis, * indicates a significant correlation at $p < 0.05$.

Susceptibility criteria

	Preferred habitat	**Survival**	**Range**	**Day/night catchability**	**Diet**	**Depth range**
Water column position	0.270*	-0.078	0.031	0.020	-0.054	0.042
Preferred habitat		-0.048	0.017	-0.062	0.073	-0.022
Survival			0.040	-0.030	-0.299*	-0.044
Range				-0.025	-0.069	0.126*
Day/night catchability					0.145*	-0.024
Diet						-0.047

Recovery criteria

	Maximum size	**Removal rate**	**Reproductive strategy**	*Hermaphroditism*	**Mortality index**
Probability of breeding	-0.205*	0.092	0.026	-0.035	0.339
Maximum size		-0.052	-0.098	-0.067	0.189*
Removal rate			-0.018	-0.068	0.392*
Reproductive strategy				-0.086	0.119*
Hermaphroditism					0.083

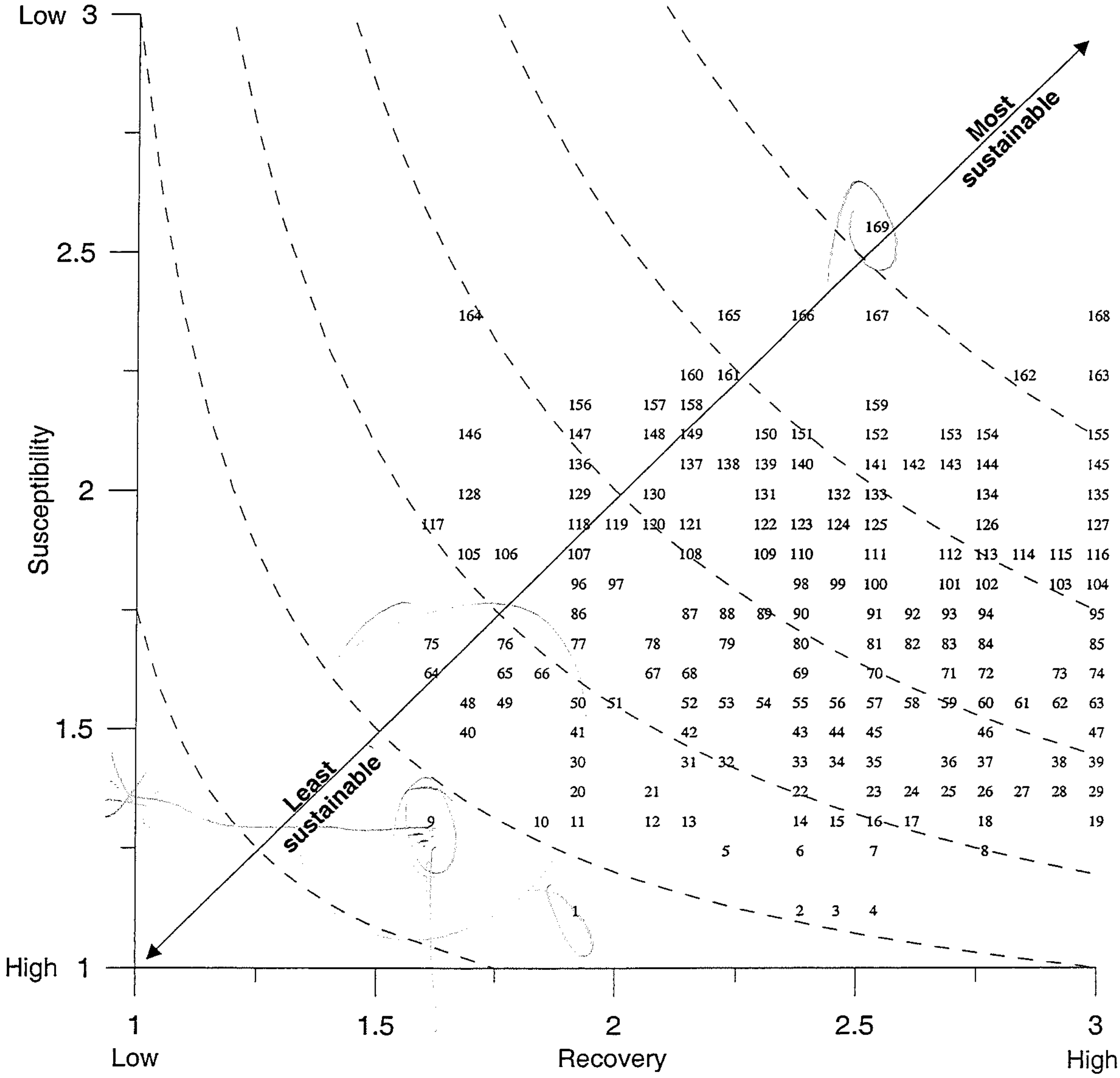

Figure 7.2.3 The ranking of teleost species with respect to criteria that reflect their susceptibility to capture and their capacity to recover. The curves delineate species that are similar with respect to their sustainability. The labels follow Table 7.2.9.

Table 7.2.9 The species list for Figure 7.2.3.

Species	Label	Species	Label
Saurida undosquamis	1	*Callionymus grossi*	23
Antennarius hispidus	2	*Pentaprion longimanus*	23
Lumiconger arafura	2	*Polydactylus multiradiatus*	23
Siphamia roseigaster	3	*Polydactylus nigripinnis*	23
Brachypleura novaezeelandiae	4	*Pseudorhombus argus*	23
Engyprosopon grandisquamum	4	*Pseudorhombus diplospilus*	23
Grammatobothus polyophthalmus	4	*Pseudorhombus elevatus*	23
Saurida micropectoralis	4	*Pseudorhombus jenynsii*	23
Apogon poecilopterus	5	*Pseudorhombus spinosus*	23
Leiognathus elongatus	6	*Sirembo imberbis*	23
Centriscus scutatus	7	*Nemipterus furcosus*	24
Synchiropus rameus	7	*Callionymus japonicus*	25
Adventor elongatus	8	*Cyclichthys hardenbergi*	25
Tathicarpus butleri	8	*Antennarius nummifer*	26
Tetrabrachium ocellatum	8	*Nemipterus marginatus*	26
Arius bilineatus	9	*Pseudorhombus arsius*	26
Arius proximus	9	*Scolopsis taeniopterus*	27
Arius nella	10	*Nemipterus nematopus*	28
Paramonacanthus japonicus	10	*Callionymus goodladi*	29
Poeciloconger kapala	11	*Nemipterus hexodon*	29
Netuma thalassinus	12	*Nemipterus peronii*	29
Siphamia fuscolineata	12	*Pomadasys maculatus*	29
Siphamia guttulatus	12	*Encheliophis gracilis*	30
Arius argyropleuron	13	*Leiognathus blochii*	30
Siphamia majimai	14	*Trachinotus cf mookalee*	30
Rogadius asper	15	*Apogon nigripinnis*	31
Arnoglossus waitei	16	*Pseudamia amblyuroptera*	31
Saurida longimanus	16	*Apogon albimaculosus*	32
Saurida sp. 2	16	*Apogon melanopus*	32
Sorsogona tuberculata	16	*Eurypegasus draconis*	33
Abalistes stellaris	17	*Inegocia harrisii*	33
Pseudomonacanthus peroni	17	*Myripristis botche*	33
Laeops parviceps	18	*Apogon fasciatus*	34
Parupeneus heptacanthus	18	*Apogon septemstriatus*	34
Valamugil cunnesius	19	*Apogon sp. 2*	34
Cyclichthys orbicularis	20	*Choerodon monostigma*	34
Psettina gigantea	20	*Cottapistus praepositus*	34
Opistognathus latitabundus	21	*Apistus carinatus*	35
Callionymus meridionalis	22	*Brachypterois serrulatus*	35
Cynoglossus bilineatus	22	*Caranx kleinii*	35
Nemipterus celebicus	22	*Inegocia japonica*	35
Pseudorhombus dupliciocellatus	22	*Leiognathus equulus*	35

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Species	Label	Species	Label
Leiognathus leuciscus	35	*Dactyloptena macracanthus*	55
Leiognathus moretoniensis	35	*Lophodiodon calori*	55
Leiognathus ruconius	35	*Muraenesox cinereus*	55
Pegasus volitans	35	*Pentapodus porosus*	55
Apogon ellioti	36	*Scolopsis affinis*	55
Acanthocepola abbreviata	37	unidentified Ogcocephalidae	55
Leiognathus decorus	37	unidentified Ophichthidae	55
Onigocia macrolepis	37	*Cynoglossus maculipinnis*	56
Choerodon sugillatum	38	*Diagramma pictum*	56
Dactylopus dactylopus	39	*Cynoglossus arel*	57
Gazza minuta	39	*Fistularia petimba*	57
Leiognathus bindus	39	*Gerres macracanthus*	57
Leiognathus fasciatus	39	*Gerres macrosoma*	57
Conger wilsoni	40	*Gerres subfasciatus*	57
Mugil cephalus	40	*Pomadasys argenteus*	57
Parupeneus barberinoides	41	*Pomadasys trifasciatus*	57
Richardsonichthys leucogaster	41	*Rhinoprenes pentanemus*	57
Samaris cristatus	41	*Sillago lutea*	57
Ariosoma anago	42	*Upeneus luzonius*	57
Batrachomoeus trispinosus	43	*Upeneus sp. 1*	57
Ariomma indica	43	*Oxyurichthys papuanus*	58
Uroconger lepturus	43	*Oxyurichthys sp.*	58
Siphamia argyrogaster	44	*Scolopsis monogramma*	58
Minous versicolor	45	*Paraplagusia longirostris*	59
Paramonacanthus filicauda	46	*Cynoglossus kopsii*	60
Coradion chrysozonus	46	*Dactyloptena papilio*	60
Gnathophis sp.	46	*Gerres baconensis*	60
Suggrundus rodericensis	46	*Harpadon translucens*	60
Upeneus asymmetricus	46	*Pomadasys kaakan*	60
Parachaetodon ocellatus	47	*Sillago sihama*	60
Psettina tosana	48	*Tragulichthys jaculiferus*	60
Acentrogobius viridipunctatus	49	*Sillago analis*	60
Ctenotrypauchen microcephalus	49	*Yongeichthys nebulosus*	61
Drombus globiceps	49	*Pentapodus paradiseus*	62
Callionymus belcheri	50	*Pristotis jerdoni*	63
Callionymus sublaevis	50	*Psettodes erumei*	63
Gerres erythrourus	50	*Sillago burrus*	63
Gerres filamentosus	51	*Upeneus moluccensis*	63
Nettastoma parviceps	52	*Upeneus tragula*	63
Acentrogobius caninus	53	*Rhabdamia gracilis*	64
Gymnothorax reticularis	53	*Apogon brevicaudata*	65
Gerres oyena	54	*Apogon aureus*	66
Parachaeturichthys polynema	55	*Apogon cavitiensis*	67
Cynoglossus macrophthalmus	55	*Apogon nigrocincta*	67

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Species	Label	Species	Label
Cheilodipterus artus	67	*Suggrundus macracanthus*	81
Papilloculiceps bosschei	68	*Torquigener pallimaculatus*	81
Antennarius pictus	69	*Torquigener tuberculiferus*	81
Antennarius striatus	69	*Torquigener whitleyi*	81
Apogon notatus	69	*Anacanthus barbatus*	82
Leptobrama mulleri	69	*Lutjanus sebae*	82
Myripristis murdjan	69	*Feroxodon multistriatus*	83
Onigocia spinosa	69	*Leiognathus smithursti*	83
Onuxodon margaritiferae	69	*Torquigener hicksi*	83
Parapercis nebulosa	69	*Monacanthus chinensis*	84
Strabozebrias cancellatus	69	*Chirocentrus dorab*	84
Lepidotrigla sp. 2	70	*Lagocephalus lunaris*	84
Pempheris analis	70	*Lutjanus carponotatus*	84
Sargocentron rubrum	70	*Neomerinthe amplisquamiceps*	84
Selaroides leptolepis	70	*Synodus hoshinonis*	84
Xiphocheilus typus	70	*Chelmon muelleri*	85
Zebrias quagga	70	*Mene maculata*	85
Myripristis hexagona	71	*Plotosus lineatus*	85
Tetrosomus gibbosus	71	*Uranoscopus cognatus*	85
Chelmon marginalis	72	*Plectorhinchus gibbosus*	86
Lepidotrigla argus	72	*Otolithes ruber*	87
Ostracion nasus	73	*Pseudochromis quinquedentatus*	88
Parastromateus niger	74	*Protonibea diacanthus*	89
Euristhmus lepturus	75	*Pomacanthus sexstriatus*	90
Chaetodermis penicilligera	76	*Scarus ghobban*	90
Heniochus diphreutes	77	*Sillago ingenuua*	91
Paracentropogon longispinus	77	*Upeneus sulphureus*	91
unidentified Chaunacidae	77	*Upeneus sundaicus*	91
unidentified Microdesmidae	77	*Trimma taylori*	92
Trachyrhamphus longirostris	78	*Pardachirus pavoninus*	93
Aluterus monoceros	79	*Chaetodontoplus duboulayi*	94
Euristhmus nudiceps	79	*Epinephelus sexfasciatus*	94
Epinephelus heniochus	79	*Paraplagusia bilineata*	94
Paramonacanthus choirocephalus	80	*Siganus fuscescens*	94
Congrogadus amplimaculatus	80	*Siganus canaliculatus*	95
Erosa erosa	80	*Chaetodon flavirostris*	96
Malakichthys sp. 1	80	*Leptojulis cyanopleura*	96
Lagocephalus spadiceus	81	*Platycephalus arenarius*	96
Leiognathus sp.	81	*Parapercis xanthozona*	97
Lutjanus johnii	81	*Ulua mentalis*	97
Minous trachycephalus	81	*Decapterus macrosoma*	98
Neomerinthe megalepis	81	*Leiognathus aureus*	98
Platycephalus endrachtensis	81	*Cociella hutchinsi*	99
Sardinella gibbosa	81	*Alepes sp.*	100

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Species	Label
Argyrops spinifer	100
Caranx bucculentus	100
Decapterus russelli	100
Elates ransonnetii	100
Scomberoides commersonnianus	100
Selar boops	100
Uraspis uraspis	100
Choerodon cephalotes	101
Cottapistus cottoides	101
Megalaspis cordyla	101
Carangoides chrysophrys	102
Carangoides talamparoides	102
Cymbacephalus nematophthalmus	102
Gnathanodon speciosus	102
Lepidotrigla spiloptera	102
Pantolabus radiatus	102
Psenopsis humerosa	102
Seriolina nigrofasciata	102
Lactarius lactarius	103
Atule mate	104
Carangoides caeruleopinnatus	104
Carangoides malabaricus	104
Scomberoides tala	104
Scomberoides tol	104
Selar crumenophthalmus	104
Ulua aurochs	104
Epinephelus malabaricus	105
Polyipnus tridentifer	106
Arothron manilensis	107
Synodus macrops	107
Conger cinereus	108
Champsodon nudivittis	109
Lagocephalus inermis	109
Dendrochirus zebra	110
Lutjanus quinquelineatus	110
Lutjanus argentimaculatus	111
Synodus sageneus	111
Platycephalus indicus	112
Inimicus sinensis	113
Lagocephalus sceleratus	113
Lutjanus erythropterus	113
Lutjanus lutjanus	113
Pterois russelli	113
Secutor insidiator	113

Species	Label
Lethrinus lentjan	114
Velifer hypselopterus	115
Chelonodon patoca	116
Leiognathus splendens	116
Lutjanus vitta	116
Terapon theraps	116
Euleptorhamphus viridis	117
Encrasicholina devisi	118
Pterocaesio chrysozona	118
Rastrelliger brachysoma	119
Bregmaceros japonicus	120
Fistularia commersonii	120
Hemiramphus robustus	120
Rachycentron canadum	121
Scolopsis vosmeri	121
Siganus lineatus	121
Stolephorus waitei	122
Epinephelus quoyanus	123
Thryssa marasriae	123
unidentified Myctophidae	123
Setipinna tenuifilis	124
Stolephorus indicus	124
unidentified Exocoetidae	124
Bregmaceros mcclellandi	125
Dexillus muelleri	125
Encrasicholina heteroloba	125
Johnius amblycephalus	125
Johnius borneensis	125
Platax batavianus	125
Thryssa hamiltonii	125
Thryssa setirostris	125
Priacanthus tayenus	126
Drepane punctata	127
Glaucosoma magnificum	127
Alectis ciliaris	128
Caranx melampygus	128
Sphyraena barracuda	129
Hyporhamphus affinis	130
Scomberomorus commerson	130
Carangoides fulvoguttatus	131
Scomberomorus semifasciatus	131
Scomberomorus munroi	132
Alectis indicus	133
Carangoides hedlandensis	133

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Species	Label
Carangoides humerosus	133
Scomberomorus queenslandicus	134
Trixiphichthys weberi	135
Pterois volitans	136
Scorpaena neglecta	136
Triacanthus biaculeatus	136
Chelmonops truncatus	137
Escualosa thoracata	137
Cephalopholis boenack	138
Epinephelus coioides	139
Sardinella albella	139
Scorpaenopsis diabolus	140
Scorpaenopsis venosa	140
Lethrinus genivittatus	141
Anodontostoma chacunda	141
Arothron stellatus	141
Dussumieria elopsoides	141
Herklotsichthys koningsbergeri	141
Herklotsichthys lippa	141
Symphorus nematophorus	141
Terapon puta	141
Epinephelus areolatus	142
Lutjanus malabaricus	143
Uranoscopus sp. 1	143
Amblygaster sirm	144
Pelates sexlineatus	144
Lutjanus russelli	145
Pellona ditchela	145
Terapon jarbua	145
Trachinocephalus myops	145
Atractoscion aequidens	146
Scatophagus multifasciatus	147
Stolephorus carpentariae	147
Scatophagus argus	148
Plectropomus leopardus	149
Siganus argenteus	149
Caesio teres	150
Plectropomus maculatus	150
Atrobucca brevis	151
Caesio caerulaurea	151
Johnius laevis	151
Pterocaesio digramma	151
Austronibea oedogenys	152
Zabidius novaemaculatus	153

Species	Label
Echeneis naucrates	154
Platax teira	154
Rastrelliger kanagurta	155
Ichthyscopus fasciatus	156
Dendrochirus brachypterus	157
Carangoides gymnostethus	158
Trichiurus lepturus	159
Megalops cyprinoides	160
Bathophilus nigerrimus	161
Eustomias multifilis	161
Lethrinus laticaudis	162
Pelates quadrilineatus	163
Sphyraena jello	164
Polyipnus elongatus	165
Sphyraena putnamiae	166
Sphyraena qenie	166
Sphyraena obtusata	167
Sphyraena forsteri	168
Sphyraena flavicauda	169

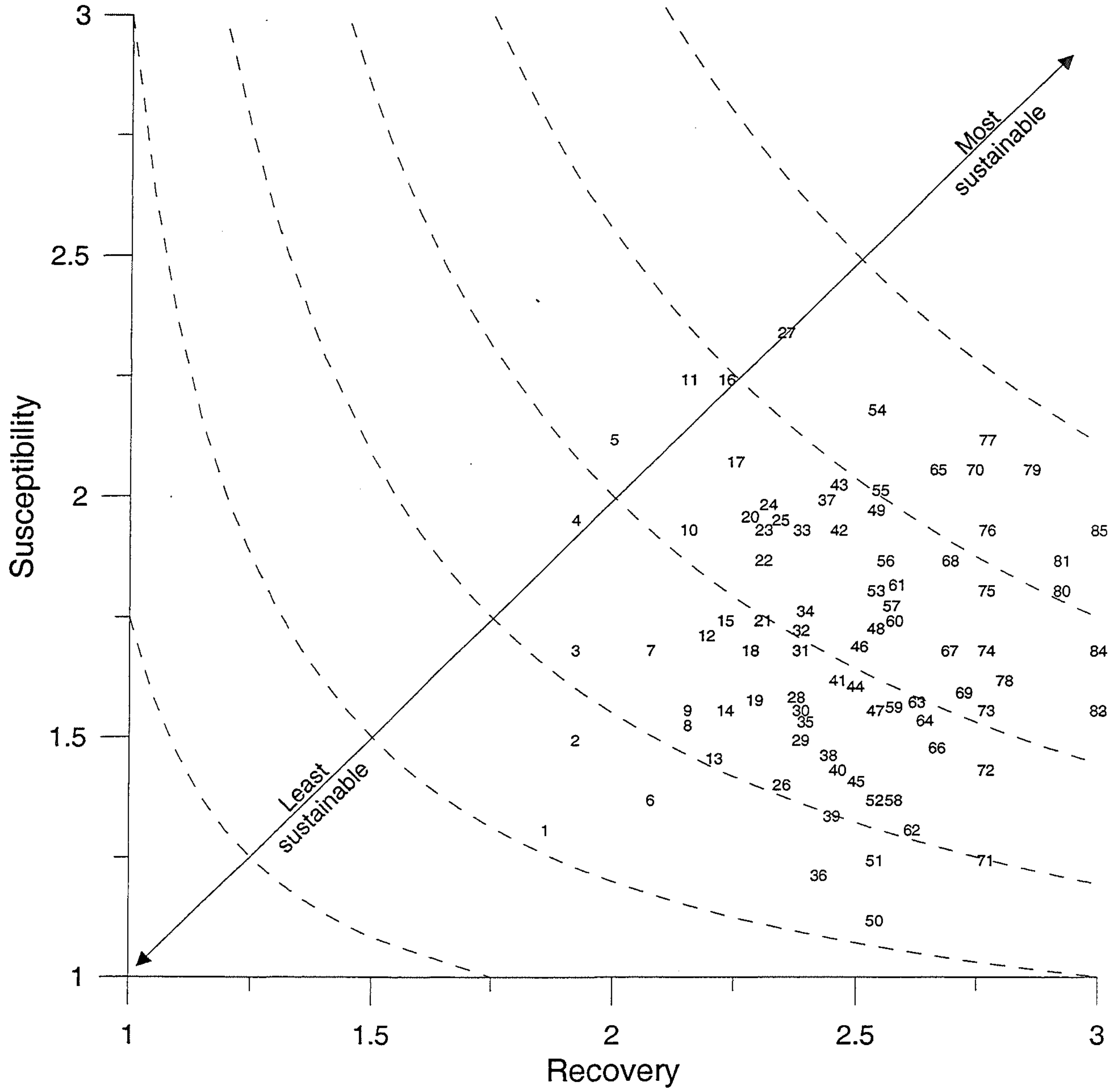


Figure 7.2.4 The mean rank of families with respect to criteria that reflect their susceptibility to capture and their capacity to recover. The labels follow Table 7.2.11.

Table 7.2.10 The labels for families in Figure 7.2.4

Family	Label
Ariidae	1
Pleuronectidae	2
Chaunacidae	3
Microdesmidae	3
Hemiramphidae	4
Scatophagidae	5
Sternoptychidae	6
Opisthognathidae	7
Syngnathidae	8
Nettastomatidae	9
Carapidae	10
Rachycentridae	11
Megalopidae	12
Pinguipedidae	13
Congridae	14
Muraenidae	14
Apogonidae	15
Pseudochromidae	16
Serranidae	16
Gobiidae	16
Melanostomiidae	17
Caesionidae	18
Plotosidae	19
Champsodontidae	20
Fistulariidae	20
Bregmacerotidae	21
Sciaenidae	22
Engraulididae	23
Mugilidae	24
Sphyraenidae	25
Scombridae	26
Monacanthidae	27
Batrachoididae	27
Congrogadidae	27
Ogcocephalidae	27
Muraenesocidae	28
Ophichthidae	28
Scaridae	29
Ariommatidae	30
Acropomatidae	31
Myctophidae	31
Scorpaenidae	32

Table 7.2.10 The labels for families in Figure 7.2.4

Gerreidae	33
Bathysauridae	34
Diodontidae	35
Bothidae	36
Pegasidae	36
Triacanthidae	37
Pempherididae	38
Exocoetidae	39
Platycephalidae	40
Callionymidae	41
Citharidae	41
Holocentridae	42
Chaetodontidae	43
Labridae	44
Centriscidae	44
Siganidae	45
Ophidiidae	46
Polynemidae	47
Soleidae	47
Haemulidae	47
Tetraodontidae	47
Uranoscopidae	48
Rhinoprenidae	49
Sparidae	50
Trichiuridae	51
Clupeidae	52
Synodontidae	53
Carangidae	54
Pomacanthidae	55
Lethrinidae	56
Antennariidae	57
Dactylopteridae	57
Balistidae	57
Cynoglossidae	58
Mullidae	58
Lutjanidae	59
Leiognathidae	60
Nemipteridae	61
Ephippidae	62
Triglidae	63
Sillaginidae	64
Aploactinidae	65
Harpadontidae	66
Cepolidae	67

Table 7.2.10 The labels for families in Figure 7.2.4

Chirocentridae	68
Centrolophidae	69
Priacanthidae	69
Echeneidae	70
Ostraciidae	71
Terapontidae	72
Veliferidae	73
Lactariidae	74
Pomacentridae	75
Psettodidae	76
Glaucosomatidae	77
Menidae	78
Drepanidae	79

Table 7.2.11 The ranking of the species that are least likely to be sustainable on the criteria on the two axes, (a) susceptibility and (b) recovery. The labels refer to Figure 7.2.3; * indicates where species specific information was not available.

(a)

Label	Family	Species	Criteria: Water column position (3)	Preferred habitat (3)	Survival (3)	Range (2)	Day/night catchability (2)	Diet (2)	Depth range (1)	Susceptibility rank
1	Bathysauridae	*Saurida undosquamis*	1	1	1*	1*	1*	1	3	1.13
2	Antennariidae	*Antennarius hispidus*	1*	1	1*	1*	2*	1	1*	1.13
2	Congridae	*Lumiconger arafura*	1	1	1*	1*	1*	1	3	1.13
3	Apogonidae	*Siphamia roseigaster*	1	1	1*	1*	1*	1	3	1.13
4	Bathysauridae	*Saurida micropectoralis*	1	1	1*	1*	1*	1	3	1.13
4	Bothidae	*Engyprosopon grandisquamum*	1	1	1*	1*	1*	1	3	1.13
4	Bothidae	*Grammatobothus polyophthalmus*	1	1	1*	1*	1*	1	3	1.13
4	Citharidae	*Brachypleura novaezeelandiae*	1	1	1*	1*	2*	1	1	1.13
9	Ariidae	*Arius bilineatus*	1*	2	1*	1*	1*	2	1	1.31
9	Ariidae	*Arius proximus*	1	2	1*	1	1	2	1	1.31
10	Ariidae	*Arius nella*	1*	2	1*	1*	2	1	1	1.31
10	Monacanthidae	*Paramonacanthus japonicus*	1*	2	1*	1*	1*	1	3	1.31
11	Congridae	*Poeciloconger kapala*	1*	2	1*	1*	1*	1	3	1.31

(b)

Label	Family	Species	Criteria: Probability of breeding (3)	Maximum size (3)	Removal rate (3)	Reproductive strategy (2)	Hermaphroditism (1)	Mortality Index (1)	Recovery rank
1	Bathysauridae	*Saurida undosquamis*	1*	3	1*	3*	3*	1*	1.92
2	Antennariidae	*Antennarius hispidus*	1*	3	3	3*	3*	1	2.38
2	Congridae	*Lumiconger arafura*	1*	3	3	3*	3*	1	2.38
3	Apogonidae	*Siphamia roseigaster*	2	3	3	1*	3*	3	2.46
4	Bathysauridae	*Saurida micropectoralis*	1	3	3	3*	3*	3	2.54
4	Bothidae	*Engyprosopon grandisquamum*	1	3	3	3*	3*	3	2.54
4	Bothidae	*Grammatobothus polyophthalmus*	1	3	3	3*	3*	3	2.54
4	Citharidae	*Brachypleura novaezeelandiae*	1	3	3	3*	3*	3	2.54
9	Ariidae	*Arius bilineatus*	1*	3	1*	1	3	1	1.62
9	Ariidae	*Arius proximus*	1*	3	1*	1*	3*	1	1.62
10	Ariidae	*Arius nella*	1*	3	2	1*	3*	1	1.85
10	Monacanthidae	*Paramonacanthus japonicus*	1	3	1*	2	3	2	1.85
11	Congridae	*Poeciloconger kapala*	1*	3	1*	3*	3*	1	1.92

Table 7.2.12 The ranking of the species that are most likely to be sustainable on the criteria on the two axes, (a) susceptibility, (b) recovery. The labels refer to Figure 7.2.3; * indicates where species specific information was not available.

(a)

			Criteria							
Label	Family	Species	Water column position (3)	Preferred habitat (3)	Survival (3)	Range (2)	Day/night catchability (2)	Diet (2)	Depth range (1)	Susceptibility rank
147	Clupeidae	*Pellona ditchela*	3	2	1*	3	1	2	3	2.06
147	Lutjanidae	*Lutjanus russelli*	2*	3	1*	2	3*	2	1	2.06
147	Synodontidae	*Trachinocephalus myops*	1*	3	2*	3	2	1	3	2.06
147	Terapontidae	*Terapon jarbua*	2*	2	2*	3	2	1	3	2.06
157	Scombridae	*Rastrelliger kanagurta*	3*	2	2*	1*	2*	2	3	2.13
164	Lethrinidae	*Lethrinus laticaudis*	2*	3	2*	3	1	2	3	2.25
165	Terapontidae	*Pelates quadrilineatus*	3	2	2*	1*	2*	3	3	2.25
169	Sphyraenidae	*Sphyraena obtusata*	3*	3	1*	3	2	2	3	2.38
170	Sphyraenidae	*Sphyraena forsteri*	3*	3	1*	3	2	3	1	2.38
171	Sphyraenidae	*Sphyraena flavicauda*	3*	3	2*	3	3	1	3	2.56

(b)

			Criteria						
Label	Family	Species	Probability of breeding (3)	Maximum size (3)	Removal rate (3)	Reproductive strategy (2)	Hermaphroditism (1)	Mortality Index (1)	Recovery rank
147	Clupeidae	*Pellona ditchela*	3	3	3	3	3	3	3.00
147	Lutjanidae	*Lutjanus russelli*	3	3	3	3	3	3	3.00
147	Synodontidae	*Trachinocephalus myops*	3	3	3	3*	3*	3	3.00
147	Terapontidae	*Terapon jarbua*	3	3	3	3	3	3	3.00
157	Scombridae	*Rastrelliger kanagurta*	3	3	3	3	3	3	3.00
164	Lethrinidae	*Lethrinus laticaudis*	3	3	3	3*	1*	3	2.85
165	Terapontidae	*Pelates quadrilineatus*	3	3	3	3*	3*	3	3.00
169	Sphyraenidae	*Sphyraena obtusata*	1	3	3	3	3	3	2.54
170	Sphyraenidae	*Sphyraena forsteri*	3	3	3	3	3	3	3.00
171	Sphyraenidae	*Sphyraena flavicauda*	1	3	3	3	3	3	2.54

7.2.4 Discussion

Assessment of the sustainability of teleost bycatch species

The high taxonomic diversity of the teleost bycatch in tropical prawn trawl fisheries, such as the NPF, presents a challenge to assessing and monitoring the impacts of prawn trawling on the bycatch species. This challenge is magnified by the lack of information about individual bycatch species most of which are rarely captured. The approach developed and applied in this section addresses this diversity and provides a process that highlights species that are least likely to sustain capture in prawn trawl bycatch and should, therefore, be the focus of research and management. This is the first time an assessment of this scale, with such a diverse bycatch, has been attempted. The use of the criteria maximises what can be determined from the limited information available. The criteria include characteristics that influence the probability of extinction of species and their sensitivity to overfishing (Roberts and Hawkins, 1999). Characteristics such as size at maturity, longevity, mortality, rarity and reproductive rate are linked to the ability of species to sustain fishing and these have been incorporated into the criteria used in this process. The result is a ranking of species with respect to their ability to sustain capture in prawn trawls, based on the information available.

The ranking shows a group of species that are the least likely to be sustainable and therefore have a high priority for research and management (Figure 7.2.3, Table 7.2.11). There is little information available on the majority of these species, aside from that summarised in Table 7.2.11. These species all have a high susceptibility to capture and mortality by prawn trawling. They are benthic or demersal and closely associated with the seafloor where prawn trawling occurs. Their habitats are primarily soft or muddy sediments, including prawn trawling grounds. Some species also utilise other habitats, such as estuaries. The diet of these species is known to include prawns or they are capable of feeding on them. There is no information on the survival of most of these species after capture or their range within the fishery and so ranks of 1 were given for these criteria. Associated with this high susceptibility to capture and mortality by prawn trawls, the species had a low capacity to recover from depletion after trawling. Although there was a wider range in the ranks on this axis. Most of the species were rare and so there were no data available to estimate the probability of individuals breeding before capture or to calculate the removal rate or mortality index. As a result these species received ranks of 1. Some of these species had relatively high recovery ranks (Table 7.2.11) but in combination with their high susceptibility they are less likely to be sustainable.

Three of the species that were the least likely to be sustainable, three ariid catfish *(A. bilineatus, A. nella, A. proximus*), are mouth brooders (McDowall 1988). This means that they potentially have a lower fecundity and therefore lower recovery capacity than other species that are broadcast spawners. However, parental care may increase survival of the young. These species are known to occur in high numbers in estuaries and freshwater in the Gulf of Carpentaria region (Blaber et al. 1989). These areas were not incorporated in the estimates of total biomass and so this may be an underestimate for these species.

One of the least sustainable species, *Saurida undosquamis,* probably reflects the taxonomic difficulties associated with this genus. *Saurida undosquamis* and *Saurida* sp. 2 can only be distinguished by genetic analysis

(Thresher et al. 1986). This has not been conducted for the region of the NPF and so it is unclear whether both species are present. We have taken the conservative approach assuming both occur. All the information collected in the study has been attributed to *Saurida* sp. 2 and this species ranked in the medium priority. *Saurida undosquamis* in comparison, due to the lack of available information and the characteristics of this species, ranked in the high priority. These taxonomic difficulties are also likely to occur in other genera, particularly within the Ariidae.

The species that ranked as most likely to be sustainable (Figure 7.2.3, Table 7.2.12) includes species from the families Clupeidae, Lethrinidae, Lutjanidae, Teraponidae, Scombridae, Sphyraenidae and Synodontidae. These species have a low susceptibility to capture and mortality from prawn trawling. Most are pelagic or benthopelagic, occurring outside the section of the water column fished by a prawn trawl. Their primary habitat is not prawn trawl grounds, they have a broad depth range, in comparison to the depth range of trawling, and their distribution in the region of the fishery is also broad. Most of these species did not have higher catch rates at night when commercial trawling occurs. Some teraponid species have been shown to have higher survival after capture in trawls than other fish species (Wassenberg & Hill 1989; Hill & Wassenberg 1990). The capacity of these species to recover after trawling was higher than the species that are unlikely to be sustainable. There was more information available for these species than those that were least likely to be sustainable. Estimates of the probability of individuals breeding before capture showed that for most of these species individuals were likely to have bred before capture. The estimate of the removal rate by trawling was low as was the mortality index.

Knowledge gaps

The process we have developed is designed to highlight species that may be unlikely to sustain capture as bycatch. It also aims to highlight the species that are likely to be sustainable and identify gaps in our knowledge that hinder this assessment. These gaps result in uncertainty around the ranks. The next step should be to closely examine individual species, starting with those that are least sustainable. This should aim to reduce the uncertainty around the ranks in order to clarify the species position and relative ability to sustain capture by prawn trawls. Research should focus on several aspects, increasing our understanding of the distribution of species, improving estimates of total biomass and removal rate, and the biology and ecology of the species.

An understanding of the fine scale distribution of species, below the level of bioregions, is vital to improving our estimates of total biomass and therefore removal rates. Trawling occurs in a restricted area of the NPF and is highly aggregated. Only about 25% of the managed area is trawled (Stobutzki and Pitcher, 1999). The comparatively large areas that are not subjected to fishing provide a potential refuge for bycatch species. However, the extent of this refuge depends on the distribution of species inside and outside the trawled areas and the dispersal ability of the species. Our assessment of the species sustainability assumes that species are uniformly distributed within bioregions, inside and outside the trawled area. This is unlikely, but until finer scale information on the distribution of species is available this cannot be addressed. Even if species are distributed inside and outside trawled areas it must be determined whether these groups are a single population or whether they are distinct populations. This will be determined by the dispersal patterns of the adults and larvae, about which little is known for most species. Specifically designed surveys should examine the distribution of bycatch species at a finer scale, providing robust estimates of the proportion of the population within trawl grounds.

These surveys would also be complimented by a monitoring program that measured the removal rate of species over time. This would provide long-term estimates of removal rates and also provide information on the extent of variation within and between years. Both the monitoring program and independent surveys also have the potential to collect biological information on species that could fill gaps in the other sustainability criteria. Information could be collected on factors such as the size/age at maturity and the probability of breeding before capture, that are important for assessing the sustainability of species.

Research should also focus on quantifying the relative catchability of species by prawn trawl nets. The process outlined here provides a qualitative assessment of the catchability of species by prawn trawl nets but quantifying this would be very beneficial. Estimating catchability coefficients for species would enable estimates of biomass to be more accurate.

The process only attempts to assess the species with respect to the direct impacts of trawling, due to capture as bycatch. Trawling also has indirect impacts on species, through changes in bottom structure, availability of food or abundance of predators (Hall, 1999). These are important impacts and will also influence the response of species to trawling. However, in order to incorporate these, the impacts and links among species must be understood and quantified for the fishery. This information is currently unknown for this fishery but should be the focus of future work. In order to ensure the sustainability of the ecosystem it is important that the impact on bycatch is examined in a holistic manner, taking into account the indirect impacts.

Management implications

The ranking of the bycatch species is aimed at assisting management to focus on species that are potentially less sustainable. However, it is important to remember that the current ranks are relative and subject to the assumptions outlined in the methods (Section 7.2.2). The uncertainty around the ranks must be examined before management action is taken on individual species. The ranks can then be used to decide on potential management strategies for bycatch species.

If management interventions are undertaken, the criteria can be used to examine how these interventions will change the likely sustainability of species. The criteria that can be influenced are the removal rate, probability of breeding and mortality index, on the recovery axis. The compulsory introduction of TEDs and BRDs into the NPF in 2000 will change the removal rate of some bycatch species. The TEDs and BRDs are also likely to change the size composition caught of some species, which will change the probability of individuals having bred before capture and the index of mortality. At present there is no species specific data available to enable us to determine which bycatch species will be reduced and to what extent. It is important that changes in the species and size composition of bycatch with the introduction of TEDs and BRDs is monitored, so that the impact on the sustainability of species can be determined. The use of closures or changes in fishing effort may have a similar impact on the criteria, with changes in removal rate, probability of breeding and the mortality index. The criteria on the axis representing the susceptibility to trawling, in their current form, can not be directly influenced by changes in management, with the exception of the depth criterion. If management strategies modified the depth range of trawling this would change this criterion.

Managers may also use the ranks to meet monitoring requirements or in the selection of bycatch sustainability indicators. The current draft guidelines under which Environment Australia (EA) will assess fisheries to determine whether they conform to the *Environment Protection and Biodiversity Conservation Act,* commencing July 2000, includes guidelines which requires an assessment of the sustainability of bycatch species. The current project provides this for the NPF. These guidelines also require the monitoring of potentially vulnerable species determined from the assessment. However, more needs to be known about the species that are least likely to be sustainable before they can clearly be regarded as vulnerable. For example, the ariids are not likely to be unsustainable if there are high abundances in the shallow inshore areas, as mentioned previously. The other species in the least sustainable group are rare, five of them were not recorded in the present study, others were recorded but in very low numbers and rarely. Monitoring these species, if naturally rare, may not provide an accurate assessment of their numbers. It may also not be feasible, given the high number of trawls required to detect changes in catch rates (Section 9).

The NPF Fishery Assessment Group, is also currently investigating the use of sustainability indicators for both the target prawn species and the bycatch species. Currently many Australian fisheries have sustainability indicators for their target species but indicators for the ecosystems or environments are "under development" (Sainsbury *et al.*, 1999). The selection of sustainability indicators for the bycatch species is not straight forward and requires substantial knowledge about the species (Faush *et al.*, 1990). Individual species are not necessarily good indicators for the sustainability of communities. The use of guilds or groups of species as indicators is also difficult (Faush *et al.*, 1990). The process of identifying sustainability indicators for communities requires substantial knowledge of those communities and the interrelationship among species. For bycatch communities, this knowledge is currently mostly unknown. The species identified as the least sustainable here are potentially more sensitive to the impacts of trawling but this does not mean they are a good indicator for the sustainability of the bycatch community. These species may not reflect changes in other bycatch species. There are also other factors that should be taken into account in the selection of sustainability indicators, such as the feasibility of monitoring the indicators. The high priority species are rare and therefore monitoring may not be feasible.

The process that we have developed and applied here is the first time an assessment of bycatch has been undertaken at this scale and it provides a valuable first step towards ensuring the sustainability of bycatch in the NPF. The process is designed to be dynamic and applicable in other fisheries. As research provides new data they can be incorporated into the current criteria, increasing the robustness of the ranks. The incorporation of new criteria is also possible. This process can also be applied to the bycatch of other fisheries. The same criteria could be applied to bycatch species in other prawn trawl fisheries, however the ranking of species may change between fisheries. The criteria that are appropriate may also vary among fisheries. The process developed here provides an approach that will assist fisheries, particularly those with highly diverse bycatch, to address and manage the sustainability of this bycatch.

7.2.5 Conclusions

- A total of 411 teleost species have been recorded in the bycatch of the NPF.
- The catch rate of 129 species was compared between day and night-time trawls and 82% showed a significant difference. This is important as commercial trawling is a mainly a night-time activity and so species may have a temporal refuge.
- In order to assess the sustainability of teleost bycatch species in the NPF and prioritise them with respect to future research and management, we developed a process that ranked species on two overriding characteristics, their susceptibility to capture and mortality due to prawn trawling, and their capacity to recover once the population is depleted. Each of these characteristics was made up of several biological and ecological criteria.
- The species ranked as the least sustainable had a high susceptibility to capture by trawls. They are benthic or demersal, their primary habitat is soft sediments, their diet includes or can potentially include prawns. Their recovery capacity is low, with a low estimate of total biomass and high removal rate.
- The species that ranked most likely to be able to sustain trawling had a low susceptibility to capture by trawls. They are generally pelagic, their primary habitat is not trawl grounds, they have a broad depth distribution and range in the fishery, higher catch rates during the day time and a higher survival after trawling. These species also have a higher capacity to recover, with most individuals having bred before capture, high total biomass and low removal rate.
- The ranks must be used with caution due to the assumptions made in the process. Further research should be aimed at clarifying the ranks. This research should focus on developing a greater understanding of the distribution patterns of species in the region of the fishery. This will help determine the extent of refuge species have outside trawl grounds. Improving estimates of the removal rates of species and our understanding of the biology of the species.
- The process addresses only the direct impacts of trawling, research is needed into the indirect impacts of trawling so that these can be taken into account when assessing the sustainability of the bycatch.
- The ranking of the species can be used by management to focus their strategies.

References

Al-Ghais, S.M., 1993. Some aspects of the biology of *Siganus canaliculatus* in the southern Arabian Gulf. Bull. Mar. Sci., 52, 886-897.

Allen, G.R., 1985. FAO species catalogue. Vol. 6. Snappers of the world. An annotated and illustrated catalogue of lutjanid species known to date. FAO Fish. Synop., 125, 236 pp.

Allen, G.R., 1997. Marine Fishes of Tropical Australia and South-East Asia: Francis Street, Perth, Western Australia, Western Australian Museum.

Allen, G.R., Swainston, R., 1988. The Marine Fishes of North-Western Australia: a Field Guide for Anglers and Divers.: Perth, Western Australia, Western Australian Museum.

Arai, H., 1994. Spawning behavior and early ontogeny of a pomacanthid fish, *Chaetodontoplus duboulayi*, in an aquarium. Jpn. J. Ichthyol., 41, 181-187.

Barry, T.P., Fast, A.W., 1992. Biology of the spotted scat (*Scatophagus argus*) in the Philippines. Asian Fish. Sci., 5, 163-179.

Bawazeer, A.S., 1987. The fishery biology and management of the stock of chim, the giant sea catfish (*Arius thalassinus*) in Kuwait waters. Kuwait Bull. Mar. Sci., 87-100.

Bawazeer, A.S., Al-Baz, A.F., 1989. Growth, mortality and yield-per-recruit of large-toothed flounder, *Pseudorhombus arsius* (Hamilton and Buchanan) in Kuwait waters. Pak. J. Zool., 22, 139-141.

Beumer, J.P., 1978. Feeding ecology of four fishes from a mangrove creek in north Queensland, Australia. J. Fish Biol., 12, 475-490.

Blaber, S.J.M., Brewer, D.T., Salini, J., 1989. Species composition and biomass of fishes in different habitats of a tropical northern Australian estuary, their occurrence in the adjoining sea and estuarine dependence. Estur. Coast. Shelf Sci. 29, 509-531.

Blaber, S.J.M., Brewer, D.T., Harris, A.N., 1994a. Distribution, biomass and community structure of demersal fishes of the Gulf of Carpentaria, Australia. Aust. J. Mar. Freshw. Res., 45, 375-396.

Blaber, S J.M., Brewer, D.T., Salini, J.P., 1994b. Diet and dentition in tropical ariid catfishes from Australia. Environ. Biol. Fish., 40, 159-174.

Bishop J., Sterling D., 1999. Survey of technology utilised in the Northern Prawn Fishery. AFMA, Canberra.

Brewer, D.T., Blaber, S.J.M., Milton, D.A., Salini, J. P., 1994. Aspects of the biology of *Caranx bucculentus* (Teleostei, Carangidae) from the Gulf of Carpentaria, Australia. Aust. J. Mar. Freshw. Res., 45, 413-427.

Brewer, D.T., Blaber, S.J.M., Salini, J. P., 1991. Predation on penaeid prawns by fishes in Albatross Bay, Gulf of Carpentaria. Mar. Biol., 109, 231-240.

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

Carpenter, K.E.; Allen, G.R., 1989. FAO species catalogue. Vol. 9. Emperor fishes and large-eye breams of the world (family Lethrinidae). An annotated and illustrated catalogue of lethrinid species known to date. FAO Fish. Synop., 125, 118.

Chapleau, F., Renaud, C.B., 1993. *Paraplagusia sinerama* (Pleuronectiformes, Cynoglossidae), a new Indo-Pacific tongue sole with a revised key to species of the genus. Copeia, 3, 798-807.

Clarke, T.A., 1996. Reproductive biology and egg abundance of the yellowtail scad or 'omaka', *Atule mate* (Carangidae), in Kaneohe Bay, Hawaii. Pac. Sci., 50, 93-107.

Clarke, T.A., Privitera, L.A., 1995. Reproductive biology of two Hawaiian pelagic carangid fishes, the bigeye scad, *Selar crumenophthalmus*, and the round scad, *Decapturus macarellus*. Bull. Mar. Sci., 56, 33-47.

Collette, B.B., Nauen, C.E., 1983. FAO species catalogue. Vol. 2. Scombrids of the world. An annotated and illustrated catalogue of tunas, mackerels, bonitos and related species known to date. FAO Fish. Synop., 125, 137pp.

Compagno, L.J.V., 1984a. FAO species catalogue. Vol. 4. Sharks of the world. An annotated and illustrated catalogue of shark species known to date. Part 1 - Hexanchiformes to Lamniformes. FAO Fish. Synop., 125, 249.

Compagno, L.J.V., 1984b. FAO species catalogue. Vol 4. Sharks of the world. An annotated and illustrated catalogue of shark species known to data. Part 2, Carcharhiniformes. FAO Fish. Synop., 125, 405pp.

Conacher, M.J. Lanzing, W.J.R., Larkum, A.W.D., 1979. Ecology of Botany Bay. 2. Aspects of the feeding ecology of the fanbellied leatherjacket, *Monacanthus chinensis* (Pisces, Monacanthidae), in *Posidonia australis* seagrass beds in Quibray Bay, Botany Bay, New South Wales. Aust. J. Mar. Freshw. Res., 30, 387-400.

Crocos, P.J., Coman, G.J., 1997. Seasonal and age variability in the reproductive performance of Penaeus semisulcatus broodstock, optimising broodstock selection. Aquaculture,155, 57-69.

Cyrus, D. P., Martin, T. J., 1991. The importance of estuaries in life histories of flatfish species on the southern coast of Africa. Neth. J. Sea Res., 27, 255-260.

Das, M., Mishra, B., 1990. On the biology of *Psettodes erumei* (Bloch & Schn.), an Indian halibut. Indian J. Fish., 37, 79-92.

Datta, N.C., Bandyopadhyay, B.K., Barman, S.S., 1984. On the food of an euryhaline perch *Scatophagus argus* (Cuv. and Val.) and the scope of its culture in fresh water. Nt. J. Acad. Ichthyol., 5, 121-124.

Dawson, C.E., 1981. Notes on four pipefishes (Syngnathidae) from the Persian Gulf. Copeia, 1, 87-95.

Druzhinin, A.D., 1977a. On the cornetfish *Fistularia petimba* Lacepede (Fistulariidae) from the Gulf of Aden area. Vopr. Ikhtiol., 17, 542-545.

Druzhinin, A.D., 1977b. The Pacific cornetfish (*Fistularia petimba*) (Family Fistulariidae) from the Gulf of Aden. J. Ichthyol., 17, 476-479.

Ebisawa, A., Kanashiro K., Kyan, T., Motonaga, F., 1995. Aspects of reproduction and sexuality in the black-spot tuskfish, *Choerodon schoenleinii*. Jpn. J. Ichthyol., 42, 121-130.

El-Sayed, A. M., Bary, K. A., 1994. Life cycle and fecundity of rabbitfish, *Siganus canaliculatus* (Teleostei, Siganidae) in the Arabian Gulf. Oebalia, 20, 79-88.

FAO/UNDP Offshore Trawling Surv. Proj., M. K., 1981. Biological Data, Analyses and Catch Records of *Pomadasys Opercularis*, Drepane Punctata and Lobster., Kenya, FAO/UNDP, Mombasa.

Fausch, K.D., Lyons, J., Karr, J.R., Angermeier, P.L., 1990. Fish communities as indicators of environmental degradataion. Amer. Fish. Soc. Symp. 8, 123-144.

Ferreira, B.P., 1995. Reproduction of the common coral trout *Plectropomus leopardus* (Serranidae, Epinephelinae) from the central and northern Great Barrier Reef, Australia . Bull. Mar. Sci., 56, 653-669.

Fishelson, L., 1975. Ethology and reproduction of pteroid fishes found in the Gulf of Agaba (Red Sea), especially Dendrochirus brachypterus (Cuvier), (Pteroidae, Teleostei). Pubbl. Stn. Zool. Napoli, 39, 635-656.

Fricke, R., 1983. A new species of the genus *Callionymus* from St. Helena (Teleostei, Callionymidae). Ann. Mus. Civ. Stor. Nat. Genova., 54, 53-92.

Froese, R., Pauly D., Editors,1999 . FishBase 99. World Wide Web electronic publication. www.fishbase.org, *Accessed* Oct. 10, 1999.

Gladstone, W., 1994. Lek-like spawning, parental care and mating periodicity of the triggerfish *Pseudobalistes flavimarginatus* (Balistidae). Environ. Biol. Fish., 39, 249-257.

Gloerfelt-Tarp, T., Kailola, P.J., 1984. Trawled Fishes of Southern Indonesia and Northwestern Australia., Australian Development Assistance Bureau; The Directorate General of Fisheres, Indonesia; The German Agency for technical Cooperation.

Golani, D., Ben-Tuvia, A., 1985. The biology of the Indo-Pacific squirrelfish, *Sargocentron rubrum* (Forsskaal), a Suez Canal migrant to the eastern Mediterranean. J. Fish Biol., 27, 249-258.

Graham, G.L., 1995. Finfish bycatch from the southeastern shrimp fishery. In Solving bycatch, considerations for today and tomorrow. Alaska Sea Grant College Program Report No 96-03, University of Alaska Fairbanks. pp. 115-120.

Grant, E.M., 1993. Grant's Guide to Fishes, Scarborough, Qld, E.M. Grant.

Hall, S.J., 1999. The Effects of Fishing on Marine Ecosystems and Communities. Blackwell Science Ltd, Great Britain.

Harris A.N., Poiner, I.R., 1991. Changes in species composition of demersal fish fauna of southeast Gulf of Carpentaria, Australia after 20 years of fishing. Mar. Biol. 111, 503-519.

Hasse, J.J., Madraisau, B.B., McVey, J.P., 1977. Some aspects of the life history of *Siganus canaliculatus* (Park) (Pisces, Siganidae) in Palau. Micronesica, 13, 297-312.

Heemstra, P.C.; Randall, J.E., 1993. FAO species catalogue. Vol. 16. Groupers of the world (family Serranidae, subfamily Epinephelinae). An annotated and illustrated catalogue of the grouper, rockcod, hind, coral grouper and lyretail species known to date , Rome, Italy, FAO, FAO Fish Synopsis, 382pp.

Hill, B.J., Wassenberg, T.J., 1990. Fate of discards from prawn trawlers in Torres Strait. Aust. J. Mar. Freshw. Res. 41, 53-61

Hill, B.J., Wassenberg, T.J., 1993. The fate of material discarded from shrimp trawlers. In, International Conference on Shrimp Bycatch, Florida, USA, pp 115-122.

Houde, E.D., 1984. Bregmacerotidae, Developement and Relationships, Moser, H. G., Richards, W. J., Cohen, D. M., Fahay, M. P., Kendall, A. W., and Richardson, S. L., Ontogeny and Systematics of Fishes , Based on an International Symposium Dedicated to the Memory of Elbert Halvor Ahlstrom, La Jolla, California, August 15-18, 1983, Special Publication (American Society of Ichthyologists and Herpetologists) ; No. 1. pp 300-308.

Hussain, S. M., 1990. Biology of *Psettodes erumei* (Schneider, 1801) and *Pseudorhombus arsius* (Hamilton, 1822) from the northern Arabian Sea. Indian J. Fish., 37, 63-66.

Ibrahim, M.A., El-Bary, K.A., Al-Khayat, J.A., 1988. Stock assessment and management of *Lethrinus nebulosus* (family Lethrinidae) of Qatar waters, Arabian Gulf. Bull. Natl. Inst. Oceanogr. Fish. (Egypt), 14, 99-111.

Iwai, T. Y. Jr., Tamaru, C. S., Yasukochi, L., Alexander, S., Yoshimura, R., Mitsuyasu, M., 1996. Natural spawning of captive bigeye scad *Selar crumenophthalmus* in Hawaii. J. World Aquacult. Soc., 27, 332-339.

Jayabalan, N., Ramamoorthi, K., 1985a. Food and feeding habits of the silverbelly, *Gazza minuta* (Bloch) in Porto Novo waters. Indian J. Mar. Sci., 14, 110-112.

Jayabalan, N., Ramamoorthi, K., 1985b. Maturation and spawning of the silverbelly, *Secutor insidiator* (Bloch) in the Porto Novo coast. Indian J. Mar. Sci., 14, 105-109.

Jayabalan, N., 1986. Reproductive biology of silverbelly *Leiognathus splendens* (Cuvier) at Porto Novo. Indian J. Fish., 33, 171-179.

Jayabalan, N., 1988a. Reproductive biology of the ponyfish, *Gazza minuta* (Bloch) from Porto Novo, east coast of India. Indian J. Mar. Sci., 17, 51-54.

Jayabalan, N., 1988b. Feeding habits and length-weight relationship of the ponyfish, *Secutor insidiator* (Bloch). In: Joseph, M., Editor, The first Indian fisheries forum, proceedings, December 4-8, 1987, Mangalore, Karnataka., pp 233-236.

Jayabalan, N., 1991. Food and feeding habits of the ponyfish *Leiognathus splendens* (Pisces, Leiognathidae) from Porto Novo coast. Indian J. Mar. Sci., 20, 157-160.

Jones, G., 1985. Revision of the Australian species of the fish family Leiognathidae. Aust. J. Mar. Freshw. Res., 36, 559-613.

Kailola, P.J., 1986. Ariidae systematics, Comparison of the giant sea catfishes *Arius thalassinus* and *A. bilineatus* of the Indo-Pacific. Indo-pacific fish biology. Proceedings of the second international conference on Indo-Pacific fishes, conducted at the Tokyo National Museum, Ueno Park, Tokyo, July 29 – August 3, 1985, Tokyo, Japan, pp 540-549.

Kartha, K.N.R., 1975. Growth rate of *Lactarius lactarius* (Schneider) at Karwar. Indian J. Fish., 22, 284-286.

Kennelly, S. J., 1995. The issue of bycatch in Australia's demersal trawl fisheries. Rev. Fish Biol. Fish., 5, 213-234.

Kothare, P.V., Bal, D.V., 1975. Length frequency distribution in *Sphyraena obtusata* (Cuv. and Val.). J. Biol. Sci., 18, 1-4.

Krishnakumar, K., Balakrishnan Nair, N. B., 1995. Breeding biology of the grey mullet, *Valamugil cunnesius* from the Ashtamudi Estuary, southwest coast of India. Fish. Technol. Soc. Fish. Technol. (India), 32, 1-5.

Kurup, B.M., Samuel, C.T., 1991. Spawning biology of *Gerres filamentosus* Cuvier in the Cochin estuary. Fish. Technol. Soc. Fish. Technol. (India), 28, 19-24.

Last, P. R.; Stevens J.D., 1994. Sharks and Rays of Australia: Australia, CSIRO Australia.

Lieske, E., Myers, R., 1994. Collins Pocket Guide. Coral Reef Fishes. Indo-Pacific and Caribbean Including the Red Sea., Haper Collins Publishers.

McDowall, R.M., 1988. Diadromy in fishes. Croom Helm, London.

Marquez, M., 1990. FAO Species Catalogue. Volume 11 - Sea turtles of the world. An annotated and illustrated catalogue of sea turtle species known to date. FAO Fisheries Synopses, 125: 85.

McKay, R.J., 1992. FAO Species catalogue. Vol. 14. Sillaginid fishes of the world (Family Sillaginidae) An Annotated and Illustrated Catalogue of the Sillago, Smelt od Indo-Pacific Whiting Species Known to Date. FAO Fish. Synop., 125, 87.

McKay, R.J., 1997. FAO Species catalogue. Vol. 17. Pearl Perches of the world (Family Glaucosomatidae) An Annotated and Illustrated Catalogue of the pearl perches Known to Date. FAO Fish. Synop., 125, 31.

Menon, N.G., Bande, V.N., Balachandran, K., 1989. Hooks and line fishery in north Kerala with particular reference to catfish resources. J. Mar. Biol. Assoc. India, 31, 205-217.

Milton, D.A., Short, S.A., O'Neill, M.F., Blaber, S.J.M., 1995. Ageing of three species of tropical snapper (Lutjanidae) from the Gulf of Carpentaria, Australia, using radiometry and otolith ring counts. Fishery Bulletin, 93, 103-115.

Mohsin, A.K.M., Ambak, M.A., 1996. Marine Fishes and Fisheries of Malaysia and Neighbouring Countries, Serdang, Malaysia, Universiti Pertanian Malaysia Press.

Moyer, J.T., 1986. Longevity of the anemonefish *Amphiprion clarkii* at Miyake-jima, Japan with notes on four other species. Copeia, 1, 135-139.

Moyer, J.T., Zaiser, M. J., 1981. Social Organization and Spawning Behavior of the Pteroine Fish *Dendrochirus zebra* at Miyake-Jima, Japan. Jpn. J. Ichthyol., 28, 52-69.

Munekiyo, M., Kuwahara, A., 1988. Maturity and spawning of ribbon fish in the western Wakasa Bay. Nippon Suisan Gakkaishi, 54, 1315-1320.

Murty, V.S., 1983. Observations on some aspects of biology of silverbelly *Leiognathus bindus* (Valenciennes) from Kakinada. Indian J. Fish., 30, 61-68.

Murty, V.S., 1986. Population characteristics of the silverbelly *Leiognathus bindus* (Valenciennes) along West Bengal coast. J. Mar. Biol. Assoc. India, 28, 41-47.

Murty, V.S., 1990. Biology and population dynamics of the silverbelly *Secutor insidiator* (bloch) from Kakinada. J. Mar. Biol. Assoc. India, 32, 10-24.

Naama, A.K., Yousif, U.H., 1987. Some observations on spawning and fecundity of *Arius thalassinus*. Indian J. Fish., 34, 476-478.

Nagasawa, T., 1990. A new record of the *Trachyrhamphus longirostris* (Pisces, Syngnathidae) from the Japan Sea. Bull. Japan Sea Natl. Fish. Res. Inst., 40, 221-225.

Nakamura, I., 1985. FAO Species catalogue. Vol. 5. Billfishes of the world. An annotated and illustrated catalogue of marlins, sailfishes, spearfishes and swordfishes known to date. FAO Fish. Synop., 125, 65.

Nakamura, I., Parin, N.V., 1993. FAO species catalogue. Vol. 15. Snake mackerels and cutlassfishes of the world (families Gempylidae and Trichiuridae). An annotated and illustrated catalogue of the snake mackerels, snoeks, escolars, gemfishes, sackfishes, domine, oilfish, cutlassfishes, scabbardfishes, hairtails, and frostfishes known to date. Rome, Italy., FAO, FAO Fish Synopsis, p 136.

Nance J.M., Scott-Denton, E., 1996. Bycatch in the Gulf of Mexico Shrimp Fishery. In Hancock, D.A., Smith D.C., Grant, A., Beumer, J.P. (eds.) Developing and sustaining world fisheries resources, the state of science and management, 2nd World Fisheries Congress proceedings, CSIRO Publishing, Australia. pp. 98-102.

Nemeth, D., 1994. Systematics and distribution of fishes of the family champsodontidae (Teleostei, Perciforms), with descriptions of three new species. Copeia, 2, 347-371.

Park, T., 1992. Morphological identification of ocean perch (*Helicolenus percoides*) stocks. Newsl. Aust. Soc. Fish Biol, 22, 45-46.

Pauly, D., Cabanban, A., Torres, F S.B.J., 1996. Fishery biology of 40 trawl-caught teleosts of Western Indonesia. ICLARM Stud. Rev., 135-216.

Pender, P.J., Willing, R.S., Ramm, D.C., 1992. Northern Prawn Fishery bycatch study, distribution, abundance, size and use of bycatch from the missed species fishery., Fishery Report No. 26 (Northern Territory Department of Primary Industry and Fisheries), 70pp.

Pillai, P.K.M., Devadoss, P., 1975. A note on the fecundity and spawning period of *Drepane punctata* (Linnaeus). Indian J. Fish., 22, 262-264.

Rajaguru, A., Shantha, G., Natarajan, R., 1988. Mangrove waters as nursery grounds for juveniles of marine flatfishes. CMFRI Spec. Publ., 62.

Randall, J.E., Allen, G.R., Steene, R.C., 1990. Fishes of the Great Barrier Reef and Coral Sea, United States of America, University of Hawaii Press.

Randall, J.E., Goren, M., 1993. A review of the gobioid fishes of the Maldives. Ichthyol. Bull., 37.

Rao, T.A., 1990. Observations on some aspects of biology of *Pentaprion longimanus* (Cantor). Indian J. Fish., 37, 67-71.

Render, J.H., Thompson, B.A., Allen, R.L., 1994. Reproductive development of striped mullet in Louisiana estuarine waters with notes on the applicability of reproductive assessment methods for isochronal species. Trans. Am. Fish. Soc., 124, 26-36.

Reuben, S., Vijayakumaran, K., Achayya, P., 1996. Growth, maturity, mortality and exploitation of *Ariomma indica* (Day) from North Andhra Pradesh coast. Indian J. Fish., 43, 39-44.

Roberts, C.M., Hawkins, J.P., 1999. Extinction risk in the sea. Trends Ecol. Evol. 14, 241-246.

Russell, B. C., 1990. FAO species catalogue. Vol. 12. Nemipterid fishes of the world (threadfin breams, whiptail breams, monocle breams, dwarf monocle breams, and coral breams) family Nemipteridae. An annotated and illustrated catalogue of nemipterid species known to date. FAO Fish. Synop., 125, 149.

Said, M.Z.M., Ambak, M.A., Mohsin, A.K.M., 1983. Some aspects of the fishery and biology of *Nemipterus tolu* C.V. off the Trengganu Coast, South China Sea. Pertanika J. Trop. Agric. Sci., 6, 108-111.

Sainsbury, K., Smith, A., Webb, H. 1999. Current use and recommendations for future development of sustainability indicators to measure performance of Australian fisheries against ESD objectives. FRDC report to FRDC. Project No. 98/168.

Sainsbury K.J., Kailola, P.J., Leyland, G.G., 1984. Continental Shelf Fishes of Northern and North-Wesrtern Australia, Canberra, Australia, Clouston & Hall and Peter Pownall Fisheries Information Service.

Sainsbury, K.J., Whitelaw, A.W., 1984. Biology of Peron's threadfin bream, *Nemipterus peronii* (Valenciennes), from the North West Shelf of Australia. Aust. J. Mar. Freshw. Res., 35, 167-185.

Salini, J.P., Blaber, S.J.M., Brewer, D.T., 1994. Diets of trawled predatory fish of the Gulf of Carpentaria, Australia, with particular reference to predation on prawns. Aust. J. Mar. Freshw. Res., 45, 397-411.

Sasaki, K., 1997. Resurrection of two East African species of *Johnius* (Perciformes, Sciaenidae). Ichthyol. Res., 44, 311-315.

Senta, T., 1977. Species and size composition of priacanthid fishes in the South China Sea and adjacent waters. Bull. Fac. Fish. Nagasaki Univ., 42, 25-31.

Shaffer, R.V.; Nakamura, E.L., 1989. Synopsis of biological data on the cobia *Rachycentron canadum* Pisces, Rachycentridae. NOAA Tech. Memo., 28.

Sokal, R.R., Rohlf, F.J., 1996. Introduction to biostatistics, 2nd editition. Freeman and Company, New York.

Somers, I, 1994. No resources, no fishery, prawns and their habitat. In, Pownall, P.C. (Ed.), Australia's Northern Prawn Fishery. NPF25, Cleveland, Australia, pp. 49-65.

Sparre, P., Venema, S.C., 1992. Introduction to tropical fish stock assessment, Part 1. FAO Fish. Tech. Pap. 306/1, 376 pp.

Staunton-Smith, J., Blaber, S.J.M., Greenwood, J.G., 1999. Interspecific differences in the distribution of adult and juvenile ponyfish (Leiognathidae) in the Gulf of Carpentaria, Australia. Mar. Freshwat. Res. 50, 643-653.

Stobutzki, I.C., Pitcher R., 1999. Assessing the response of bycatch communities to prawn trawling. In Buxton, C.D., Eayrs, E.E. (eds) Establishing meaningful targets for bycatch reduction in Australian fisheries. Australian Society for Fish Biology Workshop Proceedings, Hobart, September 1998. Australian Society for Fish Biology, Sydney.

Sumpton, W., Greenwood, J., 1990. Pre- and post-flood feeding ecology of four species of juvenile fish from the Logan-Albert estuarine system, Moreton Bay, Queensland. Aust. J. Mar. Freshw. Res., 41, 795-806.

Tanaka, Y., 1994. Reproductive behavior, egg and larval development of two species of the *Cirrhitichthys*, Cirrhitidae - *C. oxycephalus* and *C. falco*. J. Sch. Mar. Sci. Technol. Tokai Univ., 38, 213-232.

Thackway, R., Cresswell, I.D., 1998. Interim marine and coastal regionalisation for Australia; an ecosystem-based classification for marine and coastal environments. Version 3.3 Environment Australia, Commonwealth Department of the Environment, Canberra.

Thresher, R.E., Sainsbury, K.J., Gunn, J.S., Whitelaw, A.W., 1986. Life history strategies and recent changes in population structure in the lizardfish genus, *Saurida*, on the Australian northwest shelf. Copia 1986, 876-885.

Venkataramani, V.K., Natarajan, R., 1984. Age and growth in carangid fishes *Carangoides malabaricus* (Bloch and Schn.) and *Alepes kalla* (Cuv. and Val.) of Porto Novo coast. Indian J. Mar. Sci., 13, 34-36.

Venkataramani, V.K., Natarajan, R., 1984. Breeding biology of carangid fishes *Carangoides malabaricus* (Bloch and Schn.) and *Alepes kalla* (Cuv. and Val.) along Porto Novo coast. Indian J. Mar. Sci., 13, 14-18.

Venkataramani, V.K., Ramanathan, N., Venkataramanujam, K., 1995. Breeding biology of a carangid fish *Selaroides leptolepis* Cuv. (Perciformes) along Tuticorin, southeast coast of India. Indian J. Mar. Sci., 24, 207-210.

Wassenberg, T.J., Blaber, S.J.M., Burridge, C.Y., Brewer, D.T., Salini, J.P., Gribble, N., 1997. The effectiveness of fish and shrimp trawls for sampling fish communities in tropical Australia. Fish. Res. 30, 241-251.

Wassenberg, T.J., Burridge, C.Y., Connell, M., Gribble, N., 1998. A validation of short-duration scientific tows as a representation of long commercial-length tows, comparing the catch rates, size composition and species composition of prawn trawler bycatch in the far northern Great Barrier Reef, Australia.

Wassenberg, T.J., Hill, B.J., 1989. The effect of trawling and subsequent handling on the survival rates of the bycatch of prawn trawlers in Moreton Bay, Australia. Fish. Res. 7, 99-110.

Wassenberg, T.J., Blaber, S.J.M., Burridge, C.Y., Brewer, D.T., Salini, J.P., Gribble, N., 1997. The effectiveness of fish and shrimp trawls for sampling fish communities in tropical Australia. Fish. Res. 30, 241-251.

Whitehead, P.J.P., Nelson, G.J., Wongratana, T., 1988. FAO Species Catalogue. Volume 7 - Clupeoid fishes of the world (Suborder Clupeoidei). An annotated and illustrated catalogue of the herrings, sardines, pilchards, sprats, anchovies and wolf-herrings. FAO Fish. Synop., 7, 253.

Wijeyaratne, M.J.S., Costa. H.H., 1988. The food, fecundity and gonadal maturity of *Valamugil cunnesius* (Pisces, Mugilidae) in the Negombo Lagoon, Sri Lanka. Indian J. Fish., 35, 71-77.

Winterbottom, R., 1980. Two new species of the Congrogadidae (Pisces, Perciformes) from the Indo-West Pacific. Copeia, 396-402.

Winterbottom, R., 1985a. Revision and vicariance biogeography of the subfamily Congrogadinae (Pisces, Perciformes, Pseudochromidae). Indo-Pac. Fishes, 34.

Winterbottom, R., 1985b. Revision of the congrogadid *Haliophis* (Pices, Perciformes), with the description of a new species from Indonesia, and comments on the endemic fish fauna of the northen Red Sea. Can. J. Zool./Rev. Can. Zool., 63, 209-217.

Withell, A.F., Wankowski, J.W., 1988. Estimates of age and growth of ocean perch, *Helicolenus percoides* Richardson, in south-eastern Australian waters., Aust. J. Mar. Freshw. Res., v. 39, no. 4, 441-457.

Wongratana, T., 1986. Four new species of clupeoid fishes (Clupeidae and Engraulidae) from Australian waters. Proc. Biol. Soc. Wash., 100, 104-111.

Zavala Garcia, F., Flores-Coto, C., 1994a. Abundance and distribution of Bregmacerotidae (Pisces) larvae in Campeche Bay, Mexico. Cienc. Mar., 20, 219-241.

Zavala-Garcia, F., Flores-Coto, C., 1994b. Growth, mortality and feeding habits of *Bregmaceros cantori* larvae and juveniles from the southern Gulf of Mexico. Trop. Ecol., 35, 185-198.

7.3 The sustainability of elasmobranch bycatch.

7.3.1 Introduction

Australia has a highly diverse elasmobranch fauna (sharks, rays and sawfishes). Almost half of the species are endemic to Australia (Last and Stevens, 1994) and a high proportion are restricted to the Indo-Pacific region (Sant and Hayes, 1996). The biology of elasmobranchs differs from most bony fishes. They have a slow growth rate, late age at maturity, low fecundity, long gestation period and comparatively low population numbers (Heuter, 1998). These differences make them more vulnerable to over-exploitation.

There is increasing international pressure for the sustainable management and conservation of elasmobranchs. Worldwide fishing activities are currently resulting in the highest known rate of decrease of elasmobranch stocks. Annual worldwide catches are predicted to reach 827, 000 tonnes by 2000, the equivalent of hundreds of millions of animals (Heuter, 1998). One of the major issues is the under-reporting of elasmobranch catches mainly in the form of bycatch. In 1994, CITES passed a resolution calling for international fishing organisations to provide information on shark fisheries and trade for further discussion. In 1997 the FAO Committee of Fisheries instigated a technical working group on elasmobranchs to produce guidelines and an action plan for the global conservation of elasmobranchs. The IUCN is also producing a global action plan for the conservation and management of sharks. These international action plans will have implications for Australia's management and conservation of elasmobranchs.

In northern Australia elasmobranchs have been targeted by a range of fisheries which focus primarily on sharks. A Taiwanese pelagic gillnet fishery operated in northern Australian waters between 1974 and 1986. Australian gillnetters began direct involvement in the Northern Shark Fishery in 1980. Following the Offshore Constitutional Settlement (OCS), this fishery is now managed as three separate Commonwealth-State/Territory Joint Authorities across the north of Australia In the Gulf of Carpentaria, Queensland has introduced a developmental inshore shark fishery. The catch of these northern fisheries tends to be dominated by a few species of carcharhinid sharks (McLoughlin and Stevens, 1994).

The incidental catch of elasmobranchs in northern Australia has increased since the '60's due to the diversification of fishing activities. Elasmobranchs are caught as bycatch in trawl, dropline, longline and gillnet fisheries. The increase in the value of elasmobranch products, such as fins, has seen a corresponding increase in the landings of elasmobranch bycatch in other regions (e.g. the USA [Musick *et al.*, 1993]). Currently the estimates of elasmobranch bycatch in northern Australia are limited but quantification of the bycatch rates in all fisheries in this region is important for determining the sustainability of elasmobranch species.

In the NPF elasmobranchs are a commonly sighted but not abundant part of the bycatch (Section 7.2). Licensed NPF trawlers are allowed to retain shark products but are restricted with respect to the amount they can have on board at any one time (100 trunks or 200 flitches or an equivalent of 250 kg of skinless fillet and 100 fins). All retained bycatch must be recorded in the logbook. In 1998, 4,159 kg of fillet and trunk, 1,003 kg and 1,492 fins were recorded. However, there is currently no process for validating the logbook records for retained bycatch and so the accuracy of these data is unknown.

Regarding the issue of the sustainability of NPF bycatch, elasmobranchs are an important group to address. This is due to their biology, their conspicuous and charismatic nature and that at least one group (the sawfishes, family Pristidae) has previously been nominated for status as endangered. Although the nomination for the marine sawfish species was unsuccessful, it highlights the concern focused on this group.

The objectives of this section are to:

- Examine the biology of ray species, about which little is known
- Examine the sustainability of the elasmobranch species.

7.3.2 Methods

Species captured in prawn trawls

A list of elasmobranchs species that occur in the managed area of the NPF was compiled from Last and Stevens (1994). The species which have been recorded in prawn trawl bycatch in the NPF was collated from the sources outlined in Section 7.2.2. In the data presented *Carcharhinus tilstoni* is likely to be a combination of *C. tilstoni* and *C. limbatus*.

Day versus night catch rates

In October 1997, we carried out day-time trawls in the commercial fishing grounds (Table 7.2.1) in order to examine the difference in catch rate of species between night and day. A statistical comparison was made between the day-time and night-time trawls for the two most abundant species (*Carcharhinus dussumeri* and *Dasyatis leylandi*) . This followed the method outlined in Section 7.2.2.

Biological Information

There is limited biological information for species in the families Dasyatididae and Gymnuridae (Last and Stevens, 1994). Therefore, we retained specimens of species in these families from the scientific surveys for further analysis. The gonad weight, diameter of the largest egg and whether they were pregnant was recorded for females. For pregnant individuals, the number of the pups was recorded. In the case of males individuals had the gonad weight, the clasper length, and the calcification state of the clasper (uncalcified, partially calcified and totally calcified) recorded. Gonado-somatic indices (GSI) were calculated as follows:

GSI = (gonad weight/total weight) x 100.

The size at sexual maturity was estimated for females as the smallest size of pregnant female recorded, or the size when a change in GSI could be observed. In males the size at sexual maturity was taken as the size when the majority of the males had fully calcified claspers and the change in the growth rate of the claspers relative to body size had occurred (Bass *et al.,* 1973).

Survival

On the October 1998 research survey we recorded whether individuals were dead or alive when landed on the deck. The crew member observer also recorded this information. This provides an estimate of the within-net mortality. The data were examined using a logistic regression (PROC LOGISTIC, SAS Institute, 1997) to determine whether there was a relationship between the likelihood of survival and the length, weight or sex of the individual. The species were analysed in two groups, sharks (species where TL was recorded) and rays (species where DW was recorded).

Process for assessing the sustainability of elasmobranch species

All relevant available information on the biology and ecology of species was collated from the literature (Calliet *et al.*, 1983a; 1983b; Casey *et al.*, 1983; Gruber and Stout, 1983; Pratt and Casey, 1983; Schwartz, 1983; Casey *et al.*, 1985; Stevens and Wiley, 1986; Stevens and Lyle, 1989; Stevens and McLoughlin, 1991; Casey and Natanson, 1992; Last and Stevens, 1994; FishBase, 1997; Natanson *et al.*, 1998). This information was then used to rank the species along two axes that described the overriding characteristics that would determine the sustainability of the species:

Axis 1: The susceptibility of a species to capture and mortality due to a prawn trawl.
Axis 2: The capacity of a species to recover once the population is depleted.

The criteria on each axis followed Section 7.2.2 except where detailed below. The differences in criteria reflect differences in the data available for the elasmobranchs compared to the teleosts. There were 6 criteria on Axis 1 and 7 on Axis 2. Each species was given a rank from 1-3 for each criterion. A rank of 1 reflects the state of that criterion that would result in the species being highly susceptible to capture or having a low capacity to recover. A rank of 3 reflects the state of that criterion that would result in the species having a low susceptibility to capture or a high capacity to recover. Within each axis the rank for each criterion was multiplied by the criterion weighting score and then summed to produce a value for each species on the axis. The weighting scores of the criteria were determined by the NPF Fishery Assessment Group (NPF FAG), through consensus. The weighting scores reflect the relative importance of each criterion in determining the overall characteristic.

Where species specific information was not available, a species was given a rank based on the ranks for other species within its family, or a rank of 1.

Axis 1: The susceptibility of species to capture and mortality due to a prawn trawl.

The criteria were:

Water column position (weight = 3)

The distribution of the species in the water column was determined from the literature.

Rank	Description
1	Demersal or benthic species
3	Benthopelagic or pelagic species

Survival (weight = 3)

This was based on the survival data outlined previously. The range of survival is from 0% to 100% and so this was divided into thirds for the ranks.

Rank	Description
1	Species with a probability of survival that is < 33% or for which there are no data
2	Species with a probability of survival that is between 33% and 66%
3	Species with a probability of survival that is > 66%.

Range (weight = 2)

This criterion reflects the range of the distribution of the species within the NPF and was determined from the scientific surveys within the current project (Section 7.2). The presence/absence of each species was recorded in the 9 regions (Section 7.2). Species with a restricted range could potentially be impacted more heavily by trawling than those with a broader range.

Rank	Description
1	Species occurred in ≤ 3 regions
2	Species occurred in 4 to 6 regions, inclusive
3	Species occurred in > 6 regions

Day/night catchability (weight = 2)

This reflects the relative catch rate of species during night and day-time trawling determined from the current study as outlined previously. The tiger prawn fishery is predominantly a night time fishery, with day-time trawling banned for most of the season. Species with a higher catch rate during the night are, therefore, more susceptible to capture by trawls.

Rank	Description
1	Species that had a significantly higher catch rate during night-time trawling
2	Species that had no significant difference in catch rate between night and day-time trawling, or no data available for the species
3	Species that had a significantly higher catch rate during day-time trawling

Diet (weight = 2)

This criterion reflects whether the diet of the species would attract them to trawl grounds and whether they feed within the area of the water column that is swept by a prawn trawl. This was determined from literature that has examined the species' diet.

Rank	Description
1	Species that are known to feed on prawns or benthic organisms
3	Species that feed on pelagic organisms.

Depth range (weight = 1)

Trawling occurs primarily between 15 – 40 m in the NPF (Somers 1994) and so the known depth distribution of the species in relation to the depth range of trawling was examined. The depth distribution was determined from the depth at which species were recorded in previous CSIRO surveys in the area of the NPF and from the literature. The scale this criterion reflects the scale of information available for species.

Rank	Description
1	Species whose depth distribution is limited to < 60 m
3	Species whose depth distribution extends > 60 m

Axis 2: The capacity of a species to recover once the population is depleted

The criteria were:

Probability of breeding (weight = 3)

The probability that an individual of a species has bred before capture was determined from the mean length at capture of a species in comparison to the size at first maturity. A t-test (Sokal and Rohlf, 1996) was used to determine whether the mean length at capture was significantly different to the size at first maturity.

The mean length at capture of a species was determined from data collected in the present study. The size at maturity was determined from the available literature or from our observations of the biology of the species outlined previously. The size at first maturity is unknown for most species. Therefore, within families, the ratio of size at first maturity to maximum size was calculated and used to estimate the size at first maturity for those species where this was not known. For families in which there was no available information on the size at first maturity of any species, the ratio between size at first maturity and maximum size was estimated from the other families combined.

Rank	Description
1	The mean length at capture is significantly less than the size at first maturity, suggesting that the probability an individual has bred before capture is less than 50%
2	The mean length at capture is not significantly different to the size at maturity, suggesting that the probability an individual has bred before capture is 50%
3	The mean length at capture is significantly greater than the size at maturity, suggesting that the probability an individual has bred before capture is greater than 50%

Maximum size (weight = 3)

The maximum size of a species was used as an indicator of the relative recovery rate for the species. In general, larger species tend to be longer lived and their populations recover more slowly (Roberts and Hawkins, 1999). The estimate of maximum size came from the literature. If no estimate was available the largest size captured in the present study was used as the estimate.

The range of the maximum sizes of species was calculated and divided into thirds to dtermine the division between the ranks. This was calculated separately for species for which total length is recorded and species for which disc width is recorded.

Disc width

Rank	Description
2	852 mm < maximum size ≤ 1755 mm
3	≤ 550 mm

Total length

Rank	Description
1	> 4281 mm
2	1861 mm < maximum size ≤ 4281 mm
3	≤ 1861 mm

Removal rate (weight = 3)

The proportion of total biomass removed by the fishery in a year of trawling was estimated. In general, the higher the proportion of biomass removed, the lower the ability of the population to recover.

The estimate was based on the catch rates of species obtained from the research, scientific observer and crew member observer surveys in the present study.

The research and scientific surveys are described in Section 7.2.2 and summarised in Table 7.2.1. All elasmobranchs caught in trawls were identified, mostly to species, and their total number and weight recorded. Where possible individuals were sexed and their weight and length recorded. Length was recorded as total length (TL) for sharks, rhyncobatids and pristids and disc width (DW) for the remaining rays.

A crew member from the commercial fishing fleet was also trained to identify the elasmobranchs and collected information from the boats she was working on. She identified the sharks to species where possible and recorded the number and sex of individuals, and where possible, also the individual weight and length. She recorded the elasmobranchs from 141 pairs of commercial trawls (Table 7.2.1).

The catch rate for each species was calculated, along with the overall catch rate from the three sources. Catch rates were corrected for duration of the trawl (h) and the length of the headrope (km) and are presented in n h^{-1} km^{-1}. The catch rates are also expressed in terms of the swept area of the trawl in n km^{-2}. Differences in the catch rates between the three sources were examined, but not statistically tested due to the low number of replicates. The catch rate of each species in the different regions of the fishery (Figure 7.2.1) was also calculated.

An estimate of the removal rate by the commercial tiger prawn fishery in the NPF was calculated from the monitored trawls within the NPF managed area. The average catch rate for each bioregion in which trawling occurs (Figure 7.2.1) was calculated and multiplied by the effort (fishing days) in that bioregion in 1997 (Table 7.2.1). The full methods are detailed in Section 7.2.2.

An estimate of the total biomass in each of the bioregions where tiger prawn trawling occurs, was generated as described in Section 7.2.2. The total biomass for the trawled regions was the sum of these. The removal was then expressed as the percent of total biomass to give the removal rate.

The removal rate should range between 0% and 100% and this range was divided into thirds for the divisions between the ranks.

Rank	Description
1	> 66 % biomass removed
2	33% ≤ biomass removed ≤ 66 %
3	≤ 33 % biomass removed

Annual fecundity (weight = 2)

The annual fecundity of species was calculated from data in the literature and biological samples collected in the present study. The annual fecundity of a species is the average number of pups per female multiplied by the number of times they breed per year. Where the frequency of breeding was not known it was assumed to be annual, unless the known gestation period was longer than 12 months. The range of annual fecundities was calculated and divided into thirds for the ranks.

Rank	Description
1	≤ 13 young per year
2	13 young per year < annual fecundity ≤ 26
3	> 26 young per year

Mortality Index (weight = 1)

A measure of instantaneous mortality can be derived from the length frequency of a species and the von Bertelanffy parameters (Sparre and Venema, 1992). For the majority of species von Bertelanffy parameters are not available and so an index of mortality was calculated as follows:

Mortality Index = $(L_{max} - L_{ave}) / (L_{ave} - L_{min})$

The closer the average length of a species (L_{ave}) is to the maximum length (L_{max}) the lower the mortality the population is subject to. As mortality due to fishing increases the average length of species in a population approaches the minimum length (L_{min}). This assumes constant catchability across the whole length range.

The range of mortality idices was calculated and divided into thirds for the ranks.

Rank	Description
1	mortality index > 3.31
2	1.65 < mortality index $\leq$ 3.31
3	mortality index $\leq$ 1.65

Partial correlations (Sokal and Rholf, 1996) were used to determine whether there was any redundancy in the criteria. Highly correlated criteria would suggest that they are explaining the same factors and therefore, one of the criteria should be removed.

The summed ranks of each criteria (after) weighting were then graphed to determine the species that were likely to be least sustainable in bycatch. Contour lines were drawn on the graph to group species that would be similar with respect to their sustainability, as described in Section 7.2.2.

The impact of Turtle Excluder Devices on Elasmobranch bycatch

Turtle Excluder Devices (TEDs) will be compulsory in the NPF in 2000, the potential impact of these on elasmobranch bycatch was examined. Data on the size of species captured in nets fitted with TEDs and nets with standard codends were available from two sources. The crew member observer recorded 7 pairs of trawls in which one net was fitted with a TED and one was a standard codend. The TED was a Seymour TED with 110 mm bar spacing. The project FRDC 93/179 also recorded information on the elasmobranchs captured in nets with and without TEDs. The TEDs were AusTEDs, NordMore Grids, SuperShooters. The design of the trials is detailed in Brewer *et al.* (1998).

The size frequency of elasmobranchs was compared in nets with and without a TED. Firstly, species were grouped into sharks (TL measured) and rays (DW measured). The mean size of individuals captured in nets fitted with a TED was compared to nets with a standard codend using a one-way ANOVA. The sizes were transformed (log (length + 1)) prior to analysis to normalise the data. There were 3 species of shark (*Rhizoprionodon acutus, Hemigaleus microstoma, Carcharhinus dussumeri*), 2 stingrays (*Dasyatis leylandi, Himantura toshi*) and a shovel-nosed ray (*Rhynchobatus djiddensis)* for which data were sufficient to examine separately, with one-way ANOVAs.

7.3.3 Results

Species captured in the prawn trawl bycatch of the NPF
At least 79 species of elasmobranchs from 18 families, occur in the geographical region of the NPF occurs (Table 7.3.1). Of these, 56 species (16 families) have been recorded as caught in the prawn trawl fishery bycatch in the sources outlined in Section 7.2.2. The Carcharhinidae and Dasyatidae have the highest number of species recorded in bycatch, 16 and 15 respective (Table 7.3.1). These are also the most species-rich families in this geographic region. There are 9 families in which all species occuring in this region have been recorded in bycatch (Table 7.3.1).

Estimate of removal rate and total biomass in the NPF
A total of 44 species were recorded in the research and observer surveys. The species with the highest overall catch rates were *Dasyatis leylandi, Carcharhinus dussumeri,* and *Himantura toshi* (Table 7.3.2). These three species contributed over 57% of the observed elasmobranch catch. In the research surveys 30 species were recorded with *D. leylandi, C. dussumeri* and *Rhizoprionodon acutus* caught at the highest rates and contributing 61% of the elasmobranch catch (Table 7.3.3). The scientific observer surveys recorded 36 species, with the highest catch rates for *D. leylandi, C. dussumeri, R. djiddensis, C. tilstoni* and *H. toshi* which 63% of the elasmobranch catch (Table 7.3.3). The crew member observer surveys recorded 32 species, with the highest catch rates for *C. dussumeri, C. tilstoni, D. leylandi* and *H. microstoma*, which formed 79% of the elasmobranch catch (Table 7.3.3).

The species with the highest catch rates were also the ones detected in the most regions during the scientific surveys. There were 9 species that occurred in 7 or more of the nine regions surveyed (*H. microstoma, D. leylandi, G. australis, H. toshi, R. acutus, Amphotistius annotatus, C. dussumieri, C. sorrah* and *R. djiddensis).* The regions with the highest diversity of elasmobranchs were 'North Groote' (34 species) and 'Weipa' (31 species). In general, the number of species recorded increased with the number of trawls sampled in each region (Figure 7.3.1). However, 'North Mornington' had a high number of trawls and relatively few species (Figure 7.3.1) and 'Weipa' had a similar number of species to 'North Groote' and yet only one third the number of trawls (Figure 7.3.1).

Table 7.3.1 The elasmobranch families which occur in the region of the NPF and the species these that have been recorded in prawn trawl bycatch from the sources in Section 7.2.2. The label in parenthesis refers to Figure 7.3.6.

	Recorded in bycatch		
Family	**Yes**		**No**
Carcharhinidae	*Carcharhinus albimarginatus*	(Cal)	*Carcharhinus amblyrhynchoides*
	Carcharhinus amboinensis	(Cam)	*Carcharhinus amblyrhynchos*
	Carcharhinus brevipinna	(Cb)	*Carcharhinus cautus*
	Carcharhinus dussumieri	(Cd)	*Carcharhinus obscurus*
	Carcharhinus fitztroyensis	(Cf)	*Carcharhinus plumbeus*
	Carcharhinus leucas	(Cle)	*Carcharias taurus*
	Carcharhinus limbatus	(Cli)	*Carcharinus falciformis*
	Carcharhinus macloti	(Cma)	*Carcharinus melanopterus*
	Carcharhinus sorrah	(Cs)	*Loxodon macrorhinus*
	Carcharhinus tilstoni	(Ct)	*Rhizoprionodon oligolinx*
	Galeocerdo cuvier	(Ccu)	*Triaenodon obesus*
	Negaprion acutidens	(Na)	
	Prionace glauca	(Pg)	
	Rhizoprionodon acutus	(Rac)	
	Rhizoprionodon taylori	(Rt)	
Dasyatididae	*Amphotistis annotata*	(Aa)	*Dasyatis fluviorum*
	Dasyatis brevicaudatus	(Db)	*Taeniura lymma*
	Dasyatis leylandi	(Da)	
	Dasyatis kuhlii	(Dk)	
	Dasyatis sp. *A*	(Dsa)	
	Dasyatis thetidis	(Dt)	
	Himantura fai	(Hf)	
	Himantura granulata	(Hg)	
	Himantura jenkinsii	(Hj)	
	Himantura sp. *A*	(Hsa)	
	Himantura toshi	(Ht)	
	Himantura uarnak	(Hua)	
	Himantura undulata	(Hun)	
	Pastinachus sephen	(Ps)	
	Taeniura meyeni	(Tm)	
	Urogymnus asperrimus	(Ua)	
Ginglymostomatidae	*Nebrius ferrugineus*	(Nf)	
Gymnuridae	*Gymnura australis*	(Ga)	
Hemigaleidae	*Hemigaleus microstoma*	(Hm)	*Hemiscyllium ocellatum*
	Hemipristis elongatus	(He)	*Hemiscyllium trispeculare*
Hemiscylliidae	*Chiloscyllium punctatum*	(Cp)	
Mobulidae			*Manta birostris*
			Mobula eregoodootenkee
Myliobatidae	*Aetobatus narinari*	(Ana)	
	Aetomylaeus vespertilio	(Av)	
	Aetomyleus nichofii	(Ani)	
Narcinidae	*Narcine westraliensis*	(Nw)	*Narcine* sp. *A*
Orectolobidae	*Orectolobus ornatus*	(Oo)	*Eucrossorhinus dasypogon*
			Orectolobus wardi
Pristidae	*Anoxypristis cuspidata*	(Ac)	
	Pristis clavata	(Pc)	
	Pristis microdon	(Pm)	
	Pristis pectinata	(Pp)	
	Pristis zijsron	(Pz)	

Table 7.3.1 The elasmobranch families which occur in the region of the NPF and the species these that have been recorded in prawn trawl bycatch from the sources in Section 7.2.2. The label in parenthesis refers to Figure 7.3.6.

Family	Recorded in bycatch: Yes		No
Scyliorhinidae	*Atelomycterus fasciatus*	(Af)	*Atelomycterus macleayi*
	Galeus sp. A	(Gsa)	
Sphyrnidae	*Eusphyra blochii*	(Eb)	
	Sphyrna lewini	(Sl)	
	Sphyrna mokarran	(Sm)	
Squatinidae	*Squatina* sp. *A*	(Ssa)	
Stegastomatidae	*Stegastoma fasciatum*	(SF)	
Rhincodontidae			*Rhiniodon typus*
Rhinobatidae	*Rhinobatos typus*	(Rt)	*Aptychotrema* sp. *A*
Rhynchobatidae	*Rhynchobatus djiddensis*	(Rd)	
	Rhina ancylostoma	(Ran)	

Table 7.3.2 The overall catch rate of elasmobranch species within the NPF, in terms of the rate per kilometer of headrope length ($n\ h^{-1}\ km^{-1}$) and the number per swept area of the net ($n\ km^{-2}$). The percentage of the catch made up by each species is also show.

		Catch rate				
		$n\ h^{-1}\ km^{-1}$		$n\ km^{-2}$		% of
Family	**Species**	**mean**	**se**	**mean**	**se**	**catch**
Carcharhinidae	*Carcharhinus albimarginatus*	0.013	0.013	0.003	0.003	0.01
	Carcharhinus amboinensis	0.140	0.136	0.036	0.035	0.15
	Carcharhinus dussumieri	16.179	1.761	4.137	0.450	17.67
	Carcharhinus fitzroyensis	0.026	0.019	0.007	0.005	0.03
	Carcharhinus macloti	0.022	0.015	0.006	0.004	0.02
	Carcharhinus sorrah	0.330	0.133	0.084	0.034	0.36
	Carcharhinus tilstoni	5.755	0.610	1.472	0.156	6.29
	Galeocerdo cuvier	0.019	0.014	0.005	0.003	0.02
	Negaprion acutidens	0.007	0.007	0.002	0.002	0.01
	Rhizoprionodon acutus	4.752	0.825	1.215	0.211	5.19
	Rhizoprionodon taylori	0.017	0.017	0.004	0.004	0.02
	unidentified Carcharhinidae	0.455	0.193	0.116	0.049	0.50
Dasyatidae	*Amphotistius annotatus*	4.420	1.256	1.130	0.321	4.83
	Dasyatis kuhlii	0.899	0.283	0.230	0.072	0.98
	Dasyatis leylandi	29.150	3.996	7.453	1.022	31.84
	Dasyatis sp. A	0.017	0.017	0.004	0.004	0.02
	Dasyatis thetidis	0.054	0.028	0.014	0.007	0.06
	Gymnura australis	3.426	0.596	0.876	0.152	3.74
	Himantura fai	0.011	0.011	0.003	0.003	0.01
	Himantura granulata	0.025	0.018	0.006	0.005	0.03
	Himantura jenkinsii	0.095	0.042	0.024	0.011	0.10
	Himantura sp. A	0.372	0.133	0.095	0.034	0.41
	Himantura toshi	7.023	0.926	1.796	0.237	7.67
	Himantura uarnak	0.108	0.043	0.028	0.011	0.12
	Himantura undulata	0.581	0.257	0.149	0.066	0.63
	Pastinachus sephen	1.006	0.464	0.257	0.119	1.10
	Taeniura meyeni	0.011	0.011	0.003	0.003	0.01
	unidentified Dasyatididae	0.244	0.134	0.062	0.034	0.27
	Urogymnus asperrimus	0.033	0.019	0.008	0.005	0.04

Table 7.3.2 The overall catch rate of elasmobranch species within the NPF, in terms of the rate per kilometer of headrope length (n h^{-1} km^{-1}) and the number per swept area of the net (n km^{-2}). The percentage of the catch made up by each species is also show.

		Catch rate				
		n h^{-1} km^{-1}		n km^{-2}		% of
Family	**Species**	**mean**	**se**	**mean**	**se**	**catch**
Ginglymostomatidae	*Nebrius ferrugineus*	0.012	0.012	0.003	0.003	0.01
Hemigaleidae	*Hemigaleus microstoma*	5.746	0.944	1.469	0.241	6.28
	Hemipristis elongata	0.074	0.068	0.019	0.017	0.08
Hemiscylliidae	*Chiloscyllium punctatum*	1.448	0.390	0.370	0.100	1.58
Myliobatidae	*Aetobatus narinari*	0.084	0.069	0.021	0.018	0.09
	Aetomylaeus nichofii	0.387	0.202	0.099	0.052	0.42
Orectolobidae	*Orectolobus ornatus*	1.973	1.973	0.504	0.504	2.15
Pristidae	*Anoxypristis cuspidata*	0.458	0.208	0.117	0.053	0.50
Pristidae	*Pristis zijsron*	0.068	0.068	0.017	0.017	0.07
Rhinobatidae	*Rhinobatos typus*	0.030	0.016	0.008	0.004	0.03
Rhynchobatidae	*Rhina ancylostoma*	0.306	0.149	0.078	0.038	0.33
	Rhynchobatus djiddensis	4.083	0.723	1.044	0.185	4.46
Scyliorhinidae	Atelomycterus fasciatus	0.178	0.101	0.045	0.026	0.19
Sphyrnidae	*Eusphyra blochii*	0.141	0.128	0.036	0.033	0.15
Sphyrnidae	*Sphyrna lewini*	0.445	0.089	0.114	0.023	0.49
	Sphyrna mokarran	0.086	0.069	0.022	0.018	0.09
	unidentified Sphyrnidae	0.006	0.006	0.001	0.001	0.01
Stegastomatidae	*Stegastoma fasciatum*	0.395	0.158	0.101	0.040	0.43

Night versus day catch rates

The rarity of most species limited comparisons between day and night time catch rates based on the October 1997 survey. In this survey, 19 species were caught during the night (Table 7.3.4), of which 7 were recorded only at night (*Orectolobus ornatus, Stegastoma fasciatum, Chiloscylium punctatum, Rhina ancylostoma, Dasyatis kuhlii, Pastinachus sephen* and *Aetomylaus nichofii*). Thirteen species were caught during the day (Table 7.3.4), with 2 recorded only during the day (*Rhizoprionodon taylori* and *Carcharhinus macloti*). However, the latter species were recorded in night time catches during other surveys. Of the species that were recorded at both times, some appeared to have differences in catch rate with time (Table 7.3.4). The only species which were numerous enough to test for a significant difference between day and night catch rates were *D. leylandi* and *C. dussumieri*. The former species had a significantly higher catch rate at night ($F_{(1, 237)}$= 18.46, P< 0.0001) and the latter during the day ($F_{(1,266)}$ = 23.07 , P< 0.0001). There was a significant interaction between time and region for *C. dussumieri* ($F_{(7,266)}$ = 4.62 , P< 0.0001). This species had higher catch rates during the day but the magnitude of the difference between day and night varied among the regions.

Biology

Specimens of five species of ray were examined to assess the size at first maturity and provide estimates of fecundity. The size of the smallest pregnant female was taken as an indicator of the size at first maturity for the female rays (Table 7.3.5). None of the species showed a change in GSI or diameter of the largest egg that clearly indicated maturity (Figure 7.3.2 and 7.3.3). The average number of pups was low (Table 7.3.5), the majority of females had 1 or 2 pups, with the exception of *G. australis* where up to 5 pups were present (Table 7.3.5).

Table 7.3.3 The catch rate of elasmobranch species within the NPF from the three survey methods. Catch rate is given in terms of the rate per kilometre of headrope length ($n\ h^{-1}\ km^{-1}$) and the number per swept area of the net ($n\ km^{-2}$). The percentage of the catch each species contributed is also given.

		Research surveys					Scientific observer					Crew member observer				
		$n\ h^{-1}\ km^{-1}$		$n\ km^{-2}$		% of	$n\ h^{-1}\ km^{-1}$		$n\ km^{-2}$		% of	$n\ h^{-1}\ km^{-1}$		$n\ km^{-2}$		% of
Family	**Species**	**mean**	**se**	**mean**	**se**	**catch**	**mean**	**se**	**mean**	**se**	**catch**	**mean**	**se**	**mean**	**se**	**catch**
Carcharhinidae	*Carcharhinus albimarginatus*	—	—	—	—	—	0.035	0.009	0.035	0.009	0.05	—	—	—	—	—
	Carcharhinus amboinensis	0.273	0.070	0.273	0.070	0.27	—	—	—	—	—	0.034	0.009	0.034	0.009	0.03
	Carcharhinus dussumieri	10.285	2.630	1.658	0.424	10.01	11.275	2.883	1.761	0.450	15.51	54.855	14.025	10.854	2.775	54.41
	Carcharhinus fitzroyensis	—	—	—	—	—	0.070	0.018	0.050	0.013	0.10	—	—	—	—	—
	Carcharhinus macloti	—	—	—	—	—	0.058	0.015	0.041	0.010	0.08	—	—	—	—	—
	Carcharhinus sorrah	0.177	0.045	0.146	0.037	0.17	0.189	0.048	0.092	0.023	0.26	1.379	0.353	0.851	0.218	1.37
	Carcharhinus tilstoni	2.675	0.684	0.766	0.196	2.60	8.664	2.215	0.964	0.247	11.92	9.212	2.355	2.367	0.605	9.14
	Galeocerdo cuvier	0.024	0.006	0.024	0.006	0.02	—	—	—	—	—	0.055	0.014	0.055	0.014	0.05
	Negaprion acutidens	—	—	—	—	—	—	—	—	—	—	0.055	0.014	0.055	0.014	0.05
	Rhizoprionodon acutus	7.554	1.931	1.629	0.416	7.35	1.470	0.376	0.235	0.060	2.02	3.560	0.910	0.833	0.213	3.53
	Rhizoprionodon taylori	0.034	0.009	0.034	0.009	0.03	—	—	—	—	—	—	—	—	—	—
	unidentified Carcharhinidae	—	—	—	—	—	1.199	0.306	0.507	0.130	1.65	—	—	—	—	—
Dasyatidae	*Amphotistius annotatus*	7.784	1.990	2.423	0.620	7.58	1.454	0.372	0.907	0.232	2.00	—	—	—	—	—
	Dasyatis kuhlii	1.131	0.289	0.503	0.129	1.10	0.684	0.175	0.340	0.087	0.94	0.632	0.161	0.230	0.059	0.63
	Dasyatis leylandi	45.164	11.547	7.665	1.960	43.96	15.069	3.853	2.904	0.743	20.72	8.000	2.045	1.532	0.392	7.94
	Dasyatis sp. A	—	—	—	—	—	—	—	—	—	—	0.137	0.035	0.137	0.035	0.14
	Dasyatis thetidis	—	—	—	—	—	0.120	0.031	0.072	0.018	0.16	0.069	0.018	0.048	0.012	0.07
	Gymnura australis	4.999	1.278	1.083	0.277	4.87	2.159	0.552	0.660	0.169	2.97	0.989	0.253	0.290	0.074	0.98
	Himantura fai	—	—	—	—	—	0.028	0.007	0.028	0.007	0.04	—	—	—	—	—
	Himantura granulata	0.027	0.007	0.027	0.007	0.03	0.030	0.008	0.030	0.008	0.04	—	—	—	—	—
	Himantura jenkinsii	—	—	—	—	—	0.251	0.064	0.109	0.028	0.35	—	—	—	—	—
	Himantura sp. A	0.342	0.087	0.246	0.063	0.33	0.095	0.024	0.055	0.014	0.13	1.346	0.344	0.384	0.098	1.33
	Himantura toshi	5.613	1.435	1.346	0.344	5.46	10.109	2.585	1.672	0.427	13.90	3.227	0.825	0.538	0.137	3.20
	Himantura uarnak	—	—	—	—	—	0.147	0.038	0.066	0.017	0.20	0.420	0.107	0.283	0.072	0.42
	Himantura undulata	1.103	0.282	0.515	0.132	1.07	0.058	0.015	0.041	0.010	0.08	0.089	0.023	0.065	0.016	0.09
	Pastinachus sephen	1.371	0.351	0.925	0.236	1.33	0.175	0.045	0.071	0.018	0.24	2.087	0.534	0.478	0.122	2.07
	Taeniura meyeni	—	—	—	—	—	0.028	0.007	0.028	0.007	0.04	—	—	—	—	—
	unidentified Dasyatididae	0.256	0.066	0.256	0.066	0.25	0.159	0.041	0.084	0.021	0.22	0.457	0.117	0.196	0.050	0.45
	Urogymnus asperrimus	—	—	—	—	—	0.042	0.011	0.042	0.011	0.06	0.135	0.035	0.079	0.020	0.13
Ginglymostomatidae	*Nebrius ferrugineus*	—	—	—	—	—	0.032	0.008	0.032	0.008	0.04	—	—	—	—	—

Table 7.3.3 The catch rate of elasmobranch species within the NPF from the three survey methods. Catch rate is given in terms of the rate per kilometre of headrope length ($n\ h^{-1}\ km^{-1}$) and the number per swept area of the net ($n\ km^{-2}$). The percentage of the catch each species contributed is also given.

		Research surveys					**Scientific observer**					**Crew member observer**				
		$n\ h^{-1}\ km^{-1}$		**$n\ km^{-2}$**		**% of**	**$n\ h^{-1}\ km^{-1}$**		**$n\ km^{-2}$**		**% of**	**$n\ h^{-1}\ km^{-1}$**		**$n\ km^{-2}$**		**% of**
Family	**Species**	**mean**	**se**	**mean**	**se**	**catch**	**mean**	**se**	**mean**	**se**	**catch**	**mean**	**se**	**mean**	**se**	**catch**
Hemigaleidae	*Hemigaleus microstoma*	6.014	1.538	1.549	0.396	5.85	4.249	1.086	1.295	0.331	5.84	9.257	2.367	1.930	0.493	9.18
	Hemipristis elongata	0.137	0.035	0.137	0.035	0.13	—	—	—	—	—	0.046	0.012	0.046	0.012	0.05
Hemiscylliidae	*Chiloscyllium punctatum*	0.652	0.167	0.371	0.095	0.63	2.837	0.725	0.901	0.230	3.90	0.390	0.100	0.150	0.038	0.39
Myliobatidae	*Aetobatus narinari*	0.137	0.035	0.137	0.035	0.13	0.030	0.008	0.030	0.008	0.04	0.034	0.009	0.034	0.009	0.03
	Aetomylaeus nichofii	0.566	0.145	0.400	0.102	0.55	0.190	0.048	0.087	0.022	0.26	0.277	0.071	0.158	0.041	0.27
Orectolobidae	*Orectolobus ornatus*	3.969	1.015	3.969	1.015	3.86	—	—	—	—	—	—	—	—	—	—
Pristidae	*Anoxypristis cuspidata*	0.795	0.203	0.415	0.106	0.77	0.133	0.034	0.066	0.017	0.18	0.101	0.026	0.071	0.018	0.10
	Pristis zijsron	0.137	0.035	0.137	0.035	0.13	—	—	—	—	—	—	—	—	—	—
Rhinobatidae	*Rhinobatos typus*	—	—	—	—	—	0.058	0.015	0.041	0.010	0.08	0.065	0.017	0.046	0.012	0.06
Rhynchobatidae	*Rhina ancylostoma*	0.491	0.126	0.296	0.076	0.48	0.134	0.034	0.068	0.017	0.18	0.089	0.023	0.065	0.016	0.09
	Rhynchobatus djiddensis	0.266	0.068	0.094	0.024	0.26	9.716	2.484	1.867	0.477	13.36	2.150	0.550	0.409	0.105	2.13
Scyliorhinidae	*Atelomycterus fasciatus*	—	—	—	—	—	0.442	0.113	0.266	0.068	0.61	0.081	0.021	0.057	0.015	0.08
Sphyrnidae	*Eusphyra blochii*	0.256	0.066	0.256	0.066	0.25	0.035	0.009	0.035	0.009	0.05	—	—	—	—	—
	Sphyrna lewini	—	—	—	—	—	1.110	0.284	0.229	0.059	1.53	0.196	0.050	0.097	0.025	0.19
	Sphyrna mokarran	0.137	0.035	0.137	0.035	0.13	—	—	—	—	—	0.146	0.037	0.084	0.022	0.15
	unidentified Sphyrnidae	—	—	—	—	—	—	—	—	—	—	0.046	0.012	0.046	0.012	0.05
Stegastomatidae	*Stegastoma fasciatum*	0.361	0.092	0.271	0.069	0.35	0.177	0.045	0.072	0.018	0.24	1.200	0.307	0.626	0.160	1.19

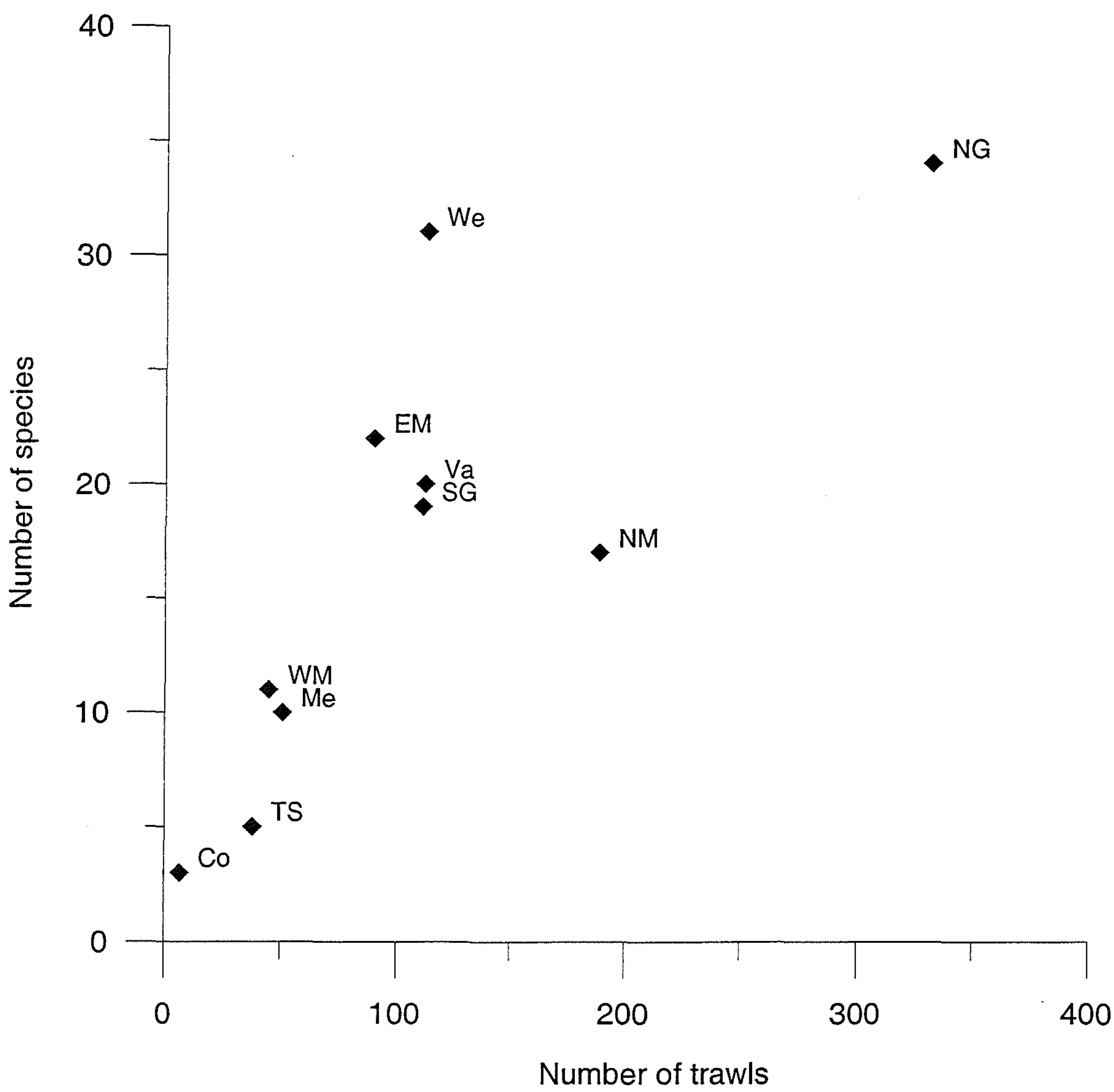


Figure 7.3.1 The number of trawls in each region and the number of elasmobranch species detected. The labelling of the regions follows Figure 6.2.1.

Table 7.3.4 The mean catch rate and standard errors (se) of elasmobranch species during day and night-time research trawls.

		$n\ h^{-1}\ km^{-1}$				$kg\ h^{-1}\ km^{-1}$			
Family	**Species**	**Night mean**	**se**	**Day mean**	**se**	**Night mean**	**se**	**Day mean**	**se**
Carcharhinidae	*Carcharhinus dussumieri*	6.78	1.68	29.69	5.73	12.38	3.07	47.30	9.48
	Carcharhinus macloti	-	-	0.62	0.62	-	-	1.54	1.54
	Carcharhinus tilstoni	3.57	1.16	2.73	2.24	29.10	13.28	10.30	9.00
	Rhizoprionodon acutus	7.20	1.91	23.90	9.30	10.67	3.38	41.41	18.77
	Rhizoprionodon taylori	-	-	45.44	24.54	-	-	27.83	15.72
Dasyatidae	*Amphotistius annotatus*	7.72	3.14	10.41	6.29	1.58	0.63	1.95	1.16
	Dasyatis kuhlii	0.78	0.55	-	-	1.29	0.93	-	-
	Dasyatis leylandi	44.56	8.50	3.99	2.44	8.85	1.90	1.19	0.93
	Gymnura australis	3.19	1.11	0.62	0.62	2.79	1.58	0.24	0.24
	Himantura toshi	3.92	1.66	3.68	1.71	17.14	8.93	15.34	7.94
	Himantura undulata	1.24	0.71	1.15	0.81	67.81	39.02	83.62	63.05
	Pastinachus sephen	2.05	1.38	-	-	81.39	46.79	-	-
Hemigaleidae	*Hemigaleus microstoma*	1.57	1.22	2.46	1.22	0.25	0.18	2.25	1.38
Hemiscylliidae	*Chiloscyllium punctatum*	0.77	0.54	-	-	0.19	0.13	-	-
Myliobatidae	*Aetomylaeus nichofii*	0.42	0.42	-	-	1.90	1.90	-	-
Orectolobidae	*Orectolobus ornatus*	5.92	5.92	-	-	0.09	0.09	-	-
Pristidae	*Anoxypristis cuspidata*	0.40	0.40	0.64	0.64	3.13	3.13	9.55	9.55
Rhynchobatidae	*Rhina ancylostoma*	0.38	0.38	-	-	3.07	3.07	-	-
Sphyrnidae	*Eusphyra blochii*	0.38	0.38	0.64	0.64	0.42	0.42	2.04	2.04
Stegastomatidae	*Stegostoma fasciatum*	0.40	0.40	-	-	7.92	7.92	-	-

Table 7.3.5 The estimated size and maturity and mean number of pups and standard error (se) for ray species. n = sample size.

	Size at maturity (mm)				Pups		
Species	**male**	**n**	**female**	**n**	**mean**	**se**	**n**
Amphotistis annotatus	200	9	233	8	1.5	0.71	2
Dasyatis kuhlii	300	10	378	6	2	-	1
Dasyatis leylandi	185	103	180	110	1.1	0.33	17
Gymnura australis	350	29	610	16	3.2	1.2	6
Himantura toshi	400	31	660	21	1.5	0.71	2

The size at first maturity of the male rays was taken as the size at which the majority had a calcified clasper and the relationship between clasper length and total length changed (Figure 7.3.4). Most species, showed an increase in GSI with calcification of the claspers (Figure 7.3.5). The estimates of size at maturity for the males are lower than the estimates for females for four of the five species. However, this is likely to be influenced by the low numbers of pregnant females sampled (Table 7.3.5). The size at maturity of the males appears to be between 44% - 79% of the maximum size for the species.

The mean size of rays caught ranged from 182.2 mm for *D. leylandi* to 1117.1 mm for *H. toshi*, with the majority of species (13) caught at an average size of < 1000 mm (Table 7.3.6). The mean size of sharks ranged from 541.2 mm for *Carcharhinus sorrah* to 1643.3 mm for *Rhina ancylostoma* (Table 7.3.6). For 29 species a size at birth is available from the literature and of these species 7 were caught in bycatch from this size (Table 7.3.6).

Where an estimate of the size at first maturity (L_m) is available for a species, an estimate can be made of the percentage of mature individuals that were captured. In species with sufficient samples sizes, the percentage of mature individuals caught ranges from very low, < 1% for *S. lewini,* to high, 55% for *R. acutus* (Table 7.3.6). Species such as *D. leylandi* and *C. dussumieri* had an average size at capture not significantly different to L_m, suggesting, on average half the individuals caught had reached maturity before capture. Species such as *C. tilstoni*, with an average size less than L_m, are those in which the majority are unlikely to have bred before capture. At the other extreme are species such as *G. australis*, where it is likely that the majority have reached maturity before capture (Table 7.3.6).

For species where estimates of the size at sexual maturity of the separate sexes, the proportion of mature individuals captured in bycatch was calculated for each sex. Most species showed a difference between the sexes in the percentage of mature individuals caught. In some species this is due to the difference in L_m between the sexes e.g. *H. microstoma*, while in others the difference was due to different size ranges of the sexes caught, e.g. *R. acutus* (Table 7.3.7).

The sex ratio of individuals caught was close to 1 for the two most common species, *D. leylandi* and *C. dussumieri* (Table 7.3.8). However, other species showed a range from predominantly male (e.g. *R. acutus*) to predominantly female (e.g. *H. toshi*) (Table 7.3.6).

Survival

Whether an individual was alive or dead when landed on the deck was recorded for 847 elasmobranchs. Overall 56% were recorded as dead after capture in the trawl and 44% alive. Logistic regressions were performed separately on the sharks and rays. Both groups showed that the likelihood of survival was lower for males than females and that survival increased with increased length of the individual (Table 7.3.8). Two-thirds of male sharks and rays were recorded as dead after the trawl, while only 23% of female sharks and 56% of female rays were recorded as dead (Table 7.3.9). The average size of rays and sharks that died was smaller than those that survived (Table 7.3.8). The overall percent of individuals of a species dying varied from 10% (*R. djiddensis)* to 82% (*C. dussumeri* and *R. acutus*) (Table 7.3.9).

Process for assessing the sustainability of elasmobranch species

The 56 species of elasmobranchs recorded as bycatch in the NPF were ranked on each of the criteria on the two axes (Tables 7.3.10 and 7.3.11). The extent to which species specific information was available varied among the criteria (Table 7.3.12). Most of the criteria were not correlated (Table 7.3.13). On the susceptibility axis the only strong correlation was between diet and water column position (Table 7.3.13). However, both criteria were retained as we believed there was sufficient difference between them.

On the susceptibility axis the species that ranked the lowest, i.e. were the most susceptible to capture and mortality by the prawn trawlers were *Himantura jenkinsii, Pristis clavata, P. microdon, P. pectinata, P. zijsron,* and *Stegastoma fasciatum* (Table 7.3.10). The least susceptible species were *Carcharhinus tilstoni, C. macloti, C. brevipinna, Sphyrna lewini, Prionace glauca*, and *Aetomyleus nichofii* (Table 7.3.10).

On the recovery axis the species with the lowest recovery capacity were *Dasyatis brevicaudatus, Pristis pectinata, P. clavata* and *Aetomyleaus vespertilio,* these species had the lowest ranks (Table 7.3.11). The species with the highest ranks and therefore, the highest recovery capacity were *Hemigaleus microstoma, Rhizoprionodon taylori, Himantura toshi, Gymnura australis* and *Eusphyra blochii* (Table 7.3.11).

When the ranks of the species on the two axes were plotted (Figure 7.3.6) the species that ranked as the least sustainable were *Dasyatis brevicaudatus, Himantura jenkinsii, Pristis clavata, P. microdon, P. pectinata* and *P. zijsron.* The species that ranked as the most sustainable were *Carcharhinus dussumieri, C. tilstoni, C. macloti, Eusphyra blochii, Gymnura australis, Hemigaleus microstoma* and *Himantura toshi.*

Impact of Turtle Exclusion Devices

The mean size of rays captured in nets with a codend fitted with a TED was 285.8 ($\pm$ 7.4) mm, significantly less than those caught in nets with a standard codend, 329.6 ($\pm$ 18.5) mm ($F_{1,569} = 4.25$, $p = 0.0398$). The maximum size in nets with a TED was 300 mm less than nets without. However the AusTED device recorded larger rays than the standard nets (Table 7.3.14). The length frequency of the rays caught in the nets with TEDs shows a lower proportion of the larger individuals (Figure 7.3.7).

The mean size of sharks was 887.3 (± 59.4) mm in the nets with a standard codend compared to 596.1 (± 36.3) in the nets fitted with a TED, this difference was significant ($F_{1,435} = 26.77$, $p < 0.0001$). The maximum size of sharks was at least 3200 mm greater in the nets without TEDs (Table 7.3.16). The length frequency of sharks caught in the nets with TEDs in comparison to the standard net (Figure 7.3.8) shows that the larger individuals were much rarer.

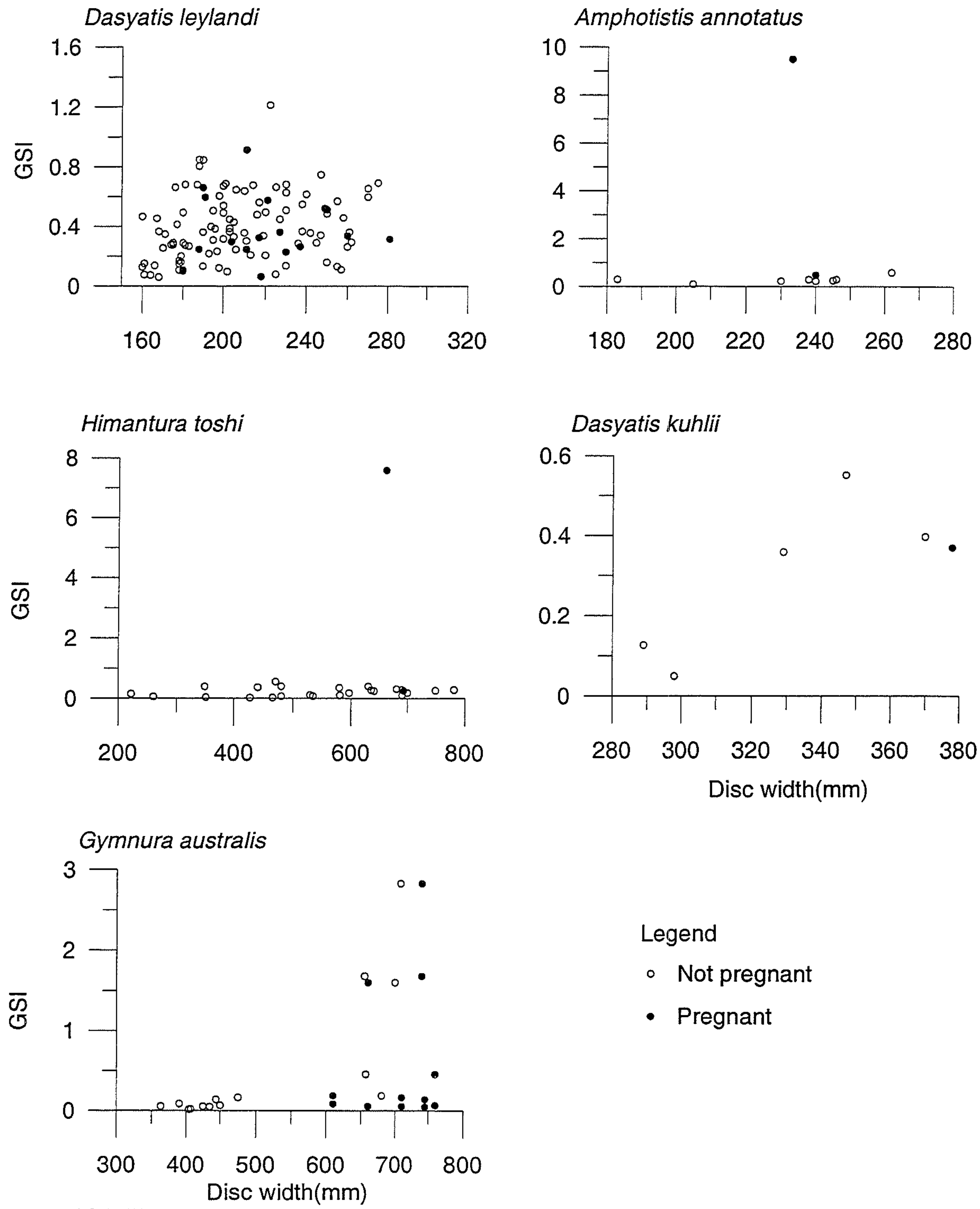


Figure 7.3.2 The relationship between gono-somatic index (GSI) and animal size for female rays.

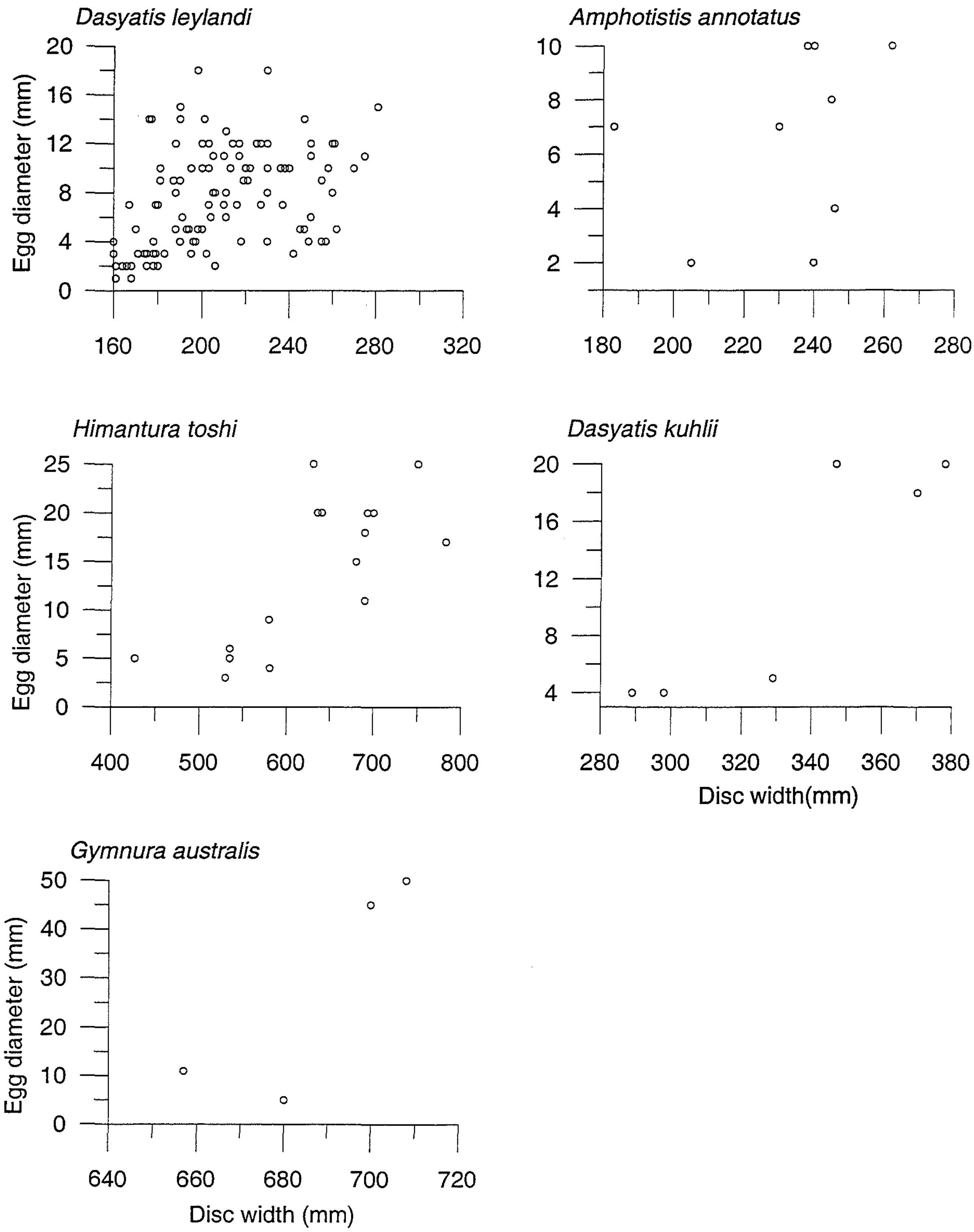


Figure 7.3.3 The relationship between egg diameter and animal size for ray species.

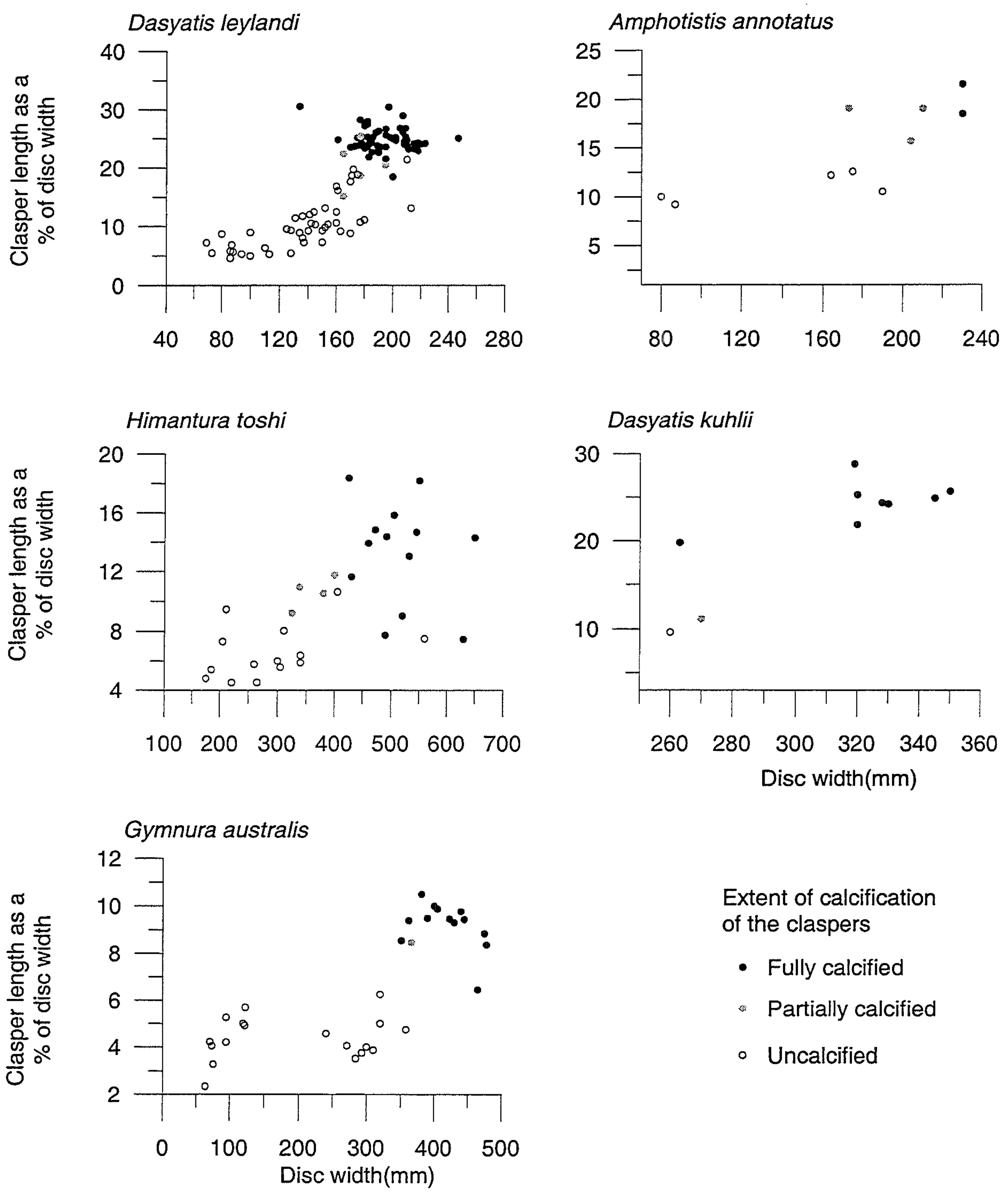


Figure 7.3.4 The relationship between clasper length, animal size and the extent of calcification of the clasper for ray species.

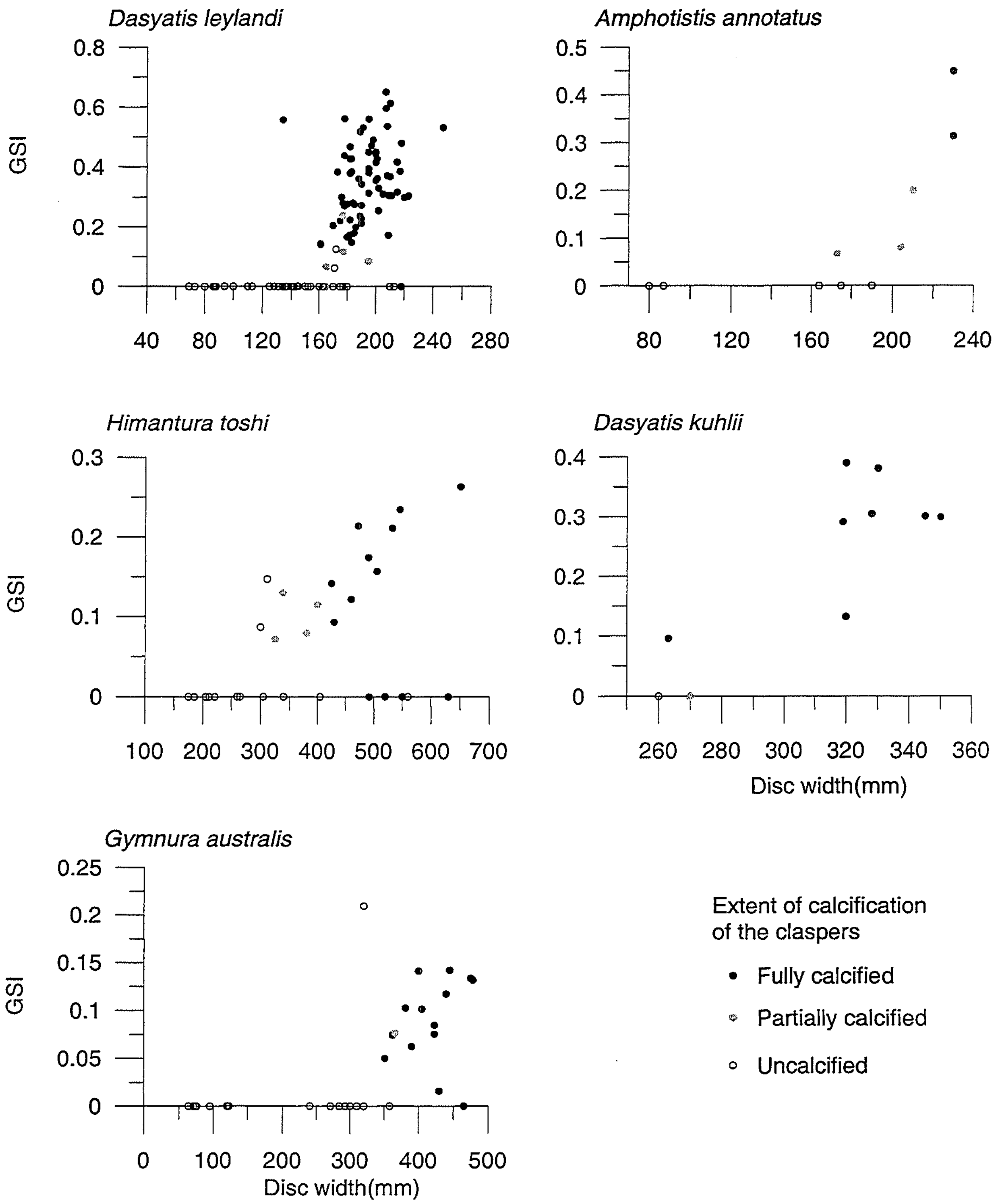


Figure 7.3.5 The relationship between gono-somatic index (GSI), size and the extent of calcification of the clasper for ray species.

Table 7.3.6 The average size (TL or DW) of elasmobranch species caught in night-time prawn trawling and the size at maturity (L_m) and at birth (pup size) from the literature or this study. The percentage of individuals caught that are mature (% mature) and the sex ratio are also shown, n = the sample size, P is the probability that the mean length at capture is different from L_m

		Size						Pup	%	Sex ratio		
Family	**Species**	**mean**	**se**	**min**	**max**	**n**	L_m	**Size**	**mature**	**F:M**	**n**	**P**
Carcharhinidae	*Carcharhinus albimarginatus*	850	-	-	-	1	1700	-	100	-	-	-
	Carcharhinus amboinensis	1700	-	-	-	1	2100	500	0	-	-	-
	Carcharhinus dussumieri	636.01	5.76	270	850	377	650	350	40.6	1.08	139	<0.05
	Carcharhinus fitzroyensis	1045	225.00	820	1270	2	810	500	50	-	-	>0.5
	Carcharhinus tilstoni	794.27	9.29	100	1950	344	1100	600-	0.6	0.95	84	<0.001
	Carcharhinus macloti	745	75.00	670	820	2	690	450	20	-	-	>0.5
	Carcharhinus sorrah	541.92	43.25	300	950	25	900	500	8	3.03	16	<0.001
	Galeocerdo cuvier	1175	285.00	890	1460	2	3000	500	0	all M	1	>0.1
	Negaprion acutidens	2600	-	-	-	1	-	380	-	-	-	-
	Rhizoprionodon acutus	688.51	13.91	280	960	140	750	-	54.3	0.56	81	<0.001
	Rhizoprionodon taylori	546	-	-	-	1	450	700	100	all F	1	-
Dasyatidae	*Amphotistius annotatus*	211.44	12.41	140	452	25	200	-	24	1.43	3	>0.5
	Dasyatis kuhlii	297.25	12.27	190	400	24	300	160	8.3	4.00	10	>0.5
	Dasyatis leylandi	182.2	2.88	110	400	206	180	110	45.6	1.05	162	>0.2
	Dasyatis sp. A	350	-	-	-	1	360	-	0	-	-	-
	Dasyatis thetidis	1162	129.09	800	1420	5	-	350	-	all M	1	-
	Himantura fai	1900	-	-	-	1	-	550	-	-	-	-
	Himantura granulata	960	-	-	-	1	-	280	-	-	-	-
	Himantura jenkinsii	890	150.27	300	1140	5	-	-	-	all M	1	-
	Himantura sp. A	349.5	64.91	80	1800	57	-	-	-	all F	12	-
	Himantura toshi	455.68	10.61	150	1330	235	400	200	11.5	4.17	52	<0.001
	Himantura uarnak	1055	131.62	290	1600	12	-	280	-	all F	2	-
Dasyatidae	*Himantura undulata*	1117.14	131.33	400	1500	7	-	200	-	all F	1	-
	Pastinachus sephen	1075.81	53.12	450	2000	43	-	180	-	3.03	12	<0.001
	Taeniura meyeni	1300	-	-	-	1	-	350	-	-	-	-
	Urogymnus asperrimus	850	106.25	530	1150	5	-	-	-	all M	2	-
Ginglymostomatidae	*Nebrius ferrugineus*	2400	-	-	-	1	2250	400	100	-	-	-
Gymnuridae	*Gymnura australis*	462.17	18.97	120	860	87	350	-	24.1	2.00	42	<0.001
Hemigaleidae	*Hemigaleus microstoma*	608.89	18.80	250	2300	152	600	300	47.4	0.68	91	>0.5
	Hemipristis elongata	1340	190.00	1150	1530	2	1200	520	50	all F	1	>0.5
Hemiscylliidae	*Chiloscyllium punctatum*	667.79	22.67	230	1000	63	700	170	52.4	2.50	7	<0.001

Table 7.3.6 The average size (TL or DW) of elasmobranch species caught in night-time prawn trawling and the size at maturity (L_m) and at birth (pup size) from the literature or this study. The percentage of individuals caught that are mature (% mature) and the sex ratio are also shown, n = the sample size, P is the probability that the mean length at capture is different from L_m

		Size						Pup	%	Sex ratio		
Family	**Species**	**mean**	**se**	**min**	**max**	**n**	**L_m**	**Size**	**mature**	**F:M**	**n**	**P**
Myliobatidae	*Aetobatus narinari*	625	125.00	500	750	2	-	260	-	all F	1	-
	Aetomylaeus nichofii	437.1	41.48	240	720	11	-	170	-	all F	3	-
	Atelomycterus fasciatus	300	0.00	300	300	2	320	-	0	-	-	-
Pristidae	*Anoxypristis cuspidata*	1930	192.91	1240	2550	8	-	-	-	all F	1	-
Rhinobatidae	*Rhinobatos typus*	1952.5	188.30	1500	2340	4	-	-	-	-	-	-
Rhynchobatidae	*Rhina ancylostoma*	1643.33	111.92	1010	2090	9	-	-	-	0.33	3	-
	Rhynchobatus djiddensis	869.35	35.88	230	2650	187	1560	-	8	4.76	35	<0.001
Sphyrnidae	*Eusphyra blochii*	990	320.00	670	1310	2	1080	450	50	-	-	>0.5
	Sphyrna lewini	832.43	53.76	400	2400	37	1400	450	2.7	all F	3	<0.001
	Sphyrna mokarran	1780	456.54	400	2400	3	2100	650	33.3	1.00	2	>0.5
Stegostomatidae	*Stegostoma fasciatum*	1305.39	81.15	400	2000	26	1470	200	23.1	0.80	3	>0.05

Table 7.3.7 The size at maturity (L_m) for the separate sexes within species and the percentage of individuals caught in night time prawn trawls that were mature. n = the sample size.

Family	Species	Sex	L_m	% Mature	n
Carcharhinidae	*Carcharhinus dussumieri*	F	650	52.8	72
		M	700	26.9	67
	Carcharhinus sorrah	F	900	0	12
		M	900	0	4
	Rhizoprionodon acutus	F	750	20.7	29
		M	750	75	52
Dasyatidae	*Amphotistius annotatus*	F	233	30	10
		M	200	0	7
	Dasyatis kuhlii	F	378	12.5	8
		M	300	50	2
	Dasyatis leylandi	F	180	60.2	83
		M	185	35.4	79
	Gymnura australis	F	350	14.3	28
		M	350	42.9	14
	Himantura toshi	F	660	9.5	42
		M	400	70	10
Hemigaleidae	*Hemigaleus microstoma*	F	650	19	37
		M	600	35.2	54
Rhynchobatidae	*Rhynchobatus djiddensis*	F	1560	20.7	29
		M	1770	0	6
Stegastomatidae	*Stegostoma fasciatum*	F	1470	25	4
		M	1690	0	5

There were three shark species and three ray species for which enough individuals were caught to compare the length frequency captured by nets with TEDs and nets with standard codends. *Carcharhinus dussumeri* and *R. djiddensis*, showed a decrease in the size of individuals caught in the net with a TED (Table 7.3.15, Figures 9.2.8 and 9.2.9). There was no significant difference for *H. microstoma, A. annotatus* and *H. toshi* (Table 7.3.15, Figures 9.2.8 and 9.2.9). *Rhizoprionodon acutus* showed significantly large individuals in the net with a TED (Table 7.3.15, Figure 9.2.8).

7.3.4 Discussion

Elasmobranch bycatch and removal rates

Elasmobranchs occur frequently in the bycatch of the NPF, with most trawls containing at least one individual. The catch is highly diverse with 56 species documented as occurring in the bycatch, 44 of which were recorded in the present study. However, three species dominated the catch of the present study (*Dasyatis leylandi, Carcharhinus dussumeri* and *Himantura toshi,* Table 7.3.2), contributing 57% of all elasmobranchs caught.

Table 7.3.8 The results of the logistic regression which looked at the probablity of elasmobranchs surving capture in a trawl and the average size of individuals that survived or died. Sharks includes all species where total length is recorded and rays includes all species where disc width is recorded.

	Logistic regression results							Size (mm)					
		Length			Sex			Alive			Dead		
Taxa	**Intercept**	**Coefficient**	**Chi-squared**	**P**	**Coefficient**	**Chi-squared**	**P**	**mean**	**se**	**n**	**mean**	**se**	**n**
Sharks	-0.404	-0.0008	4.747	*0.0294*	1.475	19.7	*0.0001*	797.35	16.8	298	684.34	9.62	394
Rays	1.5411	-0.00176	11.077	*0.0009*	0.5675	10.45	*0.0012*	546.07	32.7	256	424.3	41.08	92

Table 7.3.9 The percentage of individual elasmobranchs dying within the net, recorded on research and crew member observer surveys. Sharks refers to all species where total length is recorded and rays refers to all species where disc width is recorded.

		% Dead					
Family	**Taxa**	**Female**	**n**	**Male**	**n**	**Overall**	**n**
	Sharks	23.3	149	66	59	61	639
	Rays	56	360	67	279	40	208
Carcharhinidae	*Carcharhinus dussumieri*	48	207	58	114	52	321
	Carcharhinus tilstoni	78	40	85	33	82	73
	Carcharhinus sorrah	73	15	50	8	65	23
	Rhizoprionodon acutus	75	44	86	72	82	116
Dasyatidae	*Dasyatis leylandi*	27	22	95	19	59	41
	Himantura toshi	43	40	78	18	53	58
Gymnuridae	*Gymnura australis*	31	26	75	8	41	34
Hemigaleidae	*Hemigaleus microstoma*	44	29	64	39	62	68
Rhynchobatidae	*Rhynchobatus djiddensis*	21	24	20	5	10	59

The majority of species, 75%, contributed < 1% of the catch. To date the impact of this bycatch on elasmobranch populations in the NPF has not been assessed. There are no long term data available from which changes in catch rates of elasmobranch species could be detected. Pender *et al.* (1992) surveyed the bycatch in NT waters of the NPF during the 1980s. All of the elasmobranch species recorded by Pender *et al.* (1992) were recorded in the present study. Direct comparisons of the catch rates are not possible due to differences in the gear, season and region. While shark byproduct is currently recorded in the NPF logbooks this data is of limited value as it is not validated and not species specific.

Table 7.3.10 The ranking of species with respect to criteria that influence their susceptibility to capture and mortality due to trawling. The weight of each criterion is shown in parentheses, * indicates where species specific information was not available.

		Criteria										
Family	**Species**	**Water column postion (3)**	**Survival (3)**		**Range (2)**		**Day/ night catchability (2)**		**Diet (2)**		**Depth range (1)**	**Total**
Dasyatididae	*Himantura jenkinsii*	1	1	*	1		1	*	1	*	1	1.00
Pristidae	*Pristis clavata*	1	1	*	1	*	1	*	1	*	1	1.00
Pristidae	*Pristis microdon*	1	1	*	1	*	1	*	1	*	1	1.00
Pristidae	*Pristis pectinata*	1	1	*	1	*	1	*	1	*	1	1.00
Pristidae	*Pristis zijsron*	1	1	*	1		1	*	1	*	1	1.00
Stegastomatidae	*Stegastoma fasciatum*	1	1	*	1	*	1		1		1	1.00
Scyliorhinidae	*Atelomycterus fasciatus*	1	1	*	1		1	*	1	*	3	1.15
Carcharhinidae	*Carcharhinus amboinensis*	1	1	*	1		1	*	1		3	1.15
Carcharhinidae	*Carcharhinus leucas*	1	1	*	1	*	1	*	1		3	1.15
Dasyatididae	*Dasyatis brevicaudatus*	1	1	*	1	*	1	*	1	*	3	1.15
Dasyatididae	*Dasyatis* sp. A	1	1	*	1		1	*	1	*	3	1.15
Dasyatididae	*Dasyatis thetidis*	1	1	*	1		1	*	1	*	3	1.15
Scyliorhinidae	*Galeus* sp. A	1	1	*	1	*	1	*	1	*	3	1.15
Dasyatididae	*Himantura fai*	1	1	*	1		1	*	1	*	3	1.15
Dasyatididae	*Himantura granulata*	1	1	*	1		1	*	1		3	1.15
Dasyatididae	*Himantura uarnak*	1	1	*	1	*	1	*	1	*	3	1.15
Ginglymostomatidae	*Nebrius ferrugineus*	1	1	*	1		1	*	1		3	1.15
Carcharhinidae	*Negaprion acutides*	1	1	*	1		1	*	1		3	1.15
Orectolobidae	*Orectolobus ornatus*	1	1	*	1		1		1		3	1.15
Rhinobatidae	*Rhinobatos typus*	1	1	*	1		1	*	1	*	3	1.15
Squatinidae	*Squatina* sp A	1	1	*	1	*	1	*	1	*	3	1.15
Dasyatididae	*Taeniura meyeni*	1	1	*	1		1	*	1	*	3	1.15
Dasyatididae	*Urogymnus asperrimus*	1	1	*	1		1	*	1	*	3	1.15
Pristidae	*Anoxypristis cuspidata*	1	1	*	1	*	2		1	*	1	1.15
Dasyatididae	*Pastinachus sephen*	1	1	*	2		1	*	1		1	1.15
Hemiscylliidae	*Chiloscyllium punctatum*	1	1	*	2		1		1		3	1.31
Dasyatididae	*Dasyatis kuhlii*	1	1	*	2		1		1	*	3	1.31
Dasyatididae	*Himantura* sp. A	1	1	*	2		1	*	1	*	3	1.31

Table 7.3.10 The ranking of species with respect to criteria that influence their susceptibility to capture and mortality due to trawling. The weight of each criterion is shown in parentheses, * indicates where species specific information was not available.

		Criteria										
Family	**Species**	**Water column postion (3)**	**Survival (3)**		**Range (2)**		**Day/ night catchability (2)**		**Diet (2)**		**Depth range (1)**	**Total**
Narcinidae	*Narcine westraliensis*	1	1	*	1	*	1	*	2		3	1.31
Rhynchobatidae	*Rhina ancylostoma*	1	1	*	2		1		1		3	1.31
Carcharhinidae	*Carcharhinus fitztroyensis*	3	1	*	1		1	*	1		1	1.46
Dasyatididae	*Amphotistis annotatus*	1	1	*	2		2		1	*	3	1.46
Dasyatididae	*Himantura undulata*	1	1	*	2		2		1	*	3	1.46
Carcharhinidae	*Rhizoprionodon taylori*	1	1	*	1		3		1		3	1.46
Carcharhinidae	*Galeocerdo cuvier*	3	1	*	1		1	*	1		3	1.62
Hemiscylliidae	*Hemigaleus microstoma*	1	1		3		1	*	2		3	1.62
Dasyatididae	*Dasyatis leylandi*	1	2		3		1		1		3	1.69
Gymnuridae	*Gymnura australis*	1	2		3		2		1	*	1	1.69
Carcharhinidae	*Carcharhinus sorrah*	3	1		2		1	*	1		3	1.77
Carcharhinidae	*Rhizoprionodon acutus*	1	1		3		3		1		3	1.77
Rhynchobatidae	*Rhynchobatus djiddensis*	1	3		2		1	*	1	*	3	1.77
Myliobatidae	*Aetobatus narinari*	3	1	*	1		1	*	2		3	1.77
Myliobatidae	*Aetomylaeus vespertilio*	3	1	*	1	*	1	*	2	*	3	1.77
Carcharhinidae	*Carcharhinus albimarginatus*	3	1	*	1		1	*	2		3	1.77
Hemiscylliidae	*Hemipristis elongatus*	3	1	*	1		1	*	2		3	1.77
Sphyrnidae	*Sphyrna mokarran*	3	1	*	1		1	*	2		3	1.77
Carcharhinidae	*Carcharhinus limbatus*	3	1		1	*	1	*	3		1	1.77
Sphyrnidae	*Eusphyra blochii*	3	1	*	1		2		1		3	1.77
Carcharhinidae	*Carcharhinus dussumieri*	1	2		2		3		1		3	1.85
Dasyatididae	*Himantura toshi*	1	2		3		2		1		3	1.85
Myliobatidae	*Aetomyleus nichofii*	3	1	*	2		1		2	*	3	1.92
Carcharhinidae	*Carcharhinus brevipinna*	3	1	*	1	*	1	*	3		3	1.92
Carcharhinidae	*Prionace glauca*	3	1	*	1	*	1	*	3		3	1.92
Sphyrnidae	*Sphyrna lewini*	3	1	*	1	*	1	*	3		3	1.92
Carcharhinidae	*Carcharhinus macloti*	3	1	*	1		3		2		3	2.08
Carcharhinidae	*Carcharhinus tilstoni*	3	2		2		2		1		3	2.15

Table 7.3.11 The ranking of species with respect to criteria which reflect their capacity to recover. The weigh of the criteria are shown in parentheses * indicates where species specific information was not available.

		Criteria									
Family	**Species**	**Probabilit y of breeding (3)**		**Maximum size (3)**	**Removal rate (3)**		**Annual fecundity (2)**		**Mortality index (1)**		**Total**
Dasyatididae	*Dasyatis brevicaudatus*	1		1	1	*	1		2		1.08
Pristidae	*Pristis pectinata*	1	*	1	1	*	2		1	*	1.17
Pristidae	*Pristis clavata*	1	*	2	1	*	1	*	1	*	1.25
Myliobatidae	*Aetomylaeus vespertilio*	1	*	2	1	*	1	*	2		1.33
Dasyatididae	*Dasyatis thetidis*	1	*	1	3		1	*	1		1.50
Pristidae	*Pristis zijsron*	1	*	1	3		1	*	1	*	1.50
Dasyatididae	*Taeniura meyeni*	1		1	3		1		1		1.50
Dasyatididae	*Himantura jenkinsii*	1	*	2	2		1	*	1		1.50
Carcharhinidae	*Carcharhinus amboinensis*	1		2	1		2		2		1.50
Carcharhinidae	*Carcharhinus leucas*	1		3	1	*	1		1		1.50
Scyliorhinidae	*Galeus* sp. A	1	*	3	1	*	1	*	1	*	1.50
Narcinidae	*Narcine westraliensis*	1	*	3	1	*	1	*	1	*	1.50
Pristidae	*Pristis microdon*	1	*	3	1	*	1	*	1	*	1.50
Squatinidae	*Squatina* sp. A	1	*	3	1	*	1	*	1	*	1.50
Carcharhinidae	*Prionace glauca*	1	*	2	1	*	3		1	*	1.58
Myliobatidae	*Aetobatus narinari*	1	*	1	3		1		2		1.58
Carcharhinidae	*Carcharhinus limbatus*	1	*	3	1	*	1		2		1.58
Carcharhinidae	*Carcharhinus albimarginatus*	1	*	2	2		2		1	*	1.67
Carcharhinidae	*Carcharhinus brevipinna*	1	*	3	1	*	2		1	*	1.67
Dasyatididae	*Himantura fai*	1	*	2	3		1	*	1	*	1.75
Dasyatididae	*Himantura granulata*	1	*	2	3		1	*	1	*	1.75
Dasyatididae	*Himantura uarnak*	1	*	2	3		1	*	1		1.75
Dasyatididae	*Himantura undulata*	1	*	2	3		1	*	1		1.75
Orectolobidae	*Orectolobus ornatus*	1	*	2	3		1	*	1	*	1.75
Rhynchobatidae	*Rhina ancylostoma*	1	*	2	3		1	*	1		1.75
Rhinobatidae	*Rhinobatos typus*	1	*	2	3		1	*	1		1.75

Table 7.3.11 The ranking of species with respect to criteria which reflect their capacity to recover. The weigh of the criteria are shown in parentheses * indicates where species specific information was not available.

		Criteria					
Family	Species	Probability of breeding (3)	Maximum size (3)	Removal rate (3)	Annual fecundity (2)	Mortality index (1)	Total
Dasyatididae	*Urogymnus asperrimus*	1	2	3	1	1	1.75
Scyliorhinidae	*Atelomycterus fasciatus*	2	2	2	1	1	1.75
Dasyatididae	*Dasyatis* sp. A	2	3	1	1 *	1 *	1.75
Dasyatididae	*Amphotistis annotatus*	2 *	1	3	1 *	2	1.83
Rhynchobatidae	*Rhynchobatus djiddensis*	1	2	3	1 *	2	1.83
Carcharhinidae	*Carcharhinus fitztroyensis*	2	2	2	1	2	1.83
Sphyrnidae	*Sphyrna mokarran*	2	1	3	2 *	1	1.92
Carcharhinidae	*Negaprion acutides*	3	2	1	2	1 *	1.92
Pristidae	*Anoxypristis cuspidata*	1	3	3	1	1 *	2.00
Hemiscylliidae	*Chiloscyllium punctatum*	1 *	3	3	1 *	1	2.00
Hemiscylliidae	*Hemipristis elongatus*	2	2	3	1	1	2.00
Carcharhinidae	*Rhizoprionodon acutus*	1	3	3	1	1	2.00
Stegastomatidae	*Stegastoma fasciatum*	2 *	2	3	1 *	1	2.00
Sphyrnidae	*Sphyrna lewini*	1 *	2	3	2 *	2 *	2.00
Myliobatidae	*Aetomyleus nichofii*	1 *	3	3	1	2	2.08
Carcharhinidae	*Carcharhinus macloti*	2	2	3	1	2	2.08
Carcharhinidae	*Carcharhinus sorrah*	1	3	3	1 *	2	2.08
Dasyatididae	*Pastinachus sephen*	3	1	3	1 *	2	2.08
Carcharhinidae	*Galeocerdo cuvier*	2	1	3	3	2	2.17
Dasyatididae	*Himantura* sp. A	1 *	3	3	1 *	3	2.17
Carcharhinidae	*Carcharhinus tilstoni*	1	3	3	1	3	2.17
Carcharhinidae	*Carcharhinus dussumieri*	3	2	3	1	1	2.25
Dasyatididae	*Dasyatis kuhlii*	2	3	3	1	1 *	2.25
Dasyatididae	*Dasyatis leylandi*	2	3	3	1 *	1 *	2.25
Ginglymostomatidae	*Nebrius ferrugineus*	3	2	3	2	1 *	2.42
Sphyrnidae	*Eusphyra blochii*	2	3	3	2	2	2.50
Gymnuridae	*Gymnura australis*	3	3	3	1	2	2.58
Dasyatididae	*Himantura toshi*	3	3	3	1	2	2.58

Table 7.3.11 The ranking of species with respect to criteria which reflect their capacity to recover. The weigh of the criteria are shown in parentheses * indicates where species specific information was not available.

		Criteria					
Family	**Species**	**Probability of breeding (3)**	**Maximum size (3)**	**Removal rate (3)**	**Annual fecundity (2)**	**Mortality index (1)**	**Total**
Carcharhinidae	*Rhizoprionodon taylori*	3	3	3	1	2	2.58
Hemiscylliidae	*Hemigaleus microstoma*	2	3	3	2	3	2.58

Table 7.3.12 The percentage of species for which the information used to rank them in criteria was species specific.

Axis	Criteria	%
Susceptability	Water column position	100
	Survival	18
	Range	71
	Day/Night catchability	32
	Diet	55
	Depth range	100
Recovery	Probability of breeding	42
	Removal rate	79
	Annual fecundity	52
	Total biomass	88
	Mortality index	64

Table 7.3.13 The correlations between the criteria on each axis, * indicates significance at P < 0.05.

Susceptibility criteria

	Survival	Range	Day/night catchability	Diet	Depth range
Water column position	0.074	-0.178	0.131	0.667*	0.069
Survival		0.477*	0.075	-0.113	-0.004
Range			0.254	0.055	0.088
Day/night catchability				-0.145	0.045
Diet					0.450

Recovery criteria

	Maximum size	Removal rate	Annual fecundity	Mortality index
Probability of breeding	0.065	0.256	0.165	0.078
Maximum size		-0.216	-0.248	0.168
Removal rate			-0.265	0.205
Annual fecundity				0.119

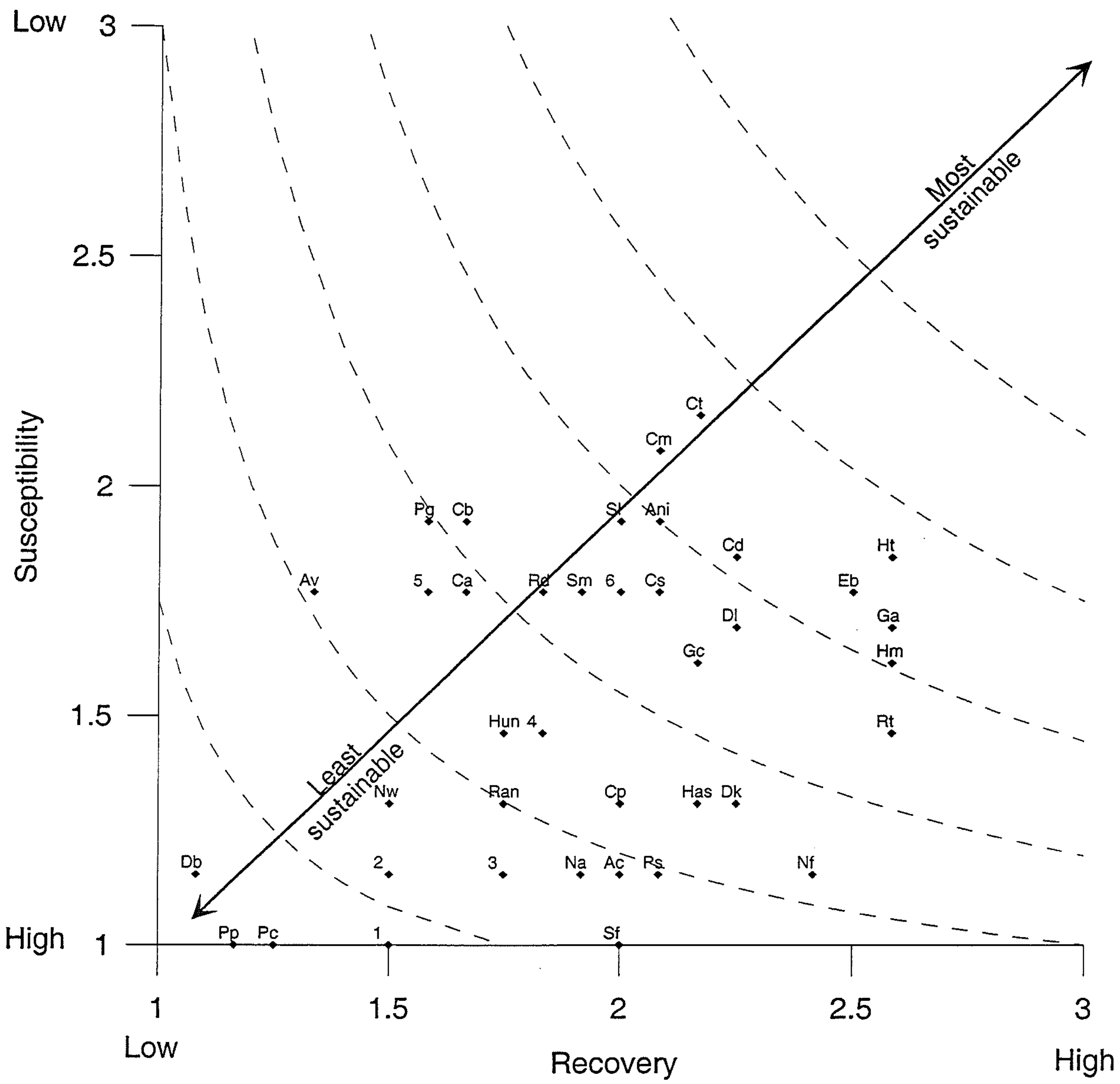


Figure 7.3.6 The ranks of the elasmobranch species with respect to criteria that reflect their susceptibility to capture and mortality from trawling and their capacity to recover. The labelling follows Table 7.3.1, 1 = Hj, Pm and Pz 2 = Ca, Cl, Dt, Gsa, Ssa and Tm, 3 = Af, Dsa, Hf, Hg, Hua, Oo, Rt and Ua, 4 = Cf and Aa, 5 = Ana and Cl, 6 = Rac and He.

Table 7.3.14 The mean, minimum and maximum length of rays and sharks capture nets with a standard codend and with TEDs fitted.

		Length				
Taxa	**Gear**	**mean**	**se**	**n**	**min**	**max**
Rays	Standard codend	329.55	18.53	157	88	1710
	Combined TEDs	285.81	7.41	414	17	1400
	AusTED	335.30	45.65	27	125	1400
	Nordmore Grid	282.20	8.71	244	17	745
	Supershooter	282.63	12.85	143	60	795
Sharks	Standard codend	887.32	59.44	168	210	5000
	Combined TEDs	596.09	12.21	269	175	1800
	AusTED	687.37	41.99	19	370	1000
	Nordmore Grid	599.68	17.71	113	175	915
	Supershooter	580.47	17.91	137	190	1800

Table 7.3.15 The average size of elasmobranch species caught in nets with codends fitted with TEDs and nets with standard codends, also the ANOVA results from the comparison of these nets.

		Length			ANOVA results		
Species	**Codend**	**mean**	**se**	**n**	**F**	**df**	**P**
Carcharhinus dussumeri	Standard	844.38	96.40	60	26.88	1,139	< 0.0001
	TED	489.05	13.79	81			
Rhizoprionodon acutus	Standard	636.89	34.23	45	7.15	1,134	0.0084
	TED	724.18	17.40	91			
Hemigaleus microstoma	Standard	708.91	148.47	23	2.77	1,79	0.0988
	TED	507.97	19.93	58			
Amphotistis annotatus	Standard	206.42	31.14	50	2.97	1,200	0.4395
	TED	169.77	3.40	156			
Himatura toshi	Standard	371	19.37	51	0.60	1,200	0.4395
	TED	351.56	9.71	151			
Rhyncobatus djidensis	Standard	1076.89	125.59	19	20.81	1,41	< 0.0001
	TED	611.63	32.27	24			

Biology and survival

There is very limited biological and ecological information available for most elasmobranch species. Most elasmobranch research focuses on species that are targeted by commercial fisheries. However, the comparatively high cost of elasmobranch research and the generally low value of these fisheries has limited the extent of research. When the Taiwanese pelagic gill net fishery operated in northern Australia, significant research was done on the target species of this fishery, primarily the carcharhinids (Stevens and Wiley, 1986; Lyle, 1987; Davenport and Stevens, 1988; Lavery and Shaklee, 1989; Stevens and Lyle, 1989; Stevens and McLoughlin, 1991; McLoughlin and Stevens, 1994;. However, for most elasmobranch species in the region of the NPF, little information is available.

This study provided valuable biological information on the biology of some rays and also on the within-net survival of elasmobranchs. The estimates of fecundity and size at first maturity (Table 7.3.5) are the first available for most of these species and enable us to determine the proportion of individuals that have bred before they are captured (Table 7.3.6). The estimates of within-net mortality obtained here are the first estimates of survival for elasmobranchs in prawn trawls. Estimates of mortality due to trawling have been previously obtained for some teleosts and invertebrates (Wassenberg and Hill, 1989; Hill and Wassenberg, 1990; 1993) but not elasmobranchs and yet these are vital to determining the mortality due to trawling. The results suggest most elasmobranchs die within the trawl net (56%) and it is primarily the smaller individuals. This pattern was consistent for both sharks and rays (Table 7.3.9). The effect of size is confounded with species differences in survival due to the grouping of data for the analysis. The rhynchobatid *R. djiddensis* had higher survival (90%)

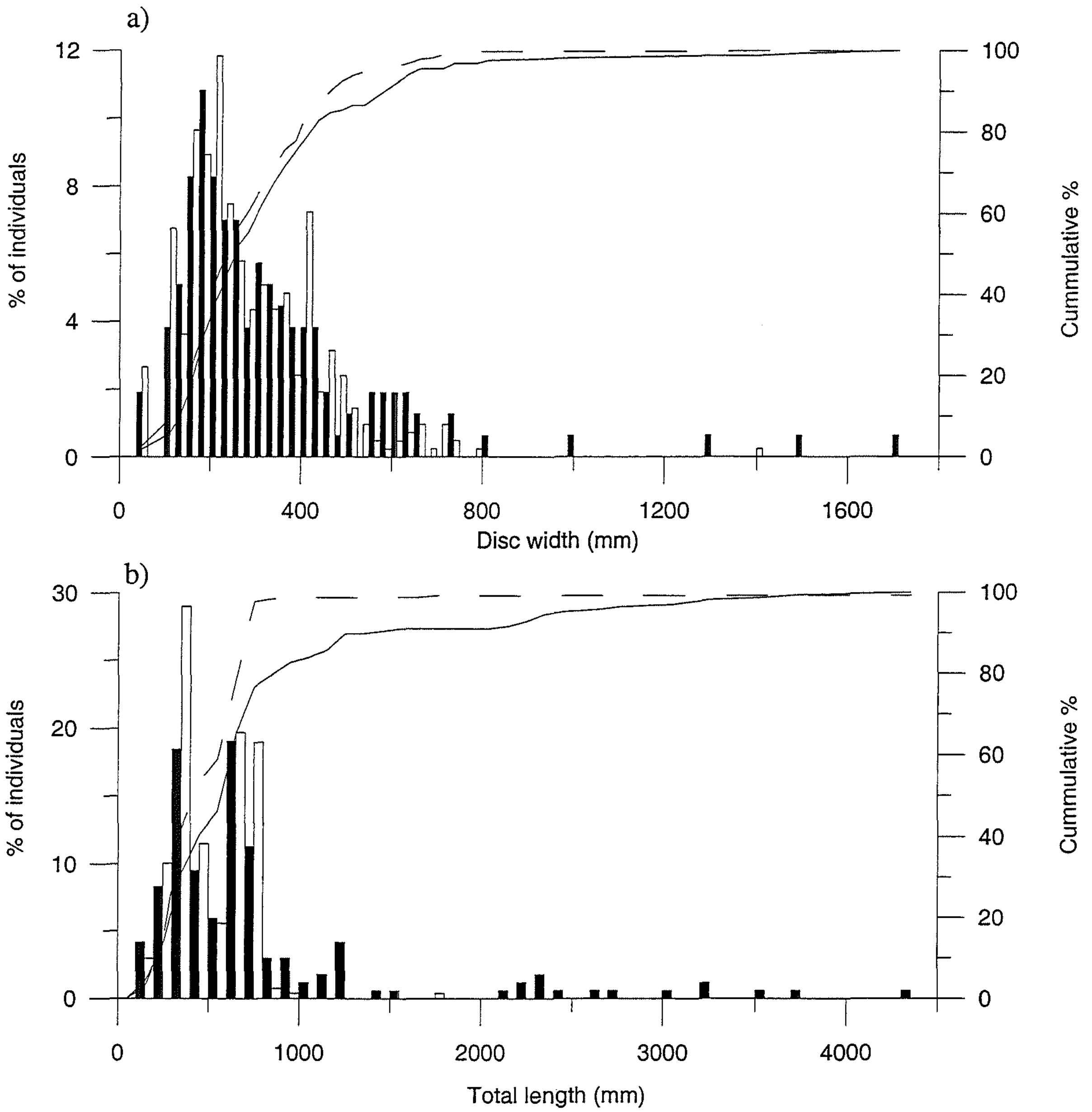


Figure 7.3.7 The length frequency and cummulative frequency of rays (a) and sharks (b) caught in nets with a standard codend (shaded column and solid line) and nets with a TED (unshaded column and broken line).

than most other species, while the lowest was for *C. tilstoni* and *R. acutus* (18%). This may contribute to the fact that *R. djiddensis* appears to have been caught in high numbers in the bycatch for at least a decade (Pender *et al.*, 1992). While the larger elasmobranchs appear to have a higher within-net survival, in the commercial fishery these are the individuals killed for their fins and so their mortality may be much higher. It is important that further research examines the survival of elasmobranch species in the bycatch. This should include determining the survival after release, the present study only examined within-net survival and may therefore, underestimate the mortality. The species specific rates of retention of elasmobranchs as byproduct by the fishery should also be determined as this contributes to mortality.

Assessment of the sustainability of elasmobranch bycatch species

We are therefore, in a situation where we know that in general elasmobranchs are very susceptible to overfishing but where we have limited information on which to determine the impact of their capture in bycatch. Even though they are generally more sensitive to overfishing than teleosts there is likely to be a range of sensitivities among the elasmobranchs species. The process we have applied here examines the different sensitivities of the species and highlights those least likely to be able to sustain capture as bycatch. The use of the criteria maximises what can be determined from the limited data available.

The four species that had the lowest ranks on both axes were *Dasyatis brevicaudatus, Himantura jenknsii, Pristis pectinata, P. clavata, P. microdon and P. zijsron.* (Figure 7.3.6). These species are the least likely to be able to sustain trawling. The pristids and *H. jenkinsii* had ranks of 1 on the susceptibility axis, the lowest possible rank (Table 7.3.10). These species are benthic or demersal and the pristids have restricted depth distributions. Nothing is known about the survival of the four species and so this was assumed to be 1. The diets of these species includes benthic organisms and is likely to include commercial prawns. Their range and day/night catchability is unknown. The combination of these factors means that these species are likely to occur in trawl grounds and they are highly susceptible to capture and mortality due to trawlers. The recovery capacity of populations of these species is also low (Table 7.3.11). These species are rare so no information was available to estimate parameters such as removal rate or the mortality index. These species are all large and therefore, likely to have slower recovery of their population than smaller species.

The species *Pristis pectinata* highlights the potential taxonomic difficulties associated with highly diverse, tropical elasmobranch faunas. This species has been recorded in bycatch in the Gulf of Carpentaria, but not in the present study and no specimans have been retained for verification of the identification due to their size. However, at this stage it is not possible to exclude the species from the analysis.

In comparison the species that ranked highest on both axes (Figure 7.3.6) were *H. toshi, C. dussumeri, C. tilstoni, Eusphyra blochii, Gymnura australis* and *Hemigaleus microstoma,* these species are more likely to be able to sustain capture in bycatch. These species had a lower susceptibility to capture and mortality due to trawling (Table 7.3.10). The four species were widely distributed across the area of the fishery and their depth distributions are broad. Their catch rates were similar between day and night, or higher during the day. This provides some refuge from the night-time commercial trawling. The data available suggests that the recovery capacity of these species is higher than most (Table 7.3.11). Individuals of these species are likely to have bred before capture and they are smaller species. The estimates of their removal rates were low. However, all species had low annual fecundities.

This assessment of the elasmobranch bycatch species is an important first step in ensuring their sustainability in bycatch. Such an assessment has never been undertaken at this scale. The only comparable work is that of Smith *et al.* (1998), where they compared the intrinsic rebound potential, or recovery capacity, of 26 Pacific sharks. Their motivation was similar to that behind the present study. They wanted to provide an assessment of the relative vulnerability to harvest of a broad range of shark species, in order to guide management and research. Their research produced valuable results and the approach is worth extending to more species but the focus was more general than this study. The assessment provided here, focuses on the vulnerability of species to bycatch in a particular fishery and takes into account not only the recovery capacity of species but also their susceptibility to the fishery.

Management implications

The assessment provided here should be used as a first step in prioritising management and research focused on the elasmobranch species. The current ranking is constrained by the available data and assumptions outlined in Section 7.2.2. The application of this process has highlighted important information gaps. Research should be focused on these gaps and the high priority species. It is clear that we do not understand enough about the basic biology and ecology of many of the species, particularly the rays and sawfishes. For many of the sharks species studies within Australia or overseas provide the necessary biological information for assessing their sustainability. However, for most rays and sawfishes this is not the case. Parameters such as the age at maturity, longevity and fecundity are fundamental for determining the sustainability of elasmobranch species and yet most are unknown. The work by Smith *et al.* (1998) showed that the rebound potential of species was most sensitive to the age at first maturity. It is important, therefore, that these biological parameters are investigated.

Research into the movement and distribution of species and stocks is also fundamental for determining the impact of trawling on populations. The NPF managed area may contain several distinct stocks of some of the less mobile species, such as the small rays, or it may contain only a part of a stock of some of the more mobile species, the large pelagic sharks. There is some information available on the movement of Carcharhinid species (Stevens and Church, 1984), but for most species their stock structure and movements are unknown. For many, particularly the rays, very little is known world wide. The movement patterns and distribution of species will influence the proportion of the population that is impacted by the fishery and the extent of spatial refuges available to them. In conjunction with this, it is important that we identify critical habitats for the species. This would include determining whether there are any distinct nursery grounds for species that are impacted by trawling. It was clear from the size range caught that individuals from some species were caught soon after birth (Table 7.3.6). The juveniles of elasmobranchs are assumed to have relatively high survival and so impacts on this stage could have significant implications on the populations capacity to sustain trawling.

More robust estimates of the removal rate of elasmobranchs by the fishery are also important to obtain. This will enable any changes over time to be observed, which could signal potential problems. However, this is not a trivial exercise, due to the difficulties in identifying elasmobranch species and the rarity of most species.

It is also important that the assessment of the sustainability of elasmobranch species is extended to include the impact of other fisheries in the region. There are gillnet fisheries targeting sharks in the region as well as coastal barramundi gillnetters that catch elasmobranchs as bycatch. As elasmobranch species may have a wide range and their populations could be impacted by several fisheries resulting in an unsustainable impact overall. We therefore should address the question of elasmobranch sustainability at a larger regional scale. However, it is important that the NPF participate in this, due to the broad geographic scale of the fishery.

The results of this process are aimed to assist in the focus of management. The high priority species should be a management priority. Management intervention may include the use of exclusion devices (TEDs and BRDs), closures or further limits on retaining shark product. The introduction of TEDs and BRDs in 2000 is likely to affect catch rates of elasmobranchs. TEDs have the potential to exclude large individuals. However, the majority of elasmobranchs caught are < 1000 mm (Figure 7.3.7) and may go through TEDs. The effectiveness of TEDs will depend on configuration of the TED (particularly the width between the bars) and the size and shape of species. *Rhynchobatus djiddensis,* a large, broad species, appeared to be excluded well by TEDs (Figure 7.3.9). In comparison the smaller rays or small, slim sharks weren't excluded well (Figures 7.3.8 and 7.3.9). Once the TEDs are introduced to the fishery it is important that the species specific exclusion is monitored. Juveniles of many elasmobranch species are still likely to be captured and this could potentially have a large impact on their populations. The TEDs are also unlikely to be effective for pristids, that usually get their saw tangled in the net or TED. Species or life stages for which exclusion devices are not effective require different management strategies, such as closures or further limits on retained shark products.

The issue of elasmobranch bycatch is one of increasing concern worldwide, due to the susceptibility of the group to overfishing. The process undertaken in this project has highlighted the fact that in the NPF there are many elasmobranch species that are highly susceptible to capture and mortality due to trawling and their recovery capacity is low. The process also highlights the limited information available for making this assessment. The likely sustainability of many species appears low given the available information and some species may be seriously threatened. It is important that further research focuses on elasmobranchs but that it takes a larger regional perspective so that their sustainability is ensured.

7.3.5 Conclusions

- Sixty-one species have been recorded in the bycatch of the NPF.
- The ranking of species with respect to their susceptibility to capture and mortality due to trawling and their capacity to recover after depletion suggests that the Pristidae and some Dasyatidae species should be high priority for research and management. These are the least likely to be able to sustain capture as bycatch. These species are bottom dwellers, feeding on benthic organisms. This makes them highly susceptible to capture in prawn trawling and their recovery capacity of these species is also low based on the criteria applied here.
- Research focusing on the species least likely to be sustainable is vital to ensure their sustainability. We need to know more about the basic biology of these species as well as their distribution, movement patterns and stock structure.
- The introduction of compulsory TEDs and BRDs in 2000 should result in the exclusion of large individuals but the majority of individuals caught are < 1000 mm and the exclusion of these may be limited. It is important that the species specific exclusion by TEDs and BRDs is monitored so that we can determine what species are not excluded and the impact of this.

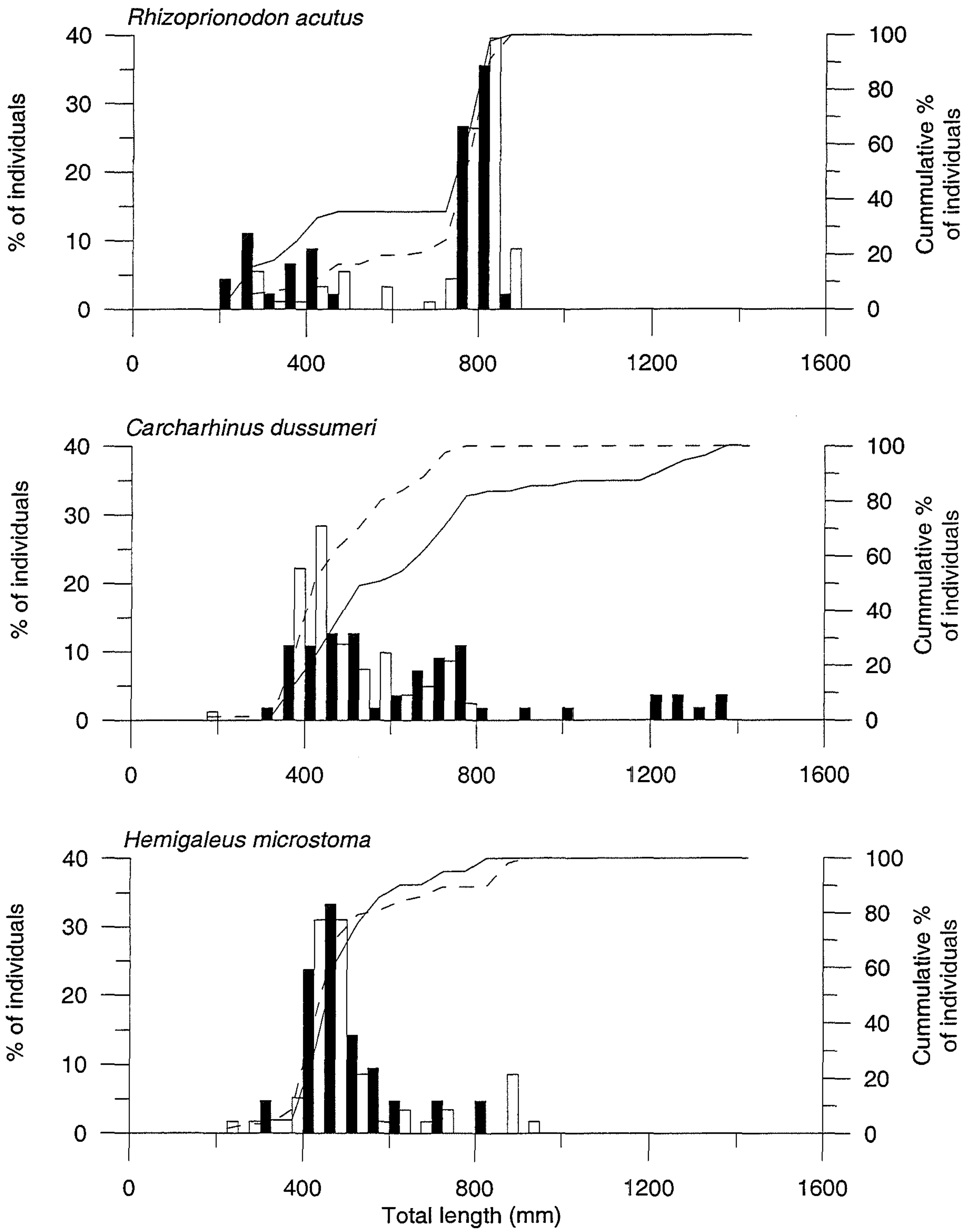


Figure 7.3.8 The length frequency and cumulative frequency of shark species caught in nets with a standard codend (shaded columns and solid line) and nets with a TED (open columns and dashed line).

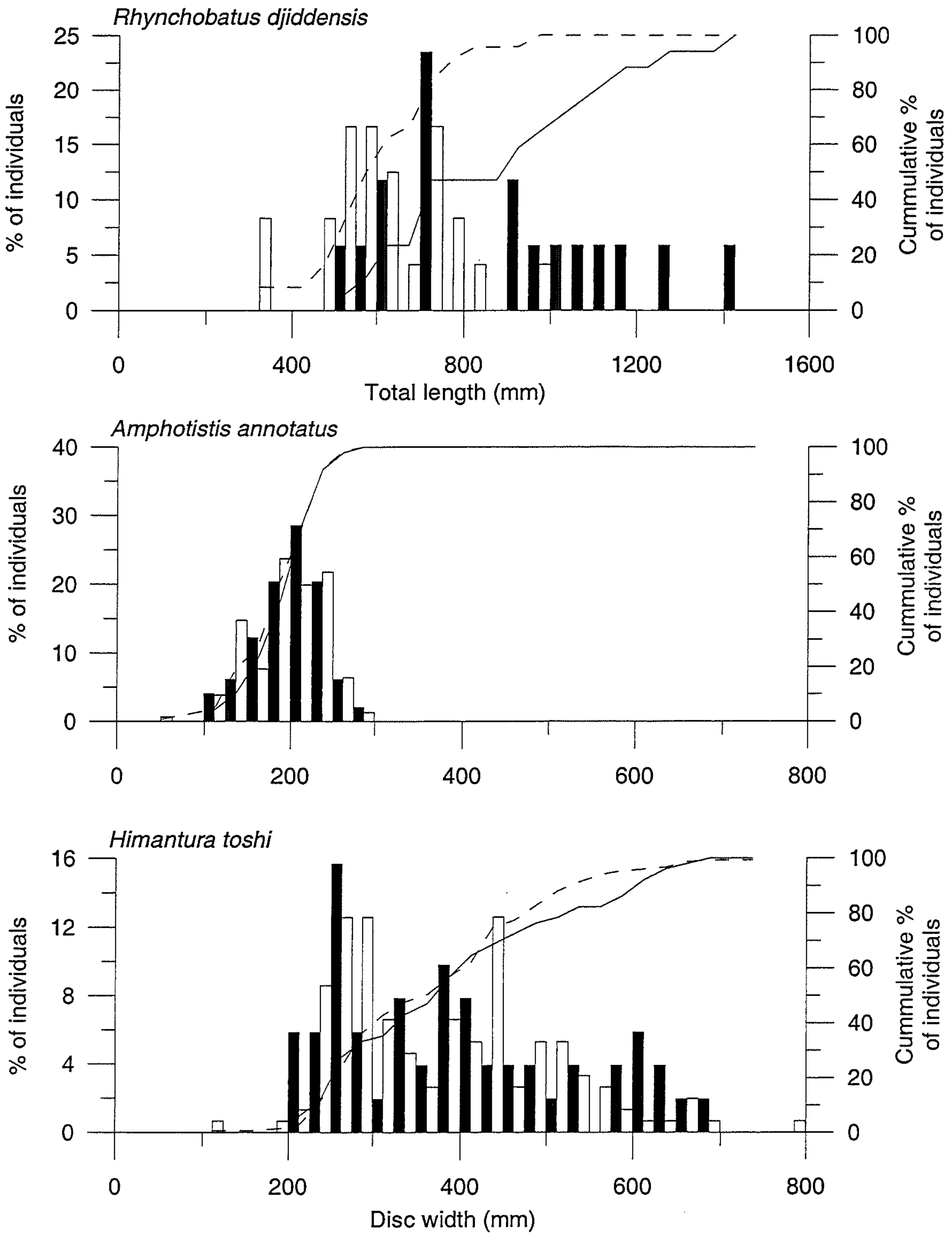


Figure 7.3.9 The length frequency and cumulative frequency of ray species caught in nets with a standard codend (shaded columns and solid line) and nets with a TED (open columns and dashed line).

References

Bass, A.J., D'Aubrey, J.D., Kistnasamy, N., 1973. Sharks of the east coast of southern Africa. I. the genus Carcharhinus (Charcharhinidae). Oceanographic Research Insitute Investigation Report No. 33.

Brewer, D.T., Rawlinson, N., Eayrs, S., Burridge, C., 1998. An assessment of bycatch reduction devices in a tropical Australian prawn trawl fishery. Fish. Res. 36, 195-215.

Calliet, G.M, Martion, L.K., Kusher, D., Wolf, Pl, Welden, B.A., 1983a. Techniques for enhancing vertebral bands in age estimation of California elasmobranchs. In Prince, E.D., Pulos, L.M. (eds) Proceedings of the International Workshop on age determination of oceanic pelagic fishes: tuna, billfishes and sharks. NOAA Tech. Rep. NMFS 8, 157-165.

Calliet, G.M, Martion, L.K., Kusher, D., Wolf, Pl, Welden, B.A., 1983b. Preliminary studies on the age and growth of blue, *Prionace glauca*, common thresher, *Alopias vulpinus,* and shortfin mako, *Isurus oxyrinchus*, sharks from California waters. In Prince, E.D., Pulos, L.M. (eds) Proceedings of the International Workshop on age determination of oceanic pelagic fishes: tuna, billfishes and sharks. NOAA Tech. Rep. NMFS 8, 179-188.

Casey, J.G., Natanson, L.J., 1992. Revised estimates of age and growth of the sandbar shark (*Carcharhinus plumbeus*) from the western north Atlantic. Can. J. Fish. Aquat. Sci. 49, 1474-1477.

Casey, J.G., Pratt, H.L., Stillwell, C.E., 1983. Age and growth of the sandbar shark, *Carcharhinus plumbeus*, from the western north Atlantic. In Prince, E.D., Pulos, L.M. (eds) Proceedings of the International Workshop on age determination of oceanic pelagic fishes: tuna, billfishes and sharks. NOAA Tech. Rep. NMFS 8, 189-191.

Casey, J.G., Pratt, H.L., Stillwell, C.E., 1985. Age and growth of the sandbar shark *Carcharhinus plumbeus*, from the western north Atlantic. Can. J. Fish. Aquat. Sci. 42, 963-975.

Davenport, S., Stevens, J.D., 1988. Age and growth of two commercially important sharks (*Carcharhinus tilstoni* and *C. sorrah*) from northern Australia. Aust. J. Mar. Freshwat. Res. 39, 417-433.

FishBase, 1997. FishBase 97 CD-ROM. ICLARM. Manila.

Gruber, S.H., Stout, R.G., 1983. Biological materials for the study of age and growth in a tropical marine elasmobranch, the lemon shark, Negaprion brevirostris (Poey). In Prince, E.D., Pulos, L.M. (eds) Proceedings of the International Workshop on age determination of oceanic pelagic fishes: tuna, billfishes and sharks. NOAA Tech. Rep. NMFS 8, 193-205.

Hill, B.J., Wassenber, T.J., 1990. Fate of discards from prawn trawlers in Torres Strait. Aust. J. Mar. Freshwat. Res. 41, 53-61.

Hill, B.J., Wassenber, T.J., 1993. The fate of material discarded from shrimp trawlers. In, International Conference on Shrimp Bycatch, Florida, USA, pp 115-122.

Hueter, R.E., 1998. Science and management of shark fisheries – Introduction. Fish. Res. 39, 105.

Last, P.R., Stevens, J.D., 1994. Sharks and rays of Australia, CSIRO Australia.

Lavery, S., Shaklee, J.B., 1989. Population genetics of two tropical sharks, Carcharhinus tilstoni and C. sorrah, in northern Australia. Aust. J. Mar. Freshwat. Res. 40, 541-557.

Lyle, J.M., 1987. Observations on the biology of Carcharhinus cautus (Whitley), C. melanopterus (Quoy and Gaimard) and C. fitzroyensis (Whitley) from northern Australia. Aust. J. Mar. Freshwat. Res. 38, 701-710.

McLoughlin, K.J., Stevens, J.D., 1994. Gill-net mesh selectivities for two species of commercial carcharhinid shark taken in northern Australia. Aust. J. Mar. Freshwat. Res. 45, 521-534.

Musick, J.A., Branstetter, S., Colvocoresses, J.A., 1993. Trends in shark abundance from 1974 to 1991 for the Chesapeake Bight region of the U.S. Mid-Atlantic coast. In S. Branstette, (ed) Conservation Biology of Elasmobranchs. NOAA Tech. Rep. NMFS 115, 1-18.

Natanson, L.J., Casey, J.G., Kohler, N.E., Colket, T., 1998. Groth of the tiger shark, *Galeocerdo cuvier*, in the western north Atlantic based on tag returns and length frequencies; and a note on the effects of taggin. Fish. Bull. 97, 944-953.

Pender, P.J., Willing, R.S., Ramm, D.C., 1992. Northern prawn fishery bycatch study: distribution, abundance, size and use of bycatch from the mixed species fishery. Fishery Report No. 26.

Pratt, H.L., Casey, J.G., 1983. Age and growth of the shortfin mako, *Isurus oxyrinchus*. In Prince, E.D., Pulos, L.M. (eds) Proceedings of the International Workshop on age determination of oceanic pelagic fishes: tuna, billfishes and sharks. NOAA Tech. Rep. NMFS 8, 175-177.

Roberts, C.M., Hawkins, J.P., 1999. Extinction risk in the sea. Trends Envir. Ecol. 14, 241-246.

Sant, G., Hayes, E., 1996. The Oceania region's harvest, trade and management of sharks and other cartilaginous fish. An overview. TRAFFIC International, Cambridge.

Schwartz, F.J. 1983. Shark ageing methods and age estimation of scalloped hammerhead, *Sphyrna lewini*, and dusky, *Carcharhinus obscurus*, sharks based on vertebral ring counts. In Prince, E.D., Pulos, L.M. (eds) Proceedings of the International Workshop on age determination of oceanic pelagic fishes: tuna, billfishes and sharks. NOAA Tech. Rep. NMFS 8, 167-173.

SAS, 1997. SAS Institute Inc., SAS/STAT Software; Changes and Enhancement through release 6.12. Cary, N.C.; SAS Inst. Inc., 1997.

Smith, S.E., Au, D.W., Show, C., 1998. Intrinsic rebound potentials of 26 species of Pacific sharks. Mar. Freshwat. Res. 49, 663-678.

Sokal, R.R., Rohlf, F.J., 1996. Introduction to biostatistics, 2nd editition. Freeman and Company, New York.

Somers, I, 1994. No resources, no fishery, prawns and their habitat. In, Pownall, P.C. (Ed.), Australia's Northern Prawn Fishery. NPF25, Cleveland, Australia, pp. 49-65.

Stevens, J.D., Church, A.G., 1984. Northern tagging project yields interesting results. Aust. Fish. 43, 6-11.

Stevens, J.D., Lyle, J.M., 1989. Biology of three hammerhead sharks (*Eusphyra blochii, Sphyrna mokarran* and *S. lewini*) from northern Australia. Aust. J. Mar. Freshwat. Res. 40, 129-146.

Stevens, J.D., McLoughlin, K.J., 1991. Distribution, size and sex composition, reproductive biology and diet of sharks from northern Australia. Aust. J. Mar. Freshwat. Res. 42, 151-199.

Stevens, J.D., Wiley, P.D., 1986. Biology of two commercially important carcharhinid sharks from northern Australia. Aust. J. Mar. Freshwat. Res. 37, 671-688.

Walker, T.I., 1998. Can shark resources be harvested sustainably? A question revisited with a review of shark fisheries. Mar. Freshwat. Res. 49, 553-572.

Wassenberg, T.J., Hill, B.J., 1989. The effect of trawling and subsequent handling on the survival rates of the bycatch of prawn trawlers in Moreton Bay, Australia. Fish. Res. 7, 99-110.

7.4 Sustainability of sea snake bycatch

7.4.1 Introduction

Northern Australia has at least 30 species of sea snakes of which approximately 50% are endemic. Sea snakes are not listed by the Convention on International Trade on Endangered Species of Wild Fauna and Flora (CITES), (ANCA 1994). However, they are listed as protected animals (Schedule 1 of the National Parks and Wildlife Regulations, 1994). Sea snakes are reptiles and are very different biologically from fish. Sea snakes breathe air into lungs while fish use gills. The habitats of many sea snake species coincide with the Kimberley Prawn Fishery, the NPF, the TSPF and the QECTF and at least 18 species are caught in Australian prawn trawl catches (Wassenberg *et al.* 1994; Ward a, b, 1996).

During 1991, it was estimated that between 100,000 and 150,000 sea snakes were caught by prawn trawlers in the Gulf of Carpentaria region of the NPF and that 33% of these died (Wassenberg *et al.*, 1994). Other studies have estimated that this mortality may be as high as 42% (Heatwole and Burns, 1987).

Most previous studies of sea snakes in Australia focussed on distribution patterns (Shuntov, 1971; Heatwole, 1975a; Redfield *et al.*, 1978; Dunson, 1975; Wassenberg *et al.*, 1994; Ward, 1996 a, b). Consequently, there is insufficient biological information available on which to evaluate the long-term sustainability of sea snake populations on trawl grounds. The little data available on the life history characteristics of many Australian species of sea snake are summarised in Greer (1997), but no detailed life history data are published for the Australian species caught by trawlers.

The main issues for the study of sea snakes in trawler bycatch are: (1) the proportion of the population of each species that is caught, (2) the proportion of those caught that survive and (3) the long term sustainability of sea snakes in and out of trawl grounds.

7.4.2 Sea snake survival

7.4.2.1 Introduction

In order to estimate the impact of capture in trawls on sea snake populations, we must have a measure of the mortality this causes. Survival of sea snakes may vary among species with the duration of the trawl, the time when the snakes enter the net, the treatment they receive on the boat and their condition when they are discarded back to the sea. The duration of commercial trawls in northern Australia varies from about 15 min to >300 min but generally is about 3 h (Unpublished commercial logbook data, AFMA). The survival of sea snakes might be expected on average to be greater in short hauls than in longer duration hauls.

The specific objectives of this section were to:

- measure the proportion of snakes that are dead when landed on deck,
- estimate the longer term mortality of sea snakes after they are discarded alive
- quantify the damage and injuries to sea snakes from trawling
- provide an estimate of the total number of sea snakes killed by trawling.

7.4.2.2 Methods

Study areas

Sea snakes were caught in research and commercial prawn trawls and research fish trawls in the prawn fishing grounds of northern and eastern Australia

Within net mortality

Data on within net mortality of sea snakes in trawls was collected on research vessels, by scientific observers and crew-member observers.

Research surveys

Sea snakes were caught aboard research and commercial vessels on the following cruises:

- Five cruises on the *RV Southern Surveyor* in the Gulf of Carpentaria in the NPF between 1995 and 1998 using prawn trawls - 111 days, see Section 6.2.2).
- One cruise by the *RV Southern Surveyor* to the north west shelf of Australia in August 1995 using a McKenna wing trawl for fish – 108 daytime trawls of mostly 30 min duration, - (see CSIRO, 1995).
- Scientific observers were placed on commercial boats in the NPF (during 1996 to 1997 - 55 days, see Section 6.2.2).
- Scientific observers on Queensland Banana Prawn Fishery (63 days, see Section 6.1.2). The data collected by scientists from research surveys and commercial boats were kept in one data set. Research trawls were mostly of 30 min duration.

In order to measure within net mortality (those arriving dead on deck) from trawls, scientific observers recorded whether the snake was alive or dead, the identity of each species, its length (snout to vent) and weight, the duration of the trawl and the total weight of the catch, if possible. On research vessels, the total trawl catch was weighed on electronic scales. On commercial boats, load cells were used or estimates of the weight of the catch were recorded (see Sections 6.1.2 Queensland Banana Prawn Fishery and 6.2.2 NPF).

Crew-member observers

Crew-member observers (26 volunteers) collected data on the survival of sea snakes from commercial trawl catches from areas within the NPF. Crew-member observers were trained to make simple taxonomic identifications in the field and record data. Data were collected from August to November 1998 from 26 boats – a total of 465 boat days. All observers identified species (to the best of their ability), recorded whether the snakes were alive or dead and the duration of the tow. To minimise the handling of live poisonous snakes, few snakes were measured and the sex of the snakes was not collected. None of the length data were used in the analysis.

Data analysis

The length and weight of each animal, the catch weight and the duration of the trawl are factors that might affect the survival of the sea snakes. In order to test for a relationship between these factors and within net mortality, we used Proc. Logistic (SAS, 1997) to perform a logistic regression on the binary data (dead or alive), collected by scientists. The logistic regression was performed on all species combined and separately on two species (*Hydrophis elegans* and *Lapemis hardwickii*) that were present in sufficient numbers. We also tested for a correlation between the catch weight ($\log_{10}$) and trawl duration.

Long-term Survival

Survival experiments were done on the FRV '*Southern Surveyor*' which provided a stable platform with safe working space. In order to simulate the snakes being returned to the sea, they were held individually, or two at a time, in a 200 litre plastic drum with continually exchanging ambient temperature seawater. A previous study had shown that four days was sufficient for estimating survival of discarded fish and invertebrate bycatch species (Wassenberg and Hill, 1993). Live sea snakes were immediately removed from the catch, identified and placed into a drum. No food was eaten by the snakes during the four day experiment.

Sea snakes were observed after 1 hour, 6, 12, and 24 h then once every 24 h for up to 4 days. Dead sea snakes and those that survived after four days were measured (snout-vent length), weighed and either retained for biological samples or released alive. Due to space limitations and the long observation period, only a restricted number of animals could be tested.

The sea snake data were analysed in three groups. The two species for which we had sufficient data were analysed individually: *Hydrophis ornatus* (17 animals), *Hydrophis elegans* (16 animals). The remaining rarer species (34 animals, 9 species) were analysed as a group.

Curves relating the probability of survival to the elapsed time since being placed in a tank were fitted to the data. This was done for *H. ornatus* and the mixed group, but not for *H. elegans*, as only one out of 17 died in the tank. An exponential decay function was assumed for the survival curve:

$$P = \exp(-t/\lambda) \qquad (1)$$

where P is the survival of a snake for t hours and λ is the time beyond which only about one in three animals is expected to survive ($\lambda \log(2)$ = half life of captured sea snakes).

Maximum likelihood was used to estimate λ. As the time interval within which a given snake died was known, but the exact time of death was not, the time of death is interval censored. The likelihood function was as follows:

$$L = \prod_{i=1}^{n} \left\{ \exp(-t_{1,i}/\lambda) - \exp(-t_{2,i}/\lambda) \right\} \qquad (2)$$

where i represented the animal, n represented the total number of animals, $t_{1,i}$ the last time at which the ith animal was observed alive and $t_{2,i}$ the first time at which the ith animal was observed dead. For those animals that survived to 96 hours, the right-hand term was set to zero (this had the effect of regarding $t_{2,i}$ as an infinitely large value). The maximum likelihood estimate of λ ($\hat{\lambda}$) was obtained by evaluating the logarithm of the likelihood function for a wide range of values of λ, at intervals of 0.1 hours, and selecting the value of λ that maximised the function. A plot of the log-likelihood confirms the choice. A confidence interval for λ was constructed by choosing those values of λ for which twice the difference between the log-likelihood and the maximum log-likelihood was 3.841 (the 95th percentile of the χ_1^2 distribution). The estimated survival curve was then evaluated using $\hat{\lambda}$. Curves corresponding to the 95% confidence limits were also evaluated. The three curves were superimposed on a plot of the observed percentage of snakes surviving to each time of observation.

It was clear that the sea snakes that survived the full 96 hours in the tank have a strong influence on the estimate of λ, resulting in an estimate much greater than 96 hours. The survival curve then appears to fit the data poorly. Therefore the data were re-analysed using only those snakes that died while in the tank. The same statistical approach was used for estimating λ and its confidence interval. However, the predicted survival curve for all the snakes was constructed as follows:

$$P = \hat{\pi} + \exp(-t/\hat{\lambda})*(1-\hat{\pi}) \qquad (3)$$

where P is the survival of a snake for t hours and $\hat{\pi}$ is the proportion of all snakes that survived for at least 96 hours and $\hat{\lambda}$ is the maximum likelihood estimate of λ.

Damage assessment

Not all sea snakes caught were retained for damage assessment and biological information. During early research cruises, all live snakes were released. Biological information was obtained by retaining all snakes from the 1997 and 1998 NPF research surveys and scientific observer and Queensland Banana Prawn Fishery scientific observer cruises. No snakes were kept by the crew-member observers. The sea snakes were frozen on board the vessels and sent to CSIRO Marine Laboratories, Cleveland, where they were dissected for information on injuries sustained, and life history parameters (Section 8.3.2). Any external damage (cuts, bruises, punctures or skin loss) to the head, mid-body or tail of sea snakes was recorded during the biological autopsies.

7.4.2.3 Results

Within net mortality

Of 571 sea snakes collected by scientists on research and commercial cruises, 19.4% were dead on arrival on the trawler (Table 7.4.2.1). In research trawls, the percentage of each species killed was relatively similar for the three most abundant species (*Hydrophis ornatus*, 21%; *H. elegans*, 23% and *Lapemis hardwickii*, 22%). *Disteira kingii* (36%) showed the highest percentage dead, but the sample size is small (n = 11).

About 28% of the 1080 sea snakes collected by crew-member observers in the NPF were dead. They recorded higher percentages of deaths than were recorded on research vessels for most of the species; particularly *H. elegans* (33%), *L. hardwickii* (52%) and *Astrotia stokesii* (44%). About 30% of the unidentified species died.

Of the 76 sea snakes caught in research fish trawls only 4% were dead on arrival on deck. Of all the snakes caught by both prawn and fish trawlers, about 24% were dead when the catch was landed on the deck.

The duration of the trawl and catch weight appear to affect the within net mortality of sea snakes (Table 7.4.2.2). Low mortalities (3%) were recorded by scientists for trawls ≤ 30 min. Mortalities ranged from 3% to 29% when all

Table 7.4.2.1 Within net mortality of sea snakes caught in prawn and research fish trawls in northern and eastern Australia during 1995-1998. The sea snakes listed under the crew-member observers have not had the taxonomy confirmed.

Species	**Research surveys and scientific observers**		**Crew-member observers**		**Research surveys**	
	Prawn trawls				**Fish trawls**	
	No caught	**%dead**	**No caught**	**%dead**	**No caught**	**%dead**
Aipysurus sp	-	-	8	12	-	-
Aipysurus apraefrontalis	-	-	-	-	1	-
Aipysurus duboisii	17	0	-	-	16	0
Aipysurus eydouxii	19	0	-	-	1	0
Aipysurus leavis	8	0	33	24	10	0
Acalyptophis peronii	9	0	35	11	8	0
Astrotia stokesii	9	0	16	44	1	0
Disteira kingii	10	36	-	-	3	0
Disteira major	18	0	44	18	2	0
Enhydrina shistosa	1	0	1	0	-	-
Emydocephalus annulatus	-	-	-	-	2	0
Hydrophis elegans	140	23	211	33	3	0
Hydrophis czeblukovi	-	-	-	-	1	0
Hydrophis mcdowelli	-	-	37	3	2	50
Hydrophis ornatus	28	21	67	18	26	4
Lapemis hardwickii	312	22	21	52	-	-
Unidentified sea snakes	-	-	607	30	-	-
Totals	571	19.4%	1080	28%	76	4%

trawls between 30 min and 180 min were considered. Trawls longer than 180 min resulted in up to 75% of sea snakes dying.

Within net mortalities for trawls ≤ 30 min duration on commercial NPF vessels were 26% (Table 7.4.2.2). When all commercial trawls longer than 30 min, but no more than 180 min were considered, mortalities ranged from 9% to 32%. In commercial trawls greater than 180 min mortalities ranged from 20% to 59%.

Table 7.4.2.2 Within net mortality of sea snakes caught in trawls of different duration in major fishing regions of northern and eastern Australia during 1995-1998.

Trawl Duration (min)	Research surveys and scientific observers			Crew-member observers	
	No caught	%dead	No. trawls	No caught	%dead
0 - 30	189	6	183	19	26
31 - 60	22	23	18	11	9
61 - 90	35	9	14	12	0
91 - 120	126	28	44	30	20
121 - 150	155	15	63	92	20
151 - 180	96	29	33	88	32
181 - 210	24	75	6	228	32
211 - 240	3	0	2	276	20
241 – 270	-	-	-	212	34
271 - 300	-	-	-	54	59
>300	-	-	-	58	22
Totals	650	17.6%	363	1080	28%

Both duration of the trawl and catch weight had significant (P <0.001) positive effects on within net mortality of all sea snake species combined (scientific observer data) (Table 7.4.2.3). It is evident that more snakes died when caught in either heavier catches or in longer trawls (Table 7.4.2.4). The level of significance for duration and catch weight did not change when we increased sample size by deleting length and weight of sea snakes.

The logistic regression analysis on *Hydrophis elegans* showed that trawl duration, catch weight and the length of *H. elegans* were significant (P<0.01) positive factors contributing to this species dying (Tables 7.4.2.5 and 7.4.2.6). In contrast, mortality of *Lapemis hardwickii* was not related to snake length, but trawl duration and catch weight were significant ((P < 0.05, Table 7.4.7).

Both *H. elegans* and *L. hardwickii* showed higher mortality in the NPF (Table 7.4.2.8). For *L. hardwickii,* up to 52% caught in the NPF died, 25.6% off Townsville and 44.6% off Bundaberg. Up to 16% of *H. elegans* caught in the QECTF died while up to 37% died in the NPF (Table 7.4.2.8). Over all fisheries studied nearly 30% of *Hydrophis elegans* and 25% of *Lapemis hardwickii* caught arrived dead on deck.

Table 7.4.2.3 Significance of terms for duration and catch weight in a logistic model fitted to survival data for sea snakes collected by scientific observers in northern and eastern Australia.

Variable	Estimate	se	P – value (χ^2 on 1df)
Intercept	-4.2787	0.4577	0.0001
Duration (h)	0.0201	0.00306	0.0001
Catch weight (kg)	0.00401	0.000807	0.0001

Table 7.4.2.4 The trawl duration and catch weight for all snake species combined, separated for those sea snakes that are alive and those that are dead on data collected on research surveys and scientific observers in northern and eastern Australia.

Status	Catch weight (kg)		Trawl Duration min	
	mean	se	mean	se
Alive	93.36	5.26	92.39	2.38
Dead	140.84	14.83	133.69	4.05

Table 7.4.2.5 Significance of terms for duration, catch weight, length and weight of snakes in a logistic model fitted to survival data for *Hydrophis elegans* collected by scientific observers in northern and eastern Australia. (n = 92 alive, 27 dead, where all variables were available).

Variable	Estimate	se	*P* – value (χ^2 on 1df)
Intercept	-5.3251	0.8531	0.0001
Duration (h)	0.0036	0.0071	0.6076
Catch-weight (kg)	0.00452	0.00149	0.0024
Length (mm)	0.00426	0.00164	0.0096
Weight (kg)	-2.0311	1.0925	0.0630

Table 7.4.2.6 Catch statistics for trawl duration and catch weight and length for all *Hydrophis elegans*, separated for those sea snakes that were alive and those that were dead.

Status	Catch weight (kg)		Trawl Duration (min)		Snake length (mm)	
	mean	se	mean	se	mean	se
Alive	103.2	12.57	101.66	4.94	1279.6	33.63
Dead	254.9	35.67	117.2	5.96	1433.7	46.63

Table 7.4.2.7 Significance of terms for duration, catch weight, length and weight of snakes in a logistic model fitted to survival data for *Lapemis hardwickii* collected by scientific observers in northern and eastern Australia. (n = 311 alive, 68 dead).

Variable	Estimate	se	*P* – value (χ^2 on 1df)
Intercept	-5.3251	0.8531	0.0001
Duration (h)	0.0271	0.00547	0.0001
Catch-weight (kg)	0.00347	0.00152	0.014
Length (mm)	-0.00067	0.00157	0.6703

Table 7.4.2.8 Within net mortality of two common sea snakes caught in prawn trawls in all major fishing regions of northern and eastern Australia during 1995-1998 based on data collected by scientists and crew-member observers.

Region	*Hydrophis elegans*		*Lapemis hardwickii*	
	No. caught	% dead	No. caught	% dead
Bundaberg	24	4	56	45
Gladstone	2	0	2	0
Mackay	17	12	76	4
Townsville	25	16	152	26
Gulf of Carpentaria	72	34	26	23
Whole NPF by crew member	211	33	21	52
Totals	351	(29%)	333	(25%)

Long-term survival

The long-term survival of a total of 67 sea snakes (11 species) was observed over four days after capture (Table 7.4.2.9). Of the 51 sea snakes caught by prawn trawls, twelve died (23.5%). Five of these died within the first hour, one died within each of 6 h, 12 h, 24 h, 36 h, 48 h and two within 72 h. Eight of the 16 sea snakes tested from fish trawls died, four within 12 h and three within 24 h and one within 72 h of being captured. Only two species were caught in sufficient numbers to be tested separately (*Hydrophis ornatus* and *H. elegans*). Only *H. ornatus* continued to suffer mortalities over the period of the experiment. *H. ornatus* showed the highest mortality rates after capture (< 50% alive after 96 hours in a tank). *H. elegans* appears to be have the lowest mortality rates after capture (94% alive after 96 hours) and the other species, taken as a group, appear to be intermediate (67% alive after 96 hours). With data from both types of trawl fishing gear combined, 29.8% of all sea snakes observed died within the four day experiment. None that died had any detectable external injuries.

Table 7.4.2.9 Long-term mortality of sea snakes on board the research vessel up to four days after capture by trawls. All trawls were of 30 min duration. (n=67).

Species	**Prawn trawls**		**Fish trawls**	
	No. tested	No. dead	No. tested	No. dead
Aipysurus duboisii	1	1	-	-
Aipysurus eydouxii	9	2	-	-
Aipysurus leavis	5	3	-	-
Acalyptophis peronii	2	2	-	-
Astrotia stokesii	4	0	-	-
Disteira kingii	3	1	2	1
Disteira major	2	0	1	0
Hydrophis elegans	14	1	2	0
Hydrophis mcdowelli	1	1	-	-
Hydrophis ornatus	6	1	11	7
Lapemis hardwickii	4	0	-	-
Totals	51	12	16	8

The parameter λ is the time beyond which only about one in three animals are expected to survive (λlog (2) = half life of captured sea snakes) and $\hat{\lambda}$ is the estimate for λ.

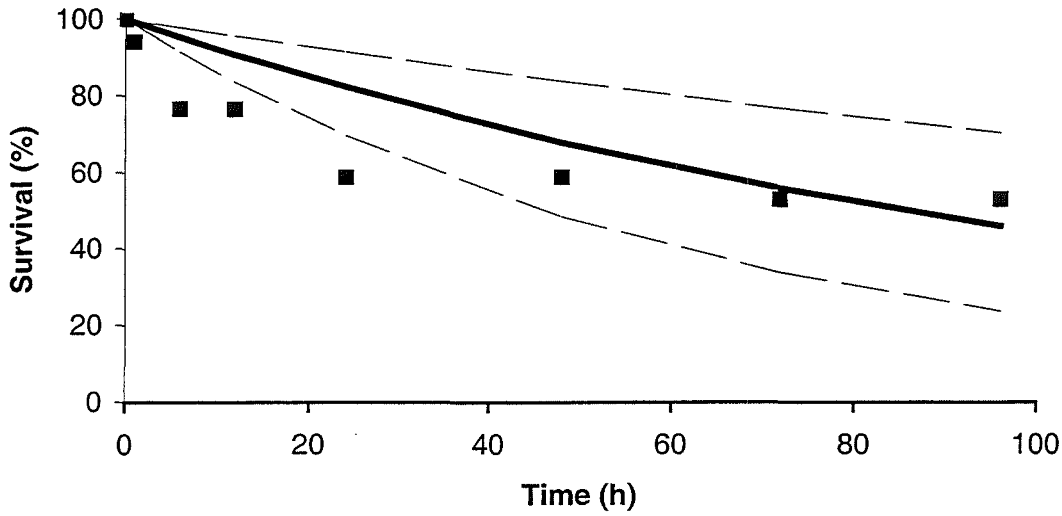
When all *H. ornatus* were included, the period when 67% mortality occurred, $\hat{\lambda}$ for all snakes was 123.5 hours (95% confidence interval: 66.4–270.3) while $\hat{\lambda}$ for only those that died in the tank was 14.9 (95% C.I.: 7.9 – 33.0).

For species other than *H. ornatus* and *H. elegans,* $\hat{\lambda}$ was 220.0 hours (95% C.I.: 128.5–423.7) while $\hat{\lambda}$ for those that died in the tank was 18.4 (95% C.I.: 10.6–35.8). Figure 7.4.2.1 shows the predicted curve and confidence intervals over time for *Hydrophis ornatus.* The predicted curve for the species other than *H. ornatus* and *H. elegans* and confidence intervals are shown in Fig 7.4.2.2.

Visible, detectable damage assessment

Damage sustained by sea snakes due to trawling was relatively low (5.4% see Table 7.4.2.10). Over half of the injuries sustained were lacerations to the head, neck or mid body regions. Some of the lacerations to the snakes were deep involving significant muscle tissue loss or were in areas of the body that could result in death (ie. head or neck). Other significant injuries were punctures to the body from fish spines. Some of these entered the body cavity with evidence of bruising.

(a)



(b)

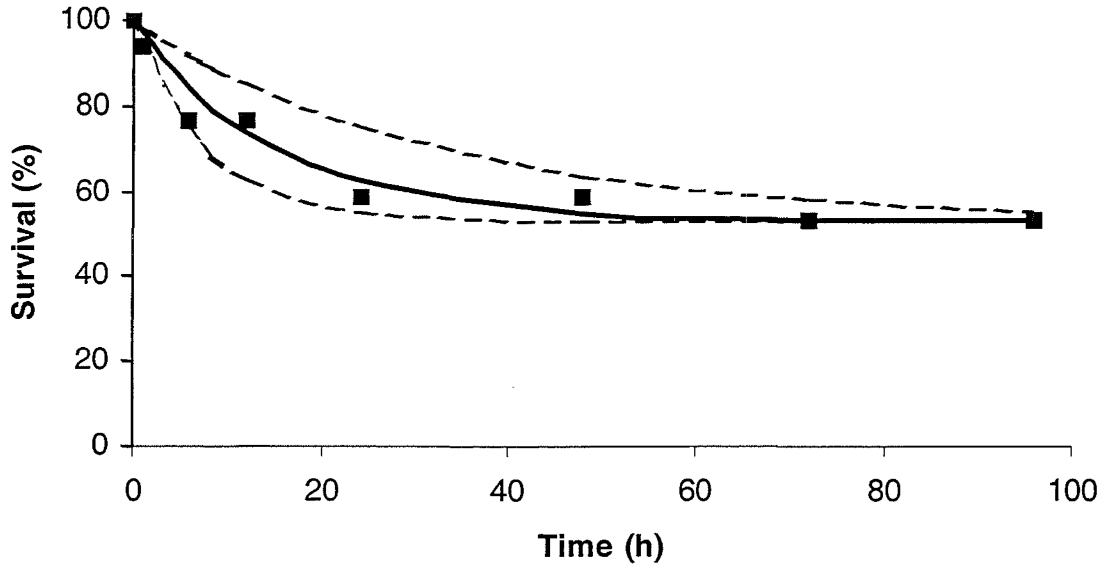
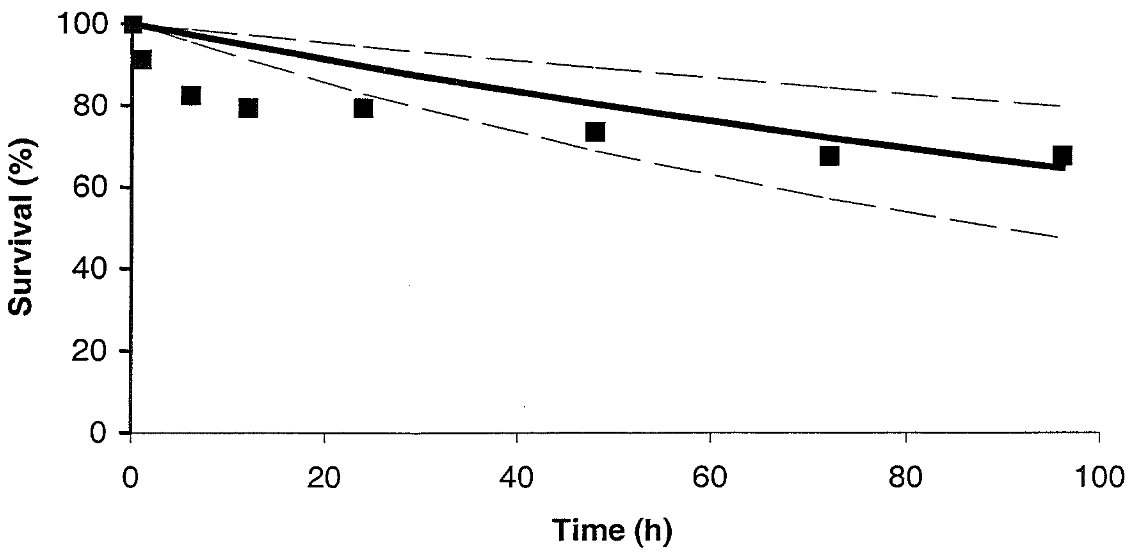


Figure 7.4.2.1 Percent survival of *Hydrophus ornatus* in relation to time after capture. The solid squares are the observed data for percent alive at a given time. The solid curve is the maximum likelihood prediction. The dashed lines are the upper and lower confidence interval for the predicted survival curve. The likelihood function was fitted to (a) all 17 snakes; (b) to the 10 snakes that died within 96 hours.

(a)



(b)

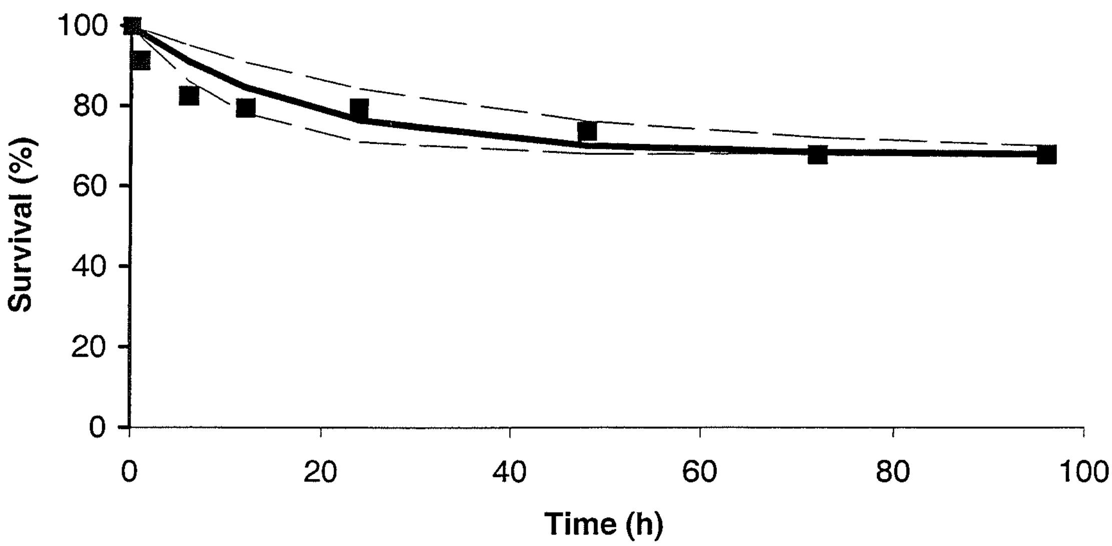


Figure 7.4.2.2 Percent survival of the sea snake species other than *Hydrophus ornatus* and *H. elegans* in relation to time after capture. The solid squares are the observed data for percent alive at a given time. The solid curve is the maximum likelihood prediction. The dashed lines are the upper and lower confidence interval for the predicted survival curve. The likelihood function was fitted to (a) all 34 snakes; (b) to the 11 snakes that died within 96 hours.

Table 7.4.2.10 Visible external damage sustained by 16 sea snakes (5.4%) from the 278 inspected of those caught by prawn trawls in northern and eastern Australia during 1995-1998 based on data collected by scientific observers. (* More than one category of damage was noted on some individuals).

Species	No.	% * damaged	Location of damage	Type of damage
Acalyptophis peronii	2	0	-	Nil
Aipysurus apraefrontalis	1	0	-	Nil
Aipysurus duboisii	4	0	-	Nil
Aipysurus leavis	10	10	Mid body	Laceration
Aipysurus eydouxii	19	5	Mid body	Laceration
Astrotia stokesii	15	7	Head/neck	Laceration
		13	Mid body	Laceration&bruising
Disteira kingii	13	0	-	Nil
Disteira major	43	0	-	Nil
Hydrophis pacificus	4	25	Mid body	Laceration
Hydrophis elegans	77	3	Head/neck	Laceration
		6	Mid body	Puncture&bruising
Hydrophis mcdowelli	2	0	-	Nil
Hydrophis czeblukovi	1	0	-	Nil
Lapemis hardwickii	72	1	Head/neck	Abrasion
		1	Mid body	Laceration
		1	Tail	Puncture

7.4.2.4 Discussion

The chance of a sea snake surviving from trawling will depend on several different factors: (a) when it enters the net, ie early or late in the tow, (b) the duration of the trawl, (c) the weight of the catch, (d) how it is treated on the deck and (e) its morphology. Under natural conditions, sea snakes may remain submerged for nearly 4 h (Heatwole, 1975b, Rubinoff et al., 1986). However, in a trawl net the conditions are far from ideal. The catch concentrates in the cod end and the contents are buffeted and swirled about due to turbulence (Main and Sangster, 1981). Fish at the rear of the net have to swim closer and closer together and make repeated attempts to break out of the net. There may be small sharks or rays present in the catch and crustaceans with sharp claws and spines. All of these animals and their efforts to escape can cause stress and injuries to each other. This is no less so for the sea snakes. Like the fish, it is probable that the sea snakes try to escape from the net and in their efforts become stressed or injured.

Over half of the observed injuries sustained by sea snakes were lacerations to the head, neck or mid body regions. The front half of the snakes were often observed to be hanging through the meshes of the cod-end. It is likely that the observed injuries result from the head and half the body of the snake passing through the net and being dragged along the seabed or bumped against the side of the boat or sorting table as the net is retrieved. Big broad headed snakes like *Astrotia stokesii* would unlikely be able to pass their head through the mesh, but those species with a fine head and long thin anterior body like Disteira kingii could easily hang through the meshes. Some of the lacerations to the snakes were deep involving significant muscle tissue loss or were in areas of the body that could result in death (ie. head or neck). Other injuries were punctures to the body from fish spines.

Compared with the number of snakes caught and dying, the observable injuries were few, suggesting that the majority of dead snakes drowned. Sea snakes have lungs to breathe air and if trapped below the surface will drown. Many of the sea snakes that arrived dead on deck, when held aloft by the tail, had water running from their mouth and nostrils suggesting they had drowned in the net. However, it is also possible that some sea snakes showing no external injuries, had been were crushed and died as a result.

The results of the logistic regression analysis indicate that both the catch weight and the duration of a trawl independently contribute to the death of sea snakes in the net. Large catches of short trawl duration kill sea snakes, as do small catches of long duration trawls. The estimate for trawl duration (Table 7.4.2.3) was much larger than the estimate for catch weight suggesting that trawl duration was a more important effect. However, this was not the case for *H. elegans* as trawl duration was not a significant contributor to mortality (Table 7.4.2.5). On average for prawn trawls, the within net mortality is about 25% and longer-term mortality over four days is estimated as 23.5%. Total fishing mortality of sea snakes from the data is estimated as 25% + 23.5% = 48.5%. Thus, about half of the sea snakes captured in trawls survive.

Wassenberg *et al.* , 1994) estimated that survival of sea snakes caught by trawl nets was about 60% for trawls of 3h duration. It was thought that shorter duration tows would reduce the risk of death for sea snakes (Wassenberg *et al.*, 1994; Ward, 1996b). Our results confirm this. Low mortalities of sea snakes were found in tows of less than 30 min in all fisheries (Table 7.4.2.2). However, the banana prawn fishery is the only fishery that has short duration trawls.

Two sea snake species demonstrated differences in long-term (4 day) survival. The long-term survival prospects for *H. ornatus* may be low as they appear to be more susceptible to continuing mortality after being trawled than the other species, with 8 deaths from 17 animals. In contrast, *H. elegans* appear to be a more robust species with only one death in 16 animals. The modelling of survival gives both best and worst-case scenarios. The worst-case suggests that sea snake mortalities continue beyond the four day survival experiments. If that is the case, then our mortality estimates may still be conservative.

Our survival experiments may underestimate the mortality of sea snakes discarded from trawlers. Sea snakes can suffer trauma from being handled on deck. On commercial fishing boats, sea snakes are discarded as soon as possible after the catch is placed on the sorting tray, to reduce the risk of someone being bitten. A usual method to dispose of the snakes is to grab them by the tail and fling them over the side of the boat, placing physical loads on the sea snake. Normally, these animals have their body weight supported by water. Once they are out of water, they become subject to the forces of gravity plus any other forces imposed by being flung through the air. In our survival experiments the sea snakes were handled carefully with tongs and their weight was supported at several places along their body or they were placed in trays to transport them to the experimental tanks. Consequently, our survival rates are probably better than for snakes caught in commercial trawls.

It has been estimated that between two and four sea snakes are caught by every boat, every fishing day, in the NPF (Ward, 1996b). Based on our experiments, slightly more than one in two dies from the effects of trawling.

Commercial handling conditions are probably less considerate than ours and are not likely to change given the danger these animals present to the crew. There are two ways in which this mortality may be reduced. Firstly, enabling more snakes to escape from the net and secondly, by reducing the overall weight of bycatch. Bycatch Reduction Devices (BRD's) in the net such as square mesh windows or fish eyes have the potential to achieve both of these aims (Blaber *et al.*, 1997; Brewer *et al.*, 1998). In the NPF, a bycatch action plan advocates the introduction of BRD's and TED's into the trawl nets. The TED's will be compulsory in nets in the NPF for the year 2000 fishing season. The TED's will reduce the number of large animals (turtles, sharks and rays and sponges) caught and BRD's will reduce the number of fish caught in the cod end thus reducing the weight of the catch and potentially reducing physical damage to any sea snakes caught. BRD's have reduced the catch rates of sea snakes by 50% (Brewer *et al.*, 1998). Thus sea snakes will benefit from both reduced weight of catch and greater probability of escapement.

7.4.2.5 Conclusions

- Overall, for both types of trawls (prawn or fish), up to 24% of sea snakes caught are dead when the catch is landed on the deck. (25% from prawn trawls)
- Heavier trawl catch weights or longer trawl duration increase the likelihood of sea snake mortality in the nets.
- With data from both types of fishing gear combined, 29.8% of sea snakes tested died within the four day survival experiment.
- With data from prawn trawls, 23.5% of sea snakes tested died within the four day survival experiment.
- Total fishing mortality of sea snakes from the data for prawn trawls is estimated as 25% + 23.5% = 48.5%, this is probably a minimum estimate.
- *Hydrophis ornatus* appears to be least able to survive the long-term effects of trawling.
- Visible damage sustained by sea snakes due to trawling is low (5.4%) and mostly of the form of lacerations or punctures from fish spines.
- Tows less than 30 min in duration result in greater sea snake survival.
- BRD's result in lower catch weight and fewer sea snakes being caught. This will result in improved survival for sea snakes in prawn fisheries using this gear.

References

Blaber, S., Brewer, D., Buckworth, R, Burridge, C., Farmer, M., Milton, D., Salini, J., Wang, Y., Wassenberg, T., Buxton, C., Cartwright, I., Eayrs, S., Rawlinson, N., Gill, N., Mounsey, R., Ramm, D., MacCartie., 1997. Effects of trawl design on bycatch and benthos in prawn and finfish fisheries. pp 1-199. Final report to the Fisheries Research & Development Corporation. 93/179.

Brewer, D., Rawlinson, N., Eayrs, S., Burridge, C., 1998. An assessment of bycatch reduction devices in a tropical Australian prawn trawl fishery. Fish. Res, 720, 1-21.

CSIRO. , 1995. CSIRO Division of Fisheries, Cruise Report SS8/95, 1-11.

Dunson, W.A., 1975. Sea snakes of tropical Queensland between 18° and 20° south latitude. In: Dunson, W.A. (Ed.) The Biology of Sea Snakes'. (University Park Press: Baltimore). pp. 151-62.

Greer, A. E., 1997. The Biology and Evolution of Australian Snakes. Surrey Beatty & Sons, Sydney.

Heatwole, H., 1975a. Sea snakes in the Gulf of Carpentaria. In: Dunson, W.A. (Ed.) (University Park Press: Baltimore). pp. 145-9.

Heatwole, H., 1975b. Voluntary submergence times of marine snakes. Marine Biology (Berlin) 32, 205-213.

Heatwole, H., Burns, G., 1987. Final report for National Parks and Wildlife Service consultancy on sea snake populations - 1984-1987. (Australian National Parks and Wildlife Service).

Main, J., Sangster, G.I., 1981. A study of the fish capture process in a bottom trawl by direct observations from a towed underwater vehicle. Sottish Fisheries research Report. 23, 1-23.

Redfield, J.A., Holmes, J.C., Holmes, R.D., 1978. Sea snakes of the eastern Gulf of Carpentaria. Aust. J. Mar. and Freshwater Research. 29, 325-34.

Rubinoff, I., Graham, J.B., Motta, J. , 1986). Diving of the sea snake *Pelamis platurus* in the Gulf of Panama. Mar. Biol. (Berlin) 91, 181-191.

SAS, 1997. SAS Institute Inc., SAS/STAT Software; Changes and Enhancement through release 6.12. Cary, N.C.; SAS Inst. Inc., 1997.

Shuntov, V.P., 1971. Sea snakes of the north Australian shelf. Ekologiya 4, 65-72.

Ward, T.M., 1996a. Sea snake bycatch of fish trawlers on the northern Australian continental shelf. Mar. Freshwater Res. 47, 625-630.

Ward, T.M., 1996b. Sea snake bycatch of prawn trawlers on the northern Australian continental shelf. Mar. Freshwater Res. 47, 631-635.

Wassenberg, T.J., Hill, B.J., 1993. Selection of the appropriate duration of experiments to measure the survival of animals discarded from trawlers. Fish. Res. 17, 343-352.

Wassenberg, T.J., Salini, J.P. Heatwole, H., Kerr, J.D., 1994. Incidental capture of sea-snakes (Hydrophiidae) by prawn trawlers in the Gulf of Carpentaria, Australia. Aust. J.Mar. Freshwat. Res. 45, 429-43.

7.4.3 The biology and sustainability of sea snakes

7.4.3.1 Introduction

The effects of prawn trawling on sea snakes in northern Australia are largely unknown. Prawn trawlers working in the Northern Prawn Fishery (NPF) were estimated to catch approximately 81 080 sea snakes in 1990 (Ward, 1996) and around 119 571 in 1991 (Wassenberg *et al.,* 1994). The sustainability of sea snakes, given these catches, depends on two characteristics of the species – the proportion of the population susceptible to capture by trawling and their capacity to recover from the increased mortality. Given sea snakes have relatively few known predators (Heatwole, 1975a; 1978) and that close to half (48.5%) of the sea snakes caught by NPF trawlers die as a result of trawl damage (Section 7.4.1), knowledge of the life history characteristics is important in order to assess their sustainability.

There are relatively few data on sea snake distribution and abundance in the NPF (Heatwole 1975b, Redfield *et al.,* 1978; Wassenberg *et al.,* 1994; Ward, 1996). These studies show that sea snake distribution and catch rates of different species in the Gulf of Carpentaria is spatially and temporally patchy. The majority of sea snake species occurring in northern Australia live in waters less than 40m deep (Heatwole, 1975b; Wassenberg *et al.,* 1994), and they occur in NPF trawling grounds (Cogger, 1975).

Sea snakes are live bearing reptiles and produce small clutches (Lemen and Voris, 1981). They are generally regarded as long-lived (eg. Burns, 1985), having low reproductive output and relatively specialised diets of specific groups of benthic fishes (Voris *et al.,* 1978; Glodek and Voris, 1982; Voris and Voris, 1983). With these abundance and life history characteristics, sea snake populations in northern Australia are unlikely to be able to sustain much fishing mortality. Yet, the NPF has been operating for 40 years and there are at least 13 species that are still being caught.

Objectives:

- Describe the life history characteristics of most species in order to assess their sustainability.
- Examine the diet of sea snakes and determine any differences between areas open and closed to prawn trawling in order to assess the influence of diet on sea snake vulnerability.
- Examine trends in the catch rates of species of sea snakes caught by prawn trawling in the NPF between 1986 and 1998 and in the Queensland East Coast Trawl Fishery (QUEENSLAND BANANA PRAWN FISHERY) during 1996-1997.
- Assess the relative sustainability of sea snake populations in the Gulf of Carpentaria to prawn trawling at current levels of fishing.

7.4.3.2 Methods

Biological sampling

Sea snakes dissected for data on life history and diet were obtained from a number of sources: (1) commercial vessels working in the Gulf of Carpentaria in 1986, (2) four RV *Southern Surveyor* research cruises in the NPF and TSPF between 1995 and 1998 (see Section 7.4.1), (3) one RV *Southern Surveyor* research cruise on the

'North West Shelf' in 1995, (4) one research cruise aboard the FRV *Gwendoline-May* in the Great Barrier Reef (GBR) in 1995, (5) scientific observer cruises aboard commercial vessels in the NPF and Queensland Banana Prawn Fishery between 1996 and 1998. All sea snakes collected during these cruises were frozen on board the vessels and transported to CSIRO Marine Laboratories, Cleveland for analysis.

In the laboratory, snakes were identified, measured (snout vent length in mm) (SVL), weighed (g) and assessed for trawl damage (see Section 7.4.2). Upon dissection, sea snakes were sexed and the gonads removed and weighed (± 0.1g). Testes were fixed in 10% formaldehyde and a subsample was examined histologically to identify the stage of development. Four stages of testicular development were identified (listed below). The proportion of each gonad section in each developmental stage was estimated:

Stage 1: primary germ cells (stem spermatogonia) (immature) to spermatocytes (maturing),
Stage 2: spermatids present (ripe/mature),
Stage 3: spermatozoa (running ripe/mature),
Stage 4: spent (signs of atresia and a few fully-developed spermatozoa).

Female sea snakes were classified as pregnant if their oviducts contained enlarged yolked eggs (eggs destined to become next clutch of offspring) or developing embryos. These eggs and embryos were counted and weighed. Fully developed embryos (term embryos) were removed and the SVL (mm) and weight (g) of each embryo was recorded. Relative clutch mass (RCM) was calculated for all pregnant females as:

$$\text{Relative Clutch Mass (RCM)} = \frac{\text{ovary weight}}{\text{Female body weight} - \text{ovary weight}}$$

Chi-squared tests were made on the sex ratio between and within the 17 species of sea snakes caught in our study to test for deviation from parity. The sex ratio of sea snakes between regions ('North West Shelf', 'Darwin', 'Groote Eylandt', 'Mornington Island', 'Weipa', 'Torres Strait', 'East Coast of Australia') was also examined for deviation from parity (1:1) using a Chi-squared test.

The proportion of pregnant and non-pregnant females of each sea snake species was analysed using a Chi squared test to determine differences between species in the proportion of pregnant females caught in trawls. The effect of RCM on sea snake catchability (Shine, 1988) was assessed with a test of proportions (Walpole, 1974).

The relationships between female SVL and clutch size and embryo SVL and embryo weight were examined using linear regression.

The stomach contents of all sea snakes dissected were examined, with the exception of sea snakes collected from NPF commercial vessels in 1986. Sea snake stomach contents were removed and identified to the lowest possible taxonomic level and the wet weight (± 0.1g) of each prey item was recorded. The species composition of prey (by weight) was calculated for each sea snake species. For one research cruise (September-October 1998), the diet of sea snakes caught in areas closed to trawling and adjacent trawl grounds were compared.

Catch Rates

Catch rates of each species of sea snake collected during our study was calculated from three RV *Southern Surveyor* research cruises between 1997 and 1998 (February-March 1997, October-November 1997 and September-October 1998) and four scientific observer cruises between 1996 and 1998 (September-October 1996, May-June 1997, September-October 1997, June 1998). Research and scientific observer log data and net configurations were obtained for each trawl (see Section 6.2). As net size and trawl duration varied between vessels and cruise, catch rates was standardised to number of sea snakes caught per trawl hour per kilometre of head rope length. We calculated this by dividing the number of sea snakes caught in each trawl by the duration in hours and total head rope length of the net used (in km). Diel changes in sea snake catch rates were examined among four time periods: dawn (06:00-07:00), day (07:00-17:30), dusk (17:30-18:30) and night (18:30-06:00) using data from these research and scientific observer cruises.

Long-term trends in catch rates were examined by comparing 1976-79 (Wassenberg *et al.,* 1994) and 1989 catch rates (Ward, 2000) with the mean catch rates of snakes caught during our three research and four scientific observer cruises between 1996-98.

Changes in the mean SVL of each sea snake species over time was examined with snakes collected from research, scientific observer and commercial trawls in the NPF between 1986 and 1998 using linear regression.

Sustainability indicators

The relative sustainability of each species of sea snake was assessed by scoring them for two sets of criteria: (1) their relative susceptibility to capture and mortality by prawn trawling and (2) the capacity of the population to recover from trawling (see Sections 7.2 and 7.3 for a similar assessment of fish and elasmobranch species). The criteria used for sea snakes varied slightly from those used in the assessments of fish and elasmobranchs because of the differences in the life history characteristics of each group and the data available. The summed ranks for each species for each set of criteria were plotted as axes on a graph to identify the least sustainable species and the priority species for research and management. These were identified as those that had the lowest ranks on both axes. Priority zones were identified based on the premise that the susceptibility and recovery effects were multiplicative. The equations for the boundaries of the three zones are given in section 7.2 and these boundaries were chosen after discussion in the NPF FAG meeting at CSIRO in November 1999.

The criteria used for the sea snakes and their relative weighting are shown below.

Axis 1: The susceptibility of species to capture and mortality by prawn trawling
Criteria were:

Preferred habitat (Weighting = 3)
Species ranked according to their preference for open offshore, turbid unstructured habitat.

Rank	Description
1	Species that primarily occur on soft or muddy sediments or specifically prawn trawl grounds
2	Species that occur in soft sediment areas but are known to migrate to coastal waters and use estuaries
3	Species that prefer habitats outside trawl areas such as reef habitat

Survival (Weighting = 3)
Species were ranked according to their ability to survive prawn trawling. Data were collected during this project and presented in Section 7.4.1.

Rank	Description
1	Species with the lowest survival from trawling (62 - 73 %)
2	Species with moderate survival from trawling (74 - 87%)
3	Species that had the greatest survival from trawling (88 - 100%)

Range (Weighting = 2)
The number of the recording bioregions in the NPF in which a species was caught during the comprehensive study by Ward (2000)

Rank	Description
1	Species that occurred in less than five of the nine bioregions
2	Species that occurred in 5 to 7 bioregions
3	Species that occurred in more than 7 bioregions

Day/night (Weighting = 2)
This was determined from a comparison of diel differences in catch rates during the current project when prawn trawls were used.

Rank	Description
1	Species that have higher catch rates in prawn trawls at night
2	Species with similar catch rates in night and daytime trawls
3	Species with higher catch rates during the day

Diet (Weighting = 2)

This factor reflects whether a species' diet would attract them to trawl grounds. Dietary information was obtained from our study and the scientific literature.

Rank	Description
1	Species that ate fish species that were definitely trawl discards
2	Species that ate benthic species found in trawl catches
3	Species that ate reef-associated species

Axis 2: The capacity of a species to recover once the population is depleted

Maximum size (Weighting = 3)

The maximum size of a species is used as an index of longevity. Within broad phyologenetic groups, larger species are usually longer-lived and have a slower recovery rate.

Rank	Description
Species with maximum length <1180 mm	
1	Species with a maximum length between 1180 and 1652 mm
2	Species with a maximum length > 1652 mm

Percentage of biomass removed (Weighting = 3)

The entire coast of Australia has recently been divided into nine bioregions with distictive faunas (Thackway and Cresswell 1997). Manson and Die (unpubl. data) have estimated the area of each bioregion in the NPF, the proportion of each of the bioregions that were fished for more than 50 boat-days in 1989 and between 1993 and 1997, and the total annual effort in each bioregion for each of these years. They estimated the mean catch rates of sea snakes caught in tiger prawn trawls in each bioregion in the Gulf of Carpentaria (GoC) in 1996-97 and used these data, together with the annual tiger prawn effort, to estimate the number of snakes caught in each bioregion. The total catch of sea snakes in 1996 and 1997 was estimated by summing the catch from each bioregion. The total population of sea snakes in the Gulf of Carpentaria was estimated by scaling the catch in the fishing ground of each bioregion to the area of the bioregion and the figure summed across all bioregions.
This approach assumes that species are equally distributed throughout each bioregion, that their catchability was similar in each region, and that all snakes in the path of the net were caught. None of these assumptions is likely to be valid, but we have limited data to estimate catchability, let alone its variability. I feel that this approach is at least conservative and should generate a maximum estimate of biomass removed.

Rank	Description
1	Species where the estimated proportion of the biomass removed was greater than a quarter.

2	Species where the estimated proportion of the biomass removed was between a sixth and a quarter.
3	Species where the estimated proportion of the biomass removed was less than one sixth.

Breeding (Weighting = 3)

Die and Caddy (1997) found that where the mean length of the fished population is greater than the length at sexual maturity ($\bar{L} > L_m$), on average, an individual will have reached maturity and have bred before being caught. This ratio can be used to determine the probability that an individual has bred before capture with a *t*-test approximation of a normal distribution.

Rank	Description
1	The mean length of the snakes caught is significantly less (P<0.001) than the length at sexual maturity
2	The mean length of the catch is similar to the length at sexual maturity
3	The mean length of the catch is significantly longer than the length at sexual maturity (P<0.001)

Total biomass (Weighting = 2)

This approach assumes that species are equally distributed throughout each bioregion, that their catchability was similar in each region and that all snakes in the path of the net were caught. None of these assumptions are likely to be valid, but we have limited data to estimate catchability, let alone its variability. We feel that this approach is at least conservative and should generate a minimum estimate of biomass.

Rank	Description
1	Species with an estimated population in the GoC < 16434
2	Species with an estimated population in the GoC between 16434 and 49506
3	Species with an estimated population in the GoC > 49506

Mortality index (Weighting = 2)

An estimate of the relative survival of each species can be obtained from the relationship between mean length ($\bar{L}$) and the smallest length caught (L') and the maximum size caught L_{max} by the equation of Beverton and Holt (1956):

$$Z = \frac{L_{\max} - \bar{L}}{L - L'}$$

Rank	Description
1	Species with a value of Z > 1.35
2	Species with a value of Z between 0.88 and 1.35
3	Species with a value of Z < 0.88

Annual fecundity (Weighting = 2)

The annual fecundity estimates for each species were ranked according to their deviation from the overall mean fecundity of all species.

Rank	Description
1	Species with an annual fecundity < 5.3
2	Species with a fecundity between 5.3 and 8.2
3	Species with a fecundity > 8.2

Data to score all sea snake species for the Susceptibility criteria were obtained from the scientific literature (eg. papers in Dunson, 1975; Cogger, 1992; review in Greer, 1997). Individual species were subjectively assigned to a rank based on the evidence available. This approach differed from that used to estimate each species rank for the Recovery criteria. Species were scored for these criteria by their absolute value and how it related to the mean and range of all species on that criterion. The approach used was to calculate the overall mean and range for each Recovery criterion across all species. Then, the range between the mean and the maxima and minima were calculated separately as the data for most criteria were not normally distributed. Species with a value closer to the mean than one third of each range were scored as 2. For example, the range of sizes at sexual maturity as a proportion of maximum size varied from 0.43 to 0.82. However, the mean of all species was 0.62 and species rated a value of 2 if they were ± 33.3% of the deviation from the mean and rated a three if they were in the lower 66.6% of the range between the minimum and the mean.

The weighted ranks of each species on each criterion were then summed to give a single value for each axis (equation 1). These data were then plotted with susceptibility on the y-axis.

Zones of similar priority for further actions (research or active management) were identified, and the species were classified as having similar priority for research and management if they fell into the same zone. Priority zones were allocated after discussion with the NPF Advisory Group. Zones were chosen on the assumption that the rankings on each axis were multiplicative and the axes were symmetrical. For example, this meant that one curve separating species with similar sustainability passed through (1.5, 1.5) and the extremes (1, 3) and (3, 1). It has an equation of the form:

$$(y - 0.75)*(x - 0.75) = 9/16 \qquad (3)$$

Other curves were drawn on the graph following a similar relationship.

7.4.3.3 Results

Sea Snake Collections

Reproductive and dietary data on 471 sea snakes was obtained from commercial vessels in the NPF during 1986, research cruises in the NPF, TSPF, GBR, Queensland Banana Prawn Fishery and 'North West Shelf' between

1995 and 1998 and scientific observer cruises in the NPF during 1996 to 1998. Length and weight data from another 189 sea snakes collected from research cruises in the NPF, TSPF and GBR during 1992 to 1997 and scientific observer cruises between 1996 and 1998 in the NPF were also used in our study. Additional biological data from 1266 sea snakes caught in the Gulf of Carpentaria between 1976 and 1979 (see Wassenberg *et al.,* 1994 for details) was also used in the assessment of life history parameters. In all, data from 1926 sea snakes are presented (Table 7.4.3.1).

The diversity of sea snakes caught by commercial vessels, research cruises and scientific observer cruises was high, collecting a total of 13, 13 and 9 sea snake species respectively from the 'North West Shelf', NPF and TSPF. However the catch rates of many species varied considerably between these regions and among fishing methods.

In the 1986 commercial NPF vessel collections, *Hydrophis ornatus* and *Disteira major* were the two most abundant species caught, representing 73% of the catch. *Aipysurus eydouxii* made up 6.8% of the catch with the remaining species collected each comprising less than 4.3% of the catch. The three most abundant sea snake species caught in the NPF, TSPF and 'North West Shelf' research trawls during 1995 to 1998, (*H. elegans*, *H. ornatus* and *Lapemis hardwickii*) made up 72% of the catch. *Lapemis hardwickii* made up 13% of research catches compared to only one specimen in the 1986 commercial catch. The most abundant species in scientific observer collections from the NPF during 1996 to 1998 were *H. elegans* and *D. major* (30.8% and 27.8% respectively). Only 6.0% of the catch were *H. ornatus*. Overall, *D. major*, *H. elegans*, *H. ornatus* and *L. hardwickii* were the most commonly caught sea snakes in our study. However none of these species showed consistent high catch rates in all regions. In the Queensland Banana Prawn Fishery, *L. hardwickii* was the most common species caught (78.9%) and together with *H. elegans*, these two species made up 94% of the sea snake catch from scientific observer cruises during 1996 and 1997.

The majority of sea snakes collected from 1992 to 1995 from research vessels working in the GBR were *Aipysurus* species. *Aipysurus duboisii*, *A. eydouxii* and *A. laevis* made up 54.5% of the 90 snakes caught, with *A. duboisii* being the most common (35.6%). Only five other species were collected from this region.

Life History

Life history characteristics were analysed for sea snakes obtained from commercial vessels, research cruises and scientific observer cruises during 1986 to 1998 and from sea snakes caught in the Gulf of Carpentaria during 1976 to 1979 (Wassenberg *et al.,* 1994). Mean SVL and weight of each species of sea snake is shown in Table 7.4.3.2. Sea snakes caught around 'Mornington Island' and 'Weipa' generally had a wider size range with a greater proportion of smaller specimens of *A. eydouxii*, *D. kingii*, *E. schistosa*, *H. elegans*, *H. mcdowelli* and *L. hardwickii* than elsewhere. The largest specimens of *A. laevis*, *A. stokesii*, *H. elegans*, *H. ornatus* and *L. hardwickii* were found around 'Groote Eylandt'.

Changes in mean SVL over time was examined for 12 species of sea snakes collected from research, scientific observer and commercial vessels between 1986 and 1998 in the NPF (Figure 7.4.3.1 a-l). Mean SVL from

Wassenberg *et al.* (1994) and Ward (2000) were also included in Figure 7.4.3.1 for comparison. No significant change in mean SVL was seen for any species between 1986 and 1998 (all P>0.5) where the data were collected from comparable trawls during the tiger prawn season.

The proportion of female sea snakes caught differed significantly between species (χ_{16} = 39.1, P< 0.01) (Table 7.4.3.2). *Aipysurus eydouxii* showed the largest gender bias with 87% of the snakes being females. Females also dominated catches of *Disteira kingii* (73.5%) and *L. hardwickii* (68.1%). Sex ratios of sea snake species deviated significantly from 1:1 (χ_{16} =117.6, P<0.01). Of the 13 most common species, there were significantly more females than males in 10 species. More males were caught in *A. duboisii*, *A. laevis*, and *Hydrophis caerulescens*, but these species had small sample sizes. There were significant differences in the sex ratios of sea snakes between regions (χ_6 = 26.2, P< 0.001). Sea snakes caught in the 'Mornington Island' and 'Weipa' regions were predominantly females, frequently outnumbering males by more than 2:1, and as high as 18:0 for *A. eydouxii* caught around 'Weipa'.

Table 7.4.3.1 Sources of sea snakes examined in this study collected from trawlers in northern Australia between 1976 and 1998. Numbers in parentheses indicate sea snakes from which biological data were collected and the species percentage collected from each source are shown in italics (* data from the study by Wassenberg *et al.*, 1994).

Species	NPF Research* 1976-79	NPF Commercial 1986	NPF Scientific Observer 1996-1998	'North West Shelf', NPF, TSPF Research 1995-1998	QUEENSLAND BANANA PRAWN FISHERY Scientific Observer 1996-1997	GBR Research 1992-1995
Unid. Hydrophiidae	-	-	21	-	-	5
	-	-	*15.79*	-	-	*5.56*
A. peronii	22	5 (5)	-	3 (2)	-	16
	1.74	*3.07*	-	*1.63*	-	*17.78*
A. apraefrontalis	-	-	-	1 (1)	-	-
	-	-	-	*0.54*	-	-
A. duboisii	5	2 (2)	2 (2)	1 (1)	-	32 (1)
	0.39	*1.23*	*1.50*	*0.54*	-	*35.56*
A. eydouxii	76	11 (11)	3 (3)	14 (14)	1 (1)	7 (1)
	6.00	*6.75*	*2.26*	*7.61*	*1.11*	*7.78*
A. laevis	20	-	5 (5)	5 (5)	-	10
	1.58	-	*3.76*	*2.72*	-	*11.11*
A. stokesii	58	6 (6)	7 (6)	8 (8)	1 (1)	1
	4.58	*3.68*	*5.26*	*4.35*	*1.11*	*1.11*
D. kingii	33	7 (7)	5 (5)	10 (6)	2 (2)	-
	2.61	*4.29*	*3.76*	*5.43*	2.22	-
D. major	36	48 (48)	37 (37)	7 (5)	1 (1)	3
	2.84	*29.45*	*27.82*	*3.80*	*1.11*	*3.33*
E. annulatus	-	1 (1)	-	-	-	-
	-	*0.61*	-	-	-	-
E. schistosa	103	1 (1)	-	-	-	-
	8.14	*0.61*	-	-	-	-
H. caerulescens	8	-	-	-	-	-
	0.63	-	-	-	-	-
H. czeblukovi	-	-	-	1 (1)	-	-
	-	-	-	*0.54*	-	-

Table 7.4.3.1 Sources of sea snakes examined in this study collected from trawlers in northern Australia between 1976 and 1998. Numbers in parentheses indicate sea snakes from which biological data were collected and the species percentage collected from each source are shown in italics (* data from the study by Wassenberg *et al.,* 1994).

Species	**NPF Research***	**NPF Commercial**	**NPF Scientific Observer**	**'North West Shelf', NPF, TSPF Research**	**QUEENSLAND BANANA PRAWN FISHERY Scientific Observer**	**GBR Research**
	1976-79	**1986**	**1996-1998**	**1995-1998**	**1996-1997**	**1992-1995**
H. elegans	206	4 (4)	41 (33)	69 (34)	14 (14)	-
	16.27	*2.45*	*30.83*	*37.50*	*15.56*	-
H. inornatus	-	1 (1)	-	-	-	-
	-	*0.61*	-	-	-	-
H. mcdowelli	9	5 (5)	-	2 (2)	-	-
	0.71	*3.07*	-	*1.09*	-	-
H. ornatus	11	71 (71)	8 (8)	39 (24)	-	15
	0.87	*43.56*	*6.02*	*21.20*	-	*16.67*
H. pacificus	-	-	4 (4)	-	-	1
	-	-	*3.01*	-	-	*1.11*
L. hardwickii	677	1 (1)	-	24 (10)	71 (71)	-
	53.48	*0.61*	-	*13.04*	*78.89*	-
P. platurus	2	-	-	-	-	-
	0.16	-	-	-	-	-
Totals	1266	163 (163)	133 (103)	184 (113)	90 (90)	90 (2)

Table 7.4.3.2 Sex ratios, mean and range in snout-vent length and weight of species of sea snakes caught by trawlers in northern Australia between 1976 and 1998. Not all measurements were recorded for some sea snakes, so separate sample numbers are given for sex ratios, mean SVL and range and mean weight and range.

Species	Region	F:M	N	SVL (mm) mean ± se	SVL range (mm)	N	Weight (g) mean ± se	Weight range (g)	N
A. peronii	'Groote'	0.0 : 1	1	890	890	1	561.9	561.9	1
	'Mornington'	0.8 : 1	11	904 ± 32	763-1139	13	494.6 ± 59.2	306.3-1096.4	13
	'Weipa'	2.0 : 1	9	787 ± 25	702-920	9	360.4 ± 41.0	236.4-605.2	9
	'East Coast'	-	-	872 ± 18	840-930	5	726.3 ± 83.8	450-1800	16
A. apraefrontalis	'NW Shelf'	0.0 : 1	1	920	920	1	544.5	544.5	1
A. duboisii	'Groote'	3.0 : 0	3	1015 ± 40	955-1090	3	639.7 ± 125.0	394.3-804	3
	'Mornington'	0.0 : 2	2	890 ± 16	874-905	2	410.6 ± 29.9	380.7-440.4	2
	'Weipa'	0.5 : 1	3	937 ± 32	901-1000	3	399.7 ± 62.8	307.1-519.6	3
	'East Coast'	0.0 : 1	1	845 ± 47	550-1100	14	490.9 ± 46.1	108.1-1000	32
A. eydouxii	'Groote'	2.0 : 1	12	712 ± 25	620-850	12	446.2 ± 44.8	284.4-713.3	12
	'Mornington'	6.0 : 1	35	585 ± 11	429-740	42	272.7 ± 26.4	84.7-988.8	42
	'Weipa'	18.0 : 0	18	539 ± 14	392-646	18	193.2 ± 15.5	68.5-357	18
	'East Coast'	2.0 : 0	2	718 ± 17	690-760	4	427.6 ± 62.0	250-750	8
A. laevis	'Groote'	0.8 : 1	7	1091 ± 46	960-1300	7	1929.1 ± 446.5	1033.2-4088.5	7
	'Mornington'	2.0 : 0	2	995 ± 35	960-1030	2	1296.0 ± 9.5	1286.5-1305.5	2
	'Weipa'	0.4 : 1	14	852 ± 29	640-1034	14	734.5 ± 91.8	279-1720	14
	'Torres Strait'	0.0 : 1	1	1020	1020	1	1205.8	1205.8	1
	'East Coast'	-	-	970 ± 130	840-1100	2	920.0 ± 89.2	400-1200	10
A. stokesii	'Darwin'	0.0 : 1	1	730	730	1	478.8	478.8	1
	'Groote'	0.8 : 1	7	1021 ± 82	720-1380	8	1845.2 ± 622.1	392.1-5724.6	8
	'Mornington'	2.5 : 1	21	956 ± 24	714-1150	21	1159.4 ± 102.8	361.5-2091.9	21
	'Weipa'	1.1 : 1	33	886 ± 25	595-1239	33	799.1 ± 85.8	250.9-2184.2	33
	'East Coast'	-	-	1340	1340	1	2600.0	2600	1
D. kingii	'Mornington'	2.3 : 1	20	1192 ± 60	620-1565	22	415.9 ± 56.8	39.1-830.1	22
	'Weipa'	4.5 : 1	11	1246 ± 78	661-1650	15	503.4 ± 101.3	76.9-1700	15
	'Torres Strait'	1.0 : 0	1	1300 ± 150	1150-1450	2	512.4 ± 12.4	500-524.8	2
	'East Coast'	1.0 : 1	2	1540 ± 80	1460-1620	2	549.1 ± 80.0	469.1-629	2
D. major	'Groote'	1.0 : 1	2	1100 ± 26	1060-1150	3	829.5 ± 33.4	792.5-896.2	3

Table 7.4.3.2 Sex ratios, mean and range in snout-vent length and weight of species of sea snakes caught by trawlers in northern Australia between 1976 and 1998. Not all measurements were recorded for some sea snakes, so separate sample numbers are given for sex ratios, mean SVL and range and mean weight and range.

Species	Region	F:M	N	SVL (mm) mean ± se	SVL range (mm)	N	Weight (g) mean ± se	Weight range (g)	N
	'Mornington'	2.1 : 1	53	959 ± 20	636-1635	54	544.9 ± 23.2	150-1000	54
	'Weipa'	1.4 : 1	17	998 ± 17	875-1120	17	576.1 ± 44.2	337.2-961.7	17
	'Torres Strait'	1.0 : 0	1	1090	1090	1	1138.6	1138.6	1
	'East Coast'	0.0 : 1	1	530	530	1	746.2 ± 225.5	94.7-1090	4
E. schistosa	'Mornington'	0.7 : 1	19	725 ± 21	386-1024	32	212.3 ± 20.5	21.5-659.6	32
	'Weipa'	1.8 : 1	39	781 ± 23	471-1008	39	295.5 ± 25.3	43.4-671.4	39
H. caerulescens	'Mornington'	0.0 : 2	2	847 ± 87	760-934	2	330.8 ± 146.2	184.6-476.9	2
	'Weipa'	0.7 : 1	5	846 ± 43	710-947	5	375.6 ± 64.9	179.2-530.3	5
H. czeblukovi	'NW Shelf'	1.0 : 0	1	980	980	1	769.4	769.4	1
H. elegans	'Groote'	0.7 : 1	15	1391 ± 93	760-2010	17	1195.1 ± 231.4	91.2-3287.4	17
	'Mornington'	2.0 : 1	75	1360 ± 25	672-1920	108	776.4 ± 36.9	86.6-2066.6	106
	'Weipa'	1.0 : 1	49	1378 ± 29	760-1935	77	762.4 ± 44.4	99.8-1620	74
	'East Coast'	0.7 : 1	12	1028 ± 101	430-1700	13	383.1 ± 90.0	22.9-1166	13
H. mcdowelli	'NW Shelf'	0.0 : 1	1	780	780	1	226.5	226.5	1
	'Mornington'	2.5 : 1	7	731 ± 67	351-912	7	215.3 ± 34.6	19.9-288.7	7
	'Weipa'	1.0 : 0	1	779	779	1	301.0	301	1
H. ornatus	'NW Shelf'	0.0 : 2	2	895 ± 45	850-940	2	541.6 ± 62.0	479.4-603.5	2
	'Groote'	0.6 : 1	11	1128 ± 25	930-1240	12	1401.4 ± 133.4	514.2-2149.5	12
	'Mornington'	1.5 : 1	15	1079 ± 42	840-1574	17	879.5 ± 76.7	474.8-1459.1	17
	'Weipa'	2.3 : 1	10	1101 ± 59	700-1630	20	876.1 ± 108.5	240.4-1923.1	19
	'Torres Strait'	1.0 : 0	1	1190 ± 60	1130-1250	2	1054.4 ± 34.4	1020-1088.8	2
	'East Coast'	-	-	1004 ± 72	840-1200	5	1030.0 ± 116.5	400-2000	15
H. pacificus	'Mornington'	3.0 : 1	4	1453 ± 67	1350-1650	4	1206.9 ± 129.9	957-1558.4	4
	'East Coast'	-	-	-	-	-	2000.0	2000	1
L. hardwickii	'Darwin'	1.0 : 0	1	740	740	1	644.5	644.5	1
	'Groote'	1.3 : 1	7	1016 ± 49	770-1180	7	1355.4 ± 163.8	684.2-2088	7
	'Mornington'	2.7 : 1	178	768 ± 10	311-1094	214	539.0 ± 18.0	30.3-1255.3	214
	'Weipa'	2.5 : 1	174	790 ± 9	457-1230	183	546.7 ± 16.7	109-1300	183
	'East Coast'	0.9 : 1	70	720 ± 23	330-1030	70	611.1 ± 54.5	64.3-1612.8	70
P. platurus	'Weipa'	2.0 : 0	2	551 ± 25	526-575	2	135.0 ± 35.0	100-170	2

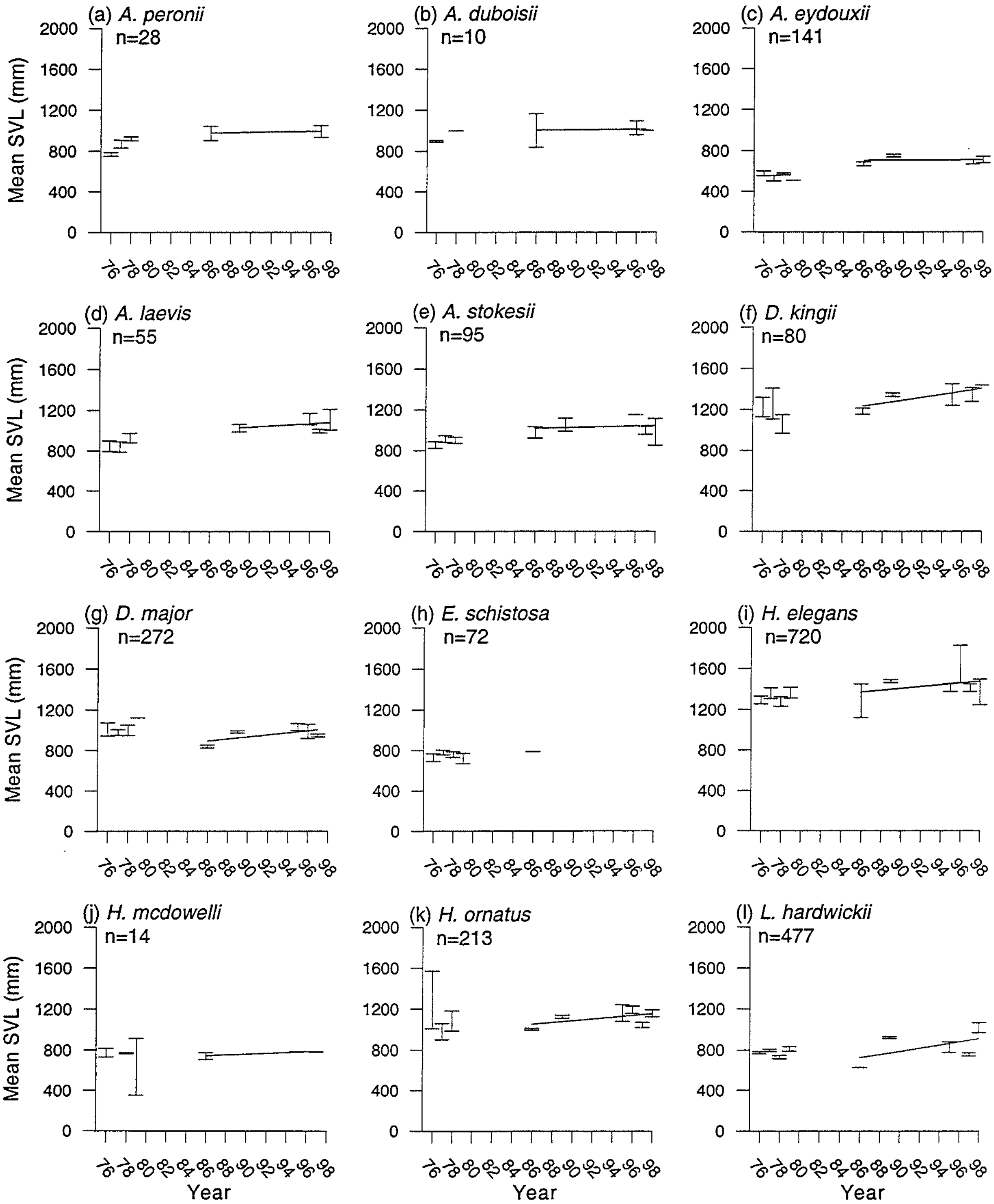


Figure 7.4.3.1 Mean SVL of sea snake species caught by trawlers in the Gulf of Carpentaria between 1986 and 1998. The 1976-1979 data of Wassenberg et al. (1994) and 1989 data of Ward (2000) is included for comparison. Vertical bars represent ± 1 se.

Estimates of the length at maturity and the proportion of mature sea snakes caught were obtained for 16 species of sea snakes (Table 7.4.3.3). For four species, *A. apraefrontalis*, *E. annulatus*, *H. czeblukovi* and *H. inornatus* only one individual was caught. Length at maturity was calculated for females from minimum lengths at which oviducal eggs or embryos were present and for males from the presence of spermatids or spermatozoa in the testes. Where data on gonad stages was available for both sexes of sea snakes, females were found to reach sexual maturity at a smaller length than males in the majority of species.

Aipysurus eydouxii became sexually mature at the smallest length of any of the species studied, 472mm (SVL) for females and 640mm for males. Both sexes of *A. laevis* and *H. elegans*, did not reach maturity until at least 1000mm SVL. This is probably a reasonable estimate for *H. elegans* since this is a very elongated species and grew to the largest length of any species in our study. However, *A. laevis* are likely to mature at a smaller length as sample sizes were low and smaller individuals were not caught. *Acalyptophis peronii* and *D. kingii* showed greatest difference in length at maturity between the sexes, with females reaching maturity at about 700 and 800mm and males becoming mature at 1090mm and 1450mm, respectively. Like *A. laevis*, we caught few male *A. peronii* and *D. kingii*, so these values may be an overestimate.

The proportion of mature sea snakes caught was high (Table 7.4.3.3). For most sea snake species where at least 10 specimens of each sex were assessed for gonad development, the proportion of mature individuals in catches was about 67% for males and 89% for females. For *A. peronii*, *A. laevis* and *D. kingii*, the proportion of sexually mature males was low (14.3-23.1%) compared to other sea snake species. This may be due to small sample sizes and the length at sexual maturity of these species are probably overestimated.

There was a significant positive relationship between female SVL and clutch size for six species of sea snake ($P<0.05$) (Figure 7.4.3.2,a-k). The number of young produced by females varied among sea snake species. Clutch size was largest in *H. elegans* and *Astrotia stokesii* with a mean of 12.3 and 9.9 young per female, respectively (Table 7.4.3.3). In contrast, *H. inornatus*, *H. mcdowelli* and *A. eydouxii* produced less than four young per brood.

Mean size (SVL) and weight of term embryos of all species showed no correlation (r^2= -0.03, P = 0.97). The largest term embryo by weight did not necessarily indicate longest SVL. Female *Disteira* species produced the largest embryos, 427mm and 573mm SVL, but only weighed 39.6g and 32.2g (Table 7.4.3.4). Term embryos of *L. hardwickii* were considerably heavier than any other species (53.6g), yet only measured 301mm SVL. The smallest term embryos by weight (*A. eydouxii*) were almost as long as offspring of *L. hardwickii.*

The effort invested in producing young varied considerably between the six species of sea snakes for which we had data. Relative clutch mass (RCM) of females carrying term embryos ranged from 13% in *D. kingii* to 44% for *A. duboisii* (Figure 7.4.3.3). The large number of *A. duboisii* embryos per clutch relative to the female size resulted in this species having the highest RCM of any sea snake species. *Disteira kingii* females had the lowest RCM and mature at a larger body length.

Table 7.4.3.3 Length at maturity, length range, percentage of mature sea snakes and sample sizes of both sexes from trawls in northern Australia between 1976 and 1998. Mean clutch size, length range* and sample size (N*) of female sea snakes assessed for gonad development are also shown and includes only pregnant snakes. Length range* and sample size (N*) for male sea snakes indicate sea snakes assessed for testicular development.

Species	Sex	Length at maturity (mm)	Length range (mm)	Mature (%)	N	Clutch size (± se)	Length range* (mm)	N*
A. peronii	Male	1090	703-1139	14.3	14		890-1090	2
	Female	716	702-1108	91.7	12	4.5 ± 1.7	716-1108	4
A. apraefrontalis	Male	-	920	-	1		-	-
	Female	-	-	-	-	-	-	-
A. duboisii	Male	-	570-1163	-	7		955	1
	Female	<910	910-1162	100.0	5	4.5 ± 1.0	910-1162	4
A. eydouxii	Male	640	547-780	53.8	13		640-650	4
	Female	472	392-850	96.9	65	3.6 ± 0.3	472-790	40
A. laevis	Male	1020	640-1060	18.8	16		1020	1
	Female	1034	712-1300	44.4	9	6.5 ± 1.8	1034-1300	4
A. stokesii	Male	>850	595-1220	51.6	31		720-850	4
	Female	817	714-1380	89.7	39	9.9 ± 1.7	817-1380	10
D. kingii	Male	<1450	661-1620	23.1	13		1110-1620	4
	Female	823	789-1572	92.9	28	4.9 ± 0.6	1000-1572	13
D. major	Male	850	530-1635	62.5	48		840-1090	12
	Female	<710	615-1431	98.6	74	4.9 ± 0.3	710-1223	45
E. annulatus	Male	-	880	-	1		-	-
	Female	-	-	-	-	-	-	-
E. schistosa	Male	-	560-881	-	25		-	-
	Female	790	471-1015	60.0	35	6.8 ± 1.2	790-977	5
H. caerulescens	Male	-	760-947	-	5		-	-
	Female	840	710-840	50.0	2	7.0 ± 0.0	840	1
H. czeblukovi	Male	-	-	-	-		-	-
	Female	<980	980	100.0	1	4.0 ± 0.0	980	1
H. elegans	Male	1170	512-1720	69.1	68		890-1720	26
	Female	1183	904-2270	87.6	89	12.3 ± 1.3	1183-2270	25
H. inornatus	Male	-	-	-	-		-	-
	Female	<920	920	100.0	1	3.0 ± 0.0	920	1
H. mcdowelli	Male	>780	760-912	50.0	4		780	1

Table 7.4.3.3 Length at maturity, length range, percentage of mature sea snakes and sample sizes of both sexes from trawls in northern Australia between 1976 and 1998. Mean clutch size, length range* and sample size (N*) of female sea snakes assessed for gonad development are also shown and includes only pregnant snakes. Length range* and sample size (N*) for male sea snakes indicate sea snakes assessed for testicular development.

Species	Sex	Length at maturity (mm)	Length range (mm)	Mature (%)	N	Clutch size (± se)	Length range* (mm)	N*
	Female	635	351-820	90.0	10	3.7 ± 0.9	635-820	3
H. ornatus	Male	850	812-1260	98.1	53		700-1260	15
	Female	<800	700-1574	96.7	60	6.0 ± 0.5	800-1210	37
H. pacificus	Male	<1410	1410	100.0	1		1410	1
	Female	-	1350-1650	-	3	-	-	-
L. hardwickii	Male	810	442-1180	39.6	134		510-1000	30
	Female	677	330-1130	84.2	291	4.3 ± 0.2	718-1130	106

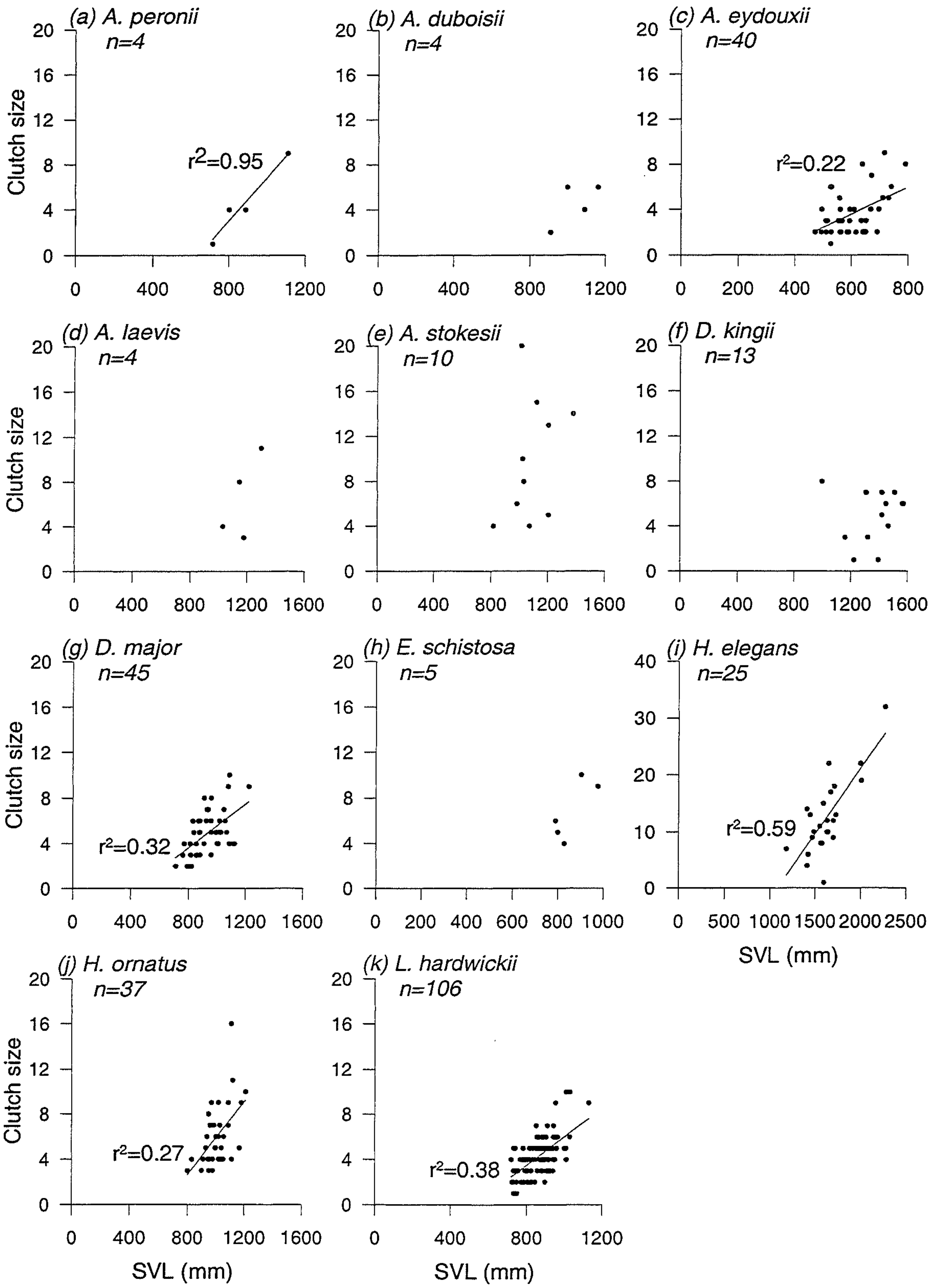


Figure 7.4.3.2 Clutch size versus snout-vent length (mm) of 11 species of sea snake from trawls during 1976 to 1998 in northern Australia. Linear regressions are included for species where the relationship is significant (P<0.05).

Table 7.4.3.4 Mean size (SVL) and weight ± se of term embryos of sea snakes caught by trawlers in northern Australia between 1976 and 1998.

Species	Embryo SVL (mm)	N	Embryo Weight (g)	N
A. peronii	215 ± 13	4	-	-
A. duboisii	308 ± 3	6	34.5± 1.3	6
A. eydouxii	274 ± 6	49	19.6± 1.8	38
D. kingii	573 ± 11	5	32.2± 0.7	5
D. major	427 ± 9	4	39.6± 1.2	4
H. inornatus	245 ± 20	3	-	-
L. hardwickii	301 ± 4	60	53.6± 1.1	59

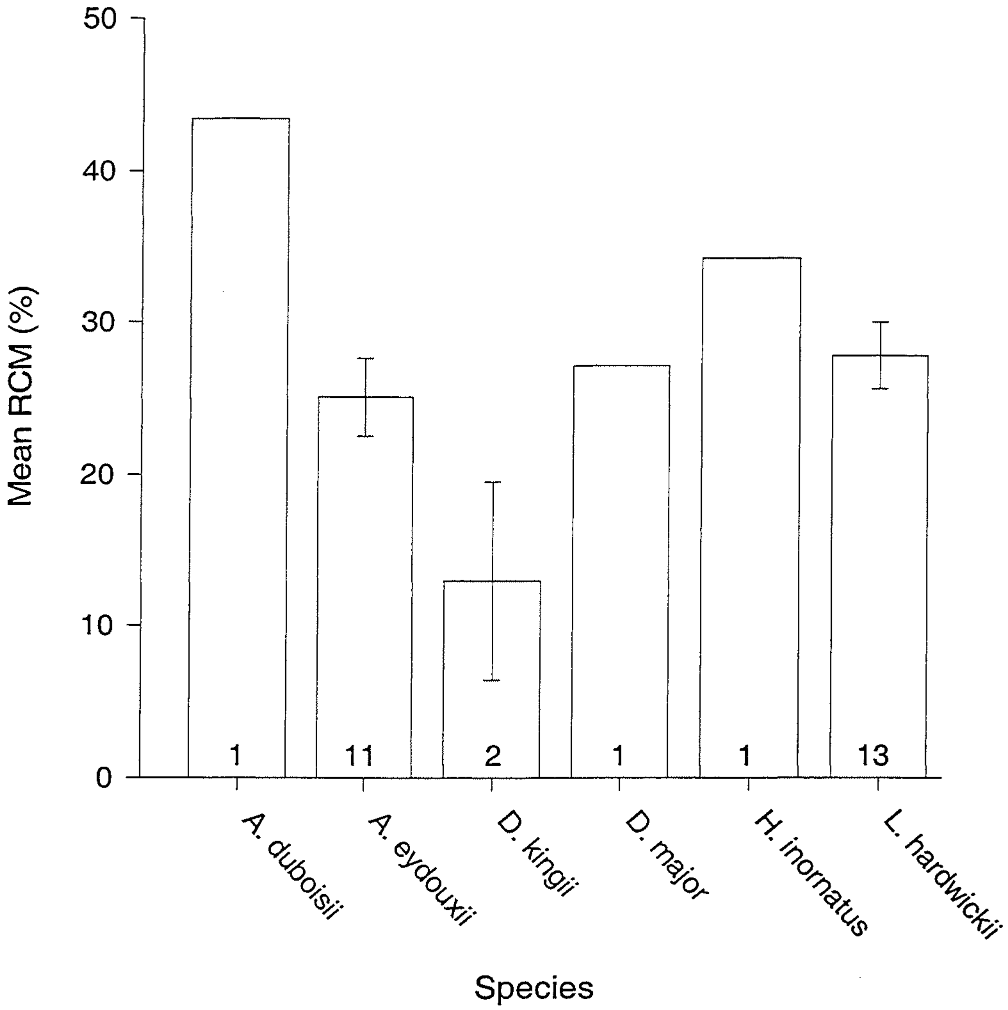


Figure 7.4.3.3 Mean relative clutch mass (RCM) for six sea snake species from trawls between 1976 and 1998 in northern Australia. Only females with term embryos are included. Vertical error bars represent ± 1 se. Sample sizes are shown within figure bars.

The strongly seasonal changes in the monthly mean RCM of female sea snakes are shown in Figure 7.4.3.4 (a-h). *Acalyptophis peronii*, *D. kingii*, *D. major*, *H. elegans*, *H. ornatus* and *L. hardwickii* showed high RCM (10% to 40%) during October to February, indicating females in late pregnancy. Pups were born between March and June, shortly before the lowest RCM for these species was seen. Females became pregnant again soon after and RCM increased over the remaining months of the year with embryos developing again late in the year and early the following year. Females of these species appeared to breed annually with a gestation time estimated to be up to 6 or 7 months. For *A. duboisii*, *D. kingii*, *D. major*, *H. elegans* and *L. hardwickii*, the proportion of females carrying term embryos during January to March was high, reaching 100% for most species (Figure 7.4.3.5). This indicates that the majority of females produce young every year.

The only species to deviate from this pattern was *A. eydouxii*, where females were found to carry term embryos between May and August (Figure 7.4.3.5b) and highest RCM was observed during these months (Figure 7.4.3.4b). *Aipysurus eydouxii* showed lowest RCM in October indicating young were probably born in September (Figure 7.4.3.4b). Similar to other species, *A. eydouxii* females followed an annual reproductive cycle and with most females appearing to breed each year.

Male reproductive cycle for sea snake species seemed to be synchronised with female reproduction (Figure 7.4.3.4). Sea snake testis contained spermatids throughout most of the year however the production of spermatozoa only occurred at, or shortly after the time females gave birth to young.

The proportion of pregnant females, non-pregnant females and males in sea snake catches is shown in Figure 7.4.3.6. There was a significant difference between species in the proportion of pregnant females to non-pregnant females ($\chi_{15} = 87.8$, $P < 0.01$). Pregnant females comprised between 14% (*E. schistosa*) and 80% (*A. duboisii*) of the female sea snake catch, with a mean of 44%. For *D. major*, *H. ornatus* and *A. duboisii*, pregnancy in female sea snakes appeared to significantly increase the probability of being caught ($P<0.05$). In Figure 7.4.3.6, sea snake species were ordered by increasing RCM to determine if RCM influenced the proportion of pregnant females caught. Relative clutch mass had little effect on the catchability of female sea snakes as species with high RCM failed to show a higher proportion of pregnant females in the catch.

Diet

Of the 310 specimens dissected for diet analysis, 36.8% (114) of stomachs were found to contain food with only 22.8% (26) of these containing more than one prey item. The composition of prey items found in the stomachs of twelve species of sea snake is shown in Table 7.4.3.5. In some cases prey items could only be identified to family as they were in a digested condition. Sea snakes preyed on at least 32 species, comprising 22 families of fishes as well as Teuthoidea. The majority of sea snake species appear selective in prey types consumed. The diets of nine species of sea snakes consisted of between one and four species of prey, mainly benthic or substrate associated fish taxa in the families Muraenidae, Nettastomatidae, Apogonidae and Gobiidae. The proportion by weight of these prey species ranged from 73% to 100% (Table 7.4.3.5).

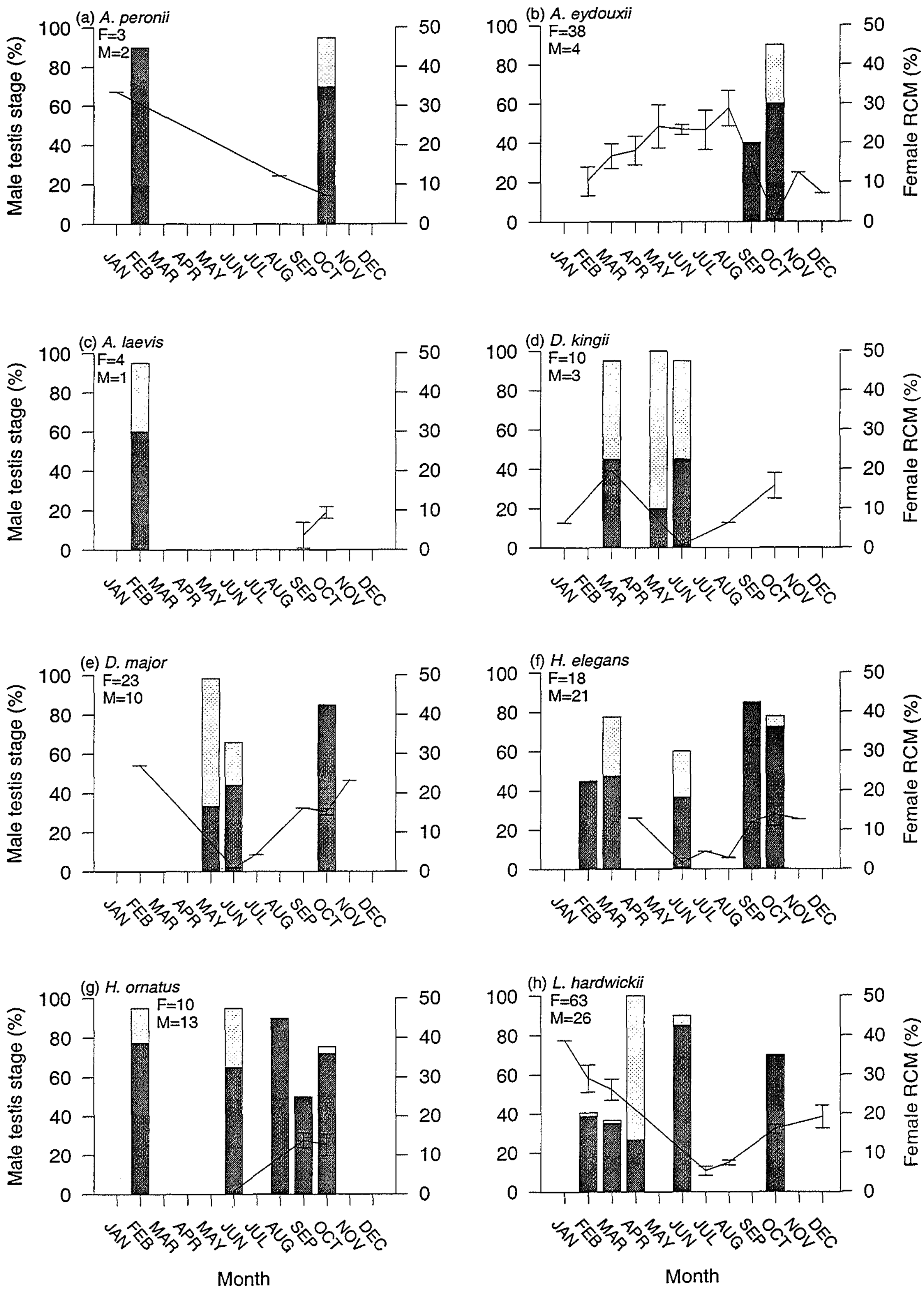


Figure 7.4.3.4 Reproduction cycle of male and female sea snakes from northern Australia between 1976 and 1998. Bars represent the male cycle: stage 2 = spermatids (dark shading bar), stage 3 = spermatozoa (light shading bar). Line graph shows seasonal changes in female RCM.

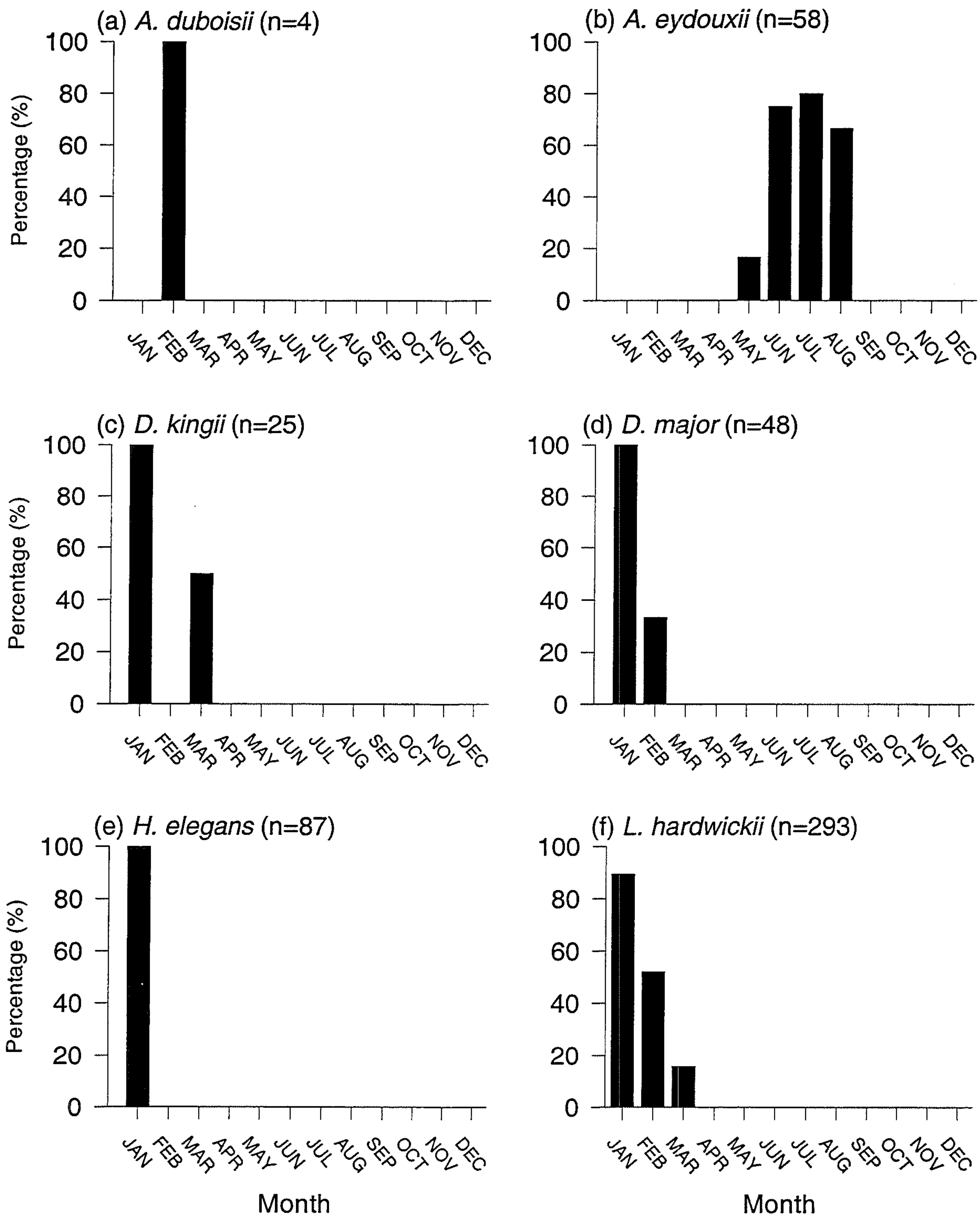


Figure 7.4.3.5 The monthly proportion of female sea snakes from northern Australia with term embryos (data accumulated from 1976 to 1998).

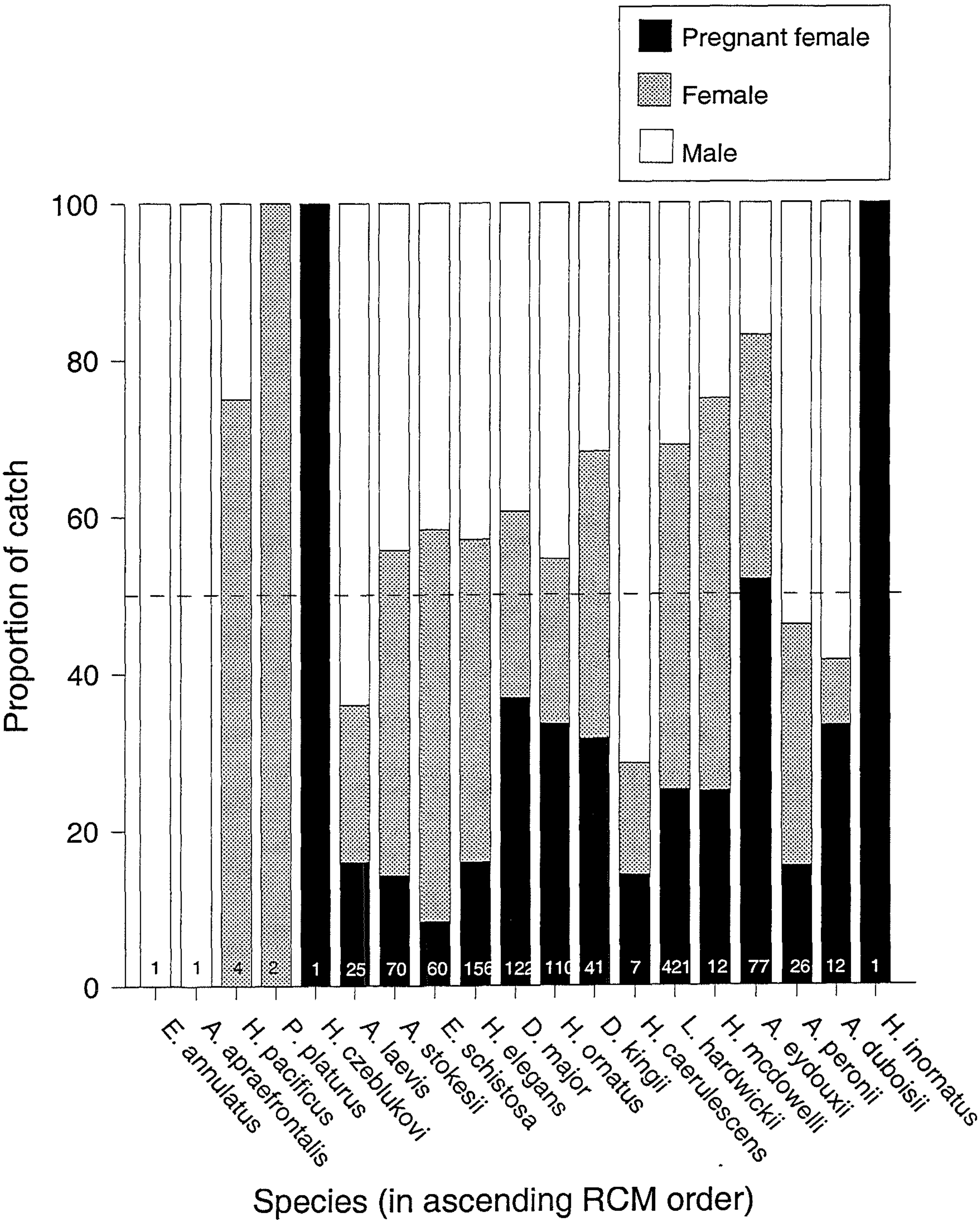


Figure 7.4.3.6 The proportion of pregnant females, non-pregnant females and males collected between 1976 and 1998 in northern Australia. Pregnant females had oviducal eggs or embryos. Sample sizes are indicated within the figure bars.

Table 7.4.3.5 The percentage (by weight) of prey for sea snake species collected from trawls in northern Australia between 1995 and 1998. Benthic and substrate associated prey are highlighted in bold

Species	***A. peronii***	***A. duboisii***	***A. eydouxii***	***A. laevis***	***A. stokesii***	***D. kingii***	***D. major***	***H. czeblukovi***	***H. elegans***	***H. mcdowelli***	***H. ornatus***	***L. hardwickii***
SVL Range (mm)	890	1090	775	1020-1300	720-1020	1000-1620	530-1120	980	512-2000	780	840-1240	442-1180
Sample Size	1	1	1	4	5	3	19	1	24	1	15	39
Muraenidae	-	-	-	-	-	**6.43**	-	-	**97.65**	**100.00**	-	-
Muraenesox cinereus	-	-	-	-	-	-	-	**100.00**	-	-	-	-
***Saurenchelys* sp**	-	-	-	-	-	-	-	-	**0.95**	-	-	-
Euristhmus nudiceps	-	-	-	-	-	**93.57**	**93.29**	-	-	-	-	-
Arius thalassinus	-	-	-	-	-	-	-	-	-	-	-	**3.40**
Synodontidae	-	-	-	-	-	-	-	-	-	-	**4.81**	**2.40**
Herklotsichthys lippa	-	-	-	-	-	-	-	-	-	-	-	5.92
Pellona ditchela	-	-	-	-	-	-	-	-	-	-	-	9.81
Acanthocepola abbreviata	-	**100.00**	-	-	-	-	-	-	-	-	-	-
Sirembo imberbis	-	-	-	-	-	-	-	-	-	-	**8.73**	-
Priacanthus tayenus	-	-	-	-	-	-	-	-	-	-	7.04	-
Apogonidae	-	-	-	-	-	-	-	-	-	-	-	**0.64**
Apogon ellioti	-	-	-	-	-	-	-	-	-	-	**12.58**	**0.76**
Apogon poecilopterus	-	-	-	-	**53.20**	-	-	-	-	-	**12.92**	**1.42**
Leiognathidae	-	-	-	-	-	-	-	-	-	-	-	3.45
Leiognathus bindus	-	-	-	-	-	-	-	-	-	-	-	4.77
Leiognathus sp	-	-	-	12.57	-	-	-	-	-	-	-	-
Leiognathus splendens	-	-	-	-	-	-	-	-	-	-	-	14.31
Gazza minuta	-	-	-	-	-	-	-	-	-	-	-	1.54
Centrogenys vaigiensis	-	-	-	**10.17**	-	-	-	-	-	-	-	-
Gerres filamentosus	-	-	-	-	-	-	-	-	-	-	-	2.27
Mullidae	-	-	-	-	-	-	-	-	-	-	7.77	1.27
Upeneus sulphureus	-	-	-	-	-	-	-	-	-	-	-	1.81
Nemipteridae	-	-	-	-	-	-	-	-	-	-	10.62	-
Nemipterus hexodon	-	-	-	22.99	-	-	-	-	-	-	-	-
Nemipterus nematopus	-	-	-	-	-	-	-	-	-	-	12.38	-
Scolopsis taeniopterus	-	-	-	29.82	-	-	-	-	-	-	-	-
Teraponidae	-	-	-	-	-	-	-	-	-	-	-	6.95
Terapon puta	-	-	-	-	-	-	-	-	-	-	-	5.31

Table 7.4.3.5 The percentage (by weight) of prey for sea snake species collected from trawls in northern Australia between 1995 and 1998. Benthic and substrate associated prey are highlighted in bold

Species	*A. peronii*	*A. duboisii*	*A. eydouxii*	*A. laevis*	*A. stokesii*	*D. kingii*	*D. major*	*H. czeblukovi*	*H. elegans*	*H. mcdowelli*	*H. ornatus*	*L. hardwickii*
SVL Range (mm)	890	1090	775	1020-1300	720-1020	1000-1620	530-1120	980	512-2000	780	840-1240	442-1180
Sample Size	1	1	1	4	5	3	19	1	24	1	15	39
Terapon theraps	-	-	-	-	-	-	-	-	-	-	-	3.84
Pelates quadrilineatus	-	-	-	-	-	-	-	-	-	-	-	0.56
Pomadasys maculatum	-	-	-	-	-	-	-	-	-	-	-	3.91
Gobiidae	**100.00**	-	-	-	-	-	-	-	-	-	-	-
Parachaeturichthys polynema	-	-	-	-	-	-	**2.53**	-	-	-	-	-
Yongeichthys nebulosus	-	-	-	-	**19.75**	-	-	-	-	-	**9.62**	-
Trichiurus lepturus	-	-	-	-	-	-	-	-	-	-	-	5.94
Cynoglossidae	-	-	-	-	-	-	-	-	-	-	-	**0.61**
Torquigener whitleyi	-	-	-	-	-	-	-	-	-	-	-	**1.05**
Teleost (unidentified)	-	-	100.00	24.45	27.05	-	4.19	-	1.29	-	13.54	14.58
Teuthoidea	-	-	-	-	-	-	-	-	0.11	-	-	3.50
Benthic/substrate associated	100.00	100.00	-	10.17	72.95	100.00	95.81	100.00	98.60	100.00	48.65	10.27
Pelagic/demersal	-	-	-	65.39	-	-	-	-	-	-	37.81	71.66
Teleost	-	-	100.00	24.45	27.05	-	4.19	-	1.29	-	13.54	14.58
Teuthoidea	-	-	-	-	-	-	-	-	0.11	-	-	3.50

In contrast, prey diversity was high for *L. hardwickii*. This species consumed a wide range of prey species, at least 18 fish species and a squid, with most being demersal, benthopelagic and pelagic, 71.7% by weight compared to 10.3% of benthic or substrate associated fish species. This indicates that *L. hardwickii* may be capable of catching fast swimming, schooling fish species or feeding on discarded trawl bycatch. Two species, *A. laevis* and *H. ornatus*, were found to also prey on a range of demersal or benthopelagic fish species (65.4% and 37.8% by weight, respectively). However, these prey items were recently consumed and may have been taken in the trawl net.

Stomach contents of sea snakes collected during the September-October 1998 research cruise from NPF areas open to trawling and adjacent areas closed to trawling are given in Table 7.4.3.6. There was little difference in the prey eaten by *H. elegans* collected in areas open and closed to fishing. This species fed predominantly on benthic fish species with Muraenidae constituting 99.7% and 100% of the diet in open and closed areas, respectively. Demersal, benthopelagic and pelagic prey types made up major portions of diets for *L. hardwickii* in NPF open and closed areas. In areas open to the NPF, squid comprised about 65.3% of the diet of *L. hardwickii* followed by *Apogon poecilopterus* at 30.1%. *Pellona ditchella*, a pelagic clupeid, and *Gerres filamentosus*, a demersal fish species, were identified from the stomachs of *L. hardwickii* caught in the NPF closed area. Together these two items comprised about 70% of the total prey weight with the remaining stomach content classified as unidentified teleost material. A comparison could not be made with the remaining four species as these species were not caught in both areas open and closed to fishing that had prey material in their stomachs (Table 7.4.3.6).

Catch Rates in 1996-98

Sea snake catch rates obtained from three research cruises during 1997 and 1998 (February-March 1997, October-November 1997, September-October 1998) varied considerably between time of day of trawl (Figure 7.4.3.7). Highest catch rates (22.3 sea snakes h^{-1} km^{-1}) were obtained during dawn trawling. However there were few trawls, generating large standard errors (Table 7.4.3.7). Mean sea snake catch rates during the day (10.6 sea snakes h^{1} km^{-1}) were higher than at night (2.7 sea snakes h^{-1} km^{-1}) (Table 7.4.3.7).

Commercial vessels recorded 124 sea snakes from 607 hours of night trawling, notably higher than the 28 sea snakes in 398 hours of research night trawling. Commercial vessels produced higher catch rates of sea snakes during the night than dawn trawling, 4.4 and 1.8 sea snakes h^{-1} km^{-1}, respectively (Table 7.4.3.8). This difference was due, in part, to a high catch rate of 9.0 sea snakes h^{-1} km^{-1} (102 sea snakes in 225.5 hours of trawling) by one trawler around 'Mornington Island' in 1997. The lowest catch rates for commercial trawlers occurred around 'Groote Eylandt' in 1997 where the mean catch rate was 0.4 sea snakes h^{-1} km^{-1}.

Changes in catch rates from 1989 to 1996-98

The overall catch rates of most species of sea snake appear to have remained stable between 1989 and 1996-98 (Figure 7.4.3.8). However, four species show evidence that their catch rates have declined. The catch rates of both *D. kingii* and *D. major* have declined and the most abundant species, *H. elegans*, also has a reduced catch rate.

Table 7.4.3.6 The percentage of prey (by weight) of six species of sea snakes collected from areas closed to trawling and adjacent NPF trawl grounds during the 1998 research cruise. Benthic and substrate-associated prey species are highlighted in bold.

Species	***A. laevis***	***H. ornatus***	***H. elegans***	***H. elegans***	***A eydouxii***	***A. stokesii***	***L. hardwickii***	***L hardwickii***
Open/Closed Area	Open	Open	Open	Closed	Closed	Closed	Open	Closed
SVL Range (mm)	1300	1090-1240	860-2000	1490-1720	775	850	1030-1130	770-1180
Sample Size	1	3	4	2	1	1	2	3
Muraenidae	**-**	**-**	**99.74**	**100.00**	**-**	**-**	**-**	**-**
Pellona ditchela	-	-	-	-	-	-	-	37.37
Apogon poecilopterus	-	55.63	-	-	-	-	30.05	-
Leiognathus sp	16.63	-	-	-	-	-	-	-
Centrogenys vaigiensis	**13.46**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Gerres filamentosus	-	-	-	-	-	-	-	33.10
Nemipterus hexodon	30.43	-	-	-	-	-	-	-
Scolopsis taeniopterus	39.48	-	-	-	-	-	-	-
Yongeichthys nebulosus	**-**	**41.39**	**-**	**-**	**-**	**100.00**	**-**	**-**
Teleost (unidentified)	-	2.98	-	-	100.00	-	4.66	29.54
Teuthoidea	-	-	0.26	-	-	-	65.28	-

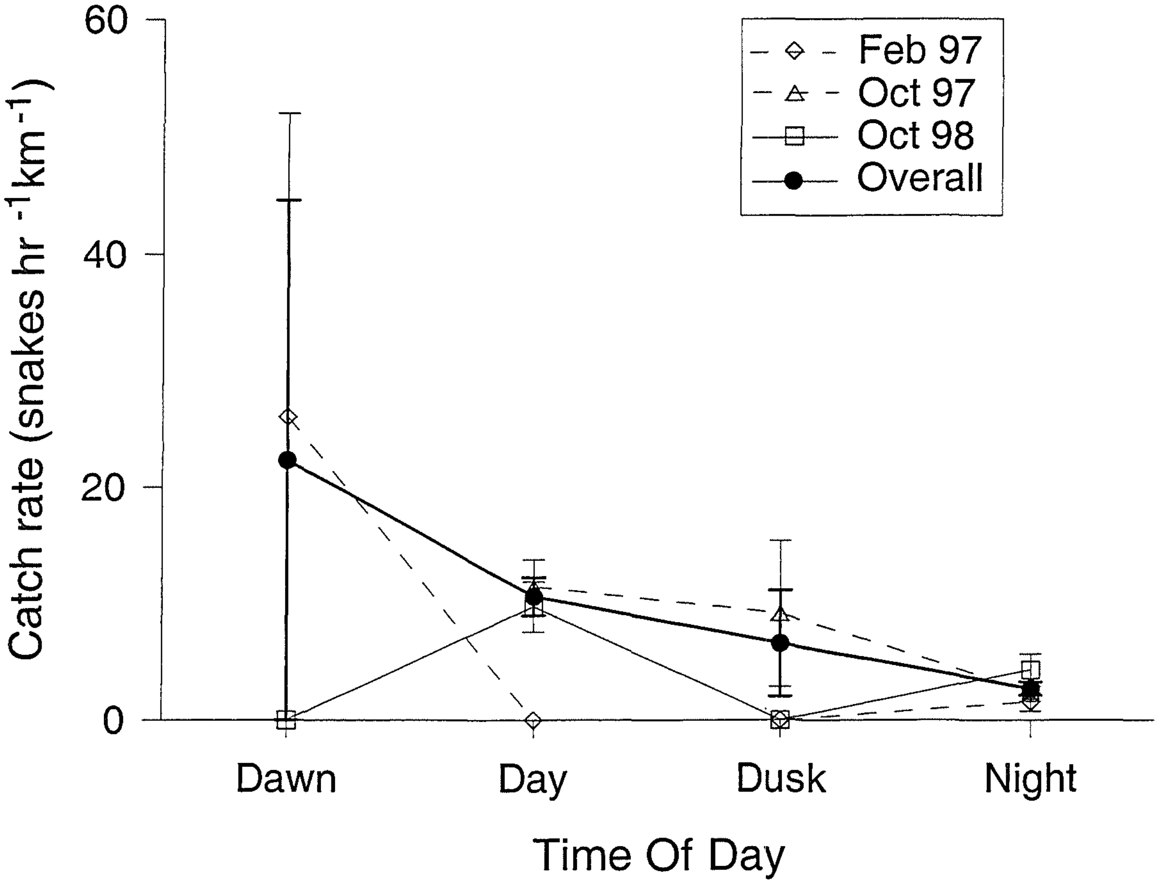


Figure 7.4.3.7 The mean catch rates of sea snakes at different times of day during 1997-1998 research cruises in the Gulf of Carpentaria. Dawn (0600-0700), day (0700-1730), dusk (1730-1830) and night (1830-0600). Vertical bars represent ± 1 se.

Table 7.4.3.7 Number of sea snakes caught and mean catch rates of snakes (snakes h^{-1} km^{-1} head rope length) collected from the RV Southern Surveyor in the Gulf of Carpentaria at different times of day. AP = *A. peronii*, AD = A. *duboisii*, AE = *A. eydouxii*, AL = *A. laevis*, AS = *A. stokesii*, DK = *D. kingii*, DM = *D. major*, HE = *H. elegans*, HM = *H. mcdowelli*, HO = *H. ornatus*, LH = *L. hardwickii*. Dawn (0600-0700), day (0700-1730), dusk (1730-1830) and night (1830-0600).

Cruise	Time	Trawl hours	Trawls N	Depth range (m)	AP	AD	AE	AL	AS	DK	DM	HE	HM	HO	LH	Snakes N	Mean catch rate ± se
Feb-Mar 1997	Day	0.2	1	21	-	-	-	-	-	-	-	-	-	-	-	0	0
	Night	133.6	240	18-58	2	1	-	-	-	-	1	1	-	-	-	5	1.5 ± 0.8
	Dawn	3.3	6	20-44	-	-	-	-	-	-	-	-	-	2	-	2	26.1 ± 26.1
	Dusk	1.7	5	21-33	-	-	-	-	-	-	-	-	-	-	-	0	0
Oct-Nov 1997	Day	95.6	188	15-58	-	-	3	1	3	1	2	5	1	10	2	28	11.4 ± 2.4
	Night	156.7	270	15-59	1	-	3	-	-	1	-	4	-	1	-	10	2.4 ± 0.8
	Dusk	9.1	18	19-47	-	-		-	-	-	2	-	-	-	-	2	9.1 ± 6.3
Sept-Oct 1998	Day	80.3	161	12-31	-	-	5	-	1	-	-	7	-	2	4	19	9.7 ± 2.2
	Night	107.4	214	10-31	-	-	2	3	4	-	-	1	-	-	3	13	4.3 ± 1.4
	Dawn	0.5	1	14-15	-	-	-	-	-	-	-	-	-	-	-	0	0
	Dusk	1.1	2	14-16	-	-	-	-	-	-	-	-	-	-	-	0	0
Total	Day	176.0	350	12-58	-	-	8	1	4	1	2	12	1	12	6	47	10.6 ± 1.6
	Night	397.7	724	10-59	3	1	5	3	4	1	1	6	-	1	3	28	2.7 ± 0.6
	Dawn	3.8	7	14-44	-	-	-	-	-	-	-	-	-	2	-	2	22.3 ± 22.3
	Dusk	11.8	25	19-47	-	-	-	-	-	-	2	-	-	-	-	2	6.6 ± 4.6

Table 7.4.3.8 The number of sea snakes caught and the mean catch rates (snakes h^{-1} km^{-1} head rope length) in the Gulf of Carpentaria at different times of day during scientific observer cruises on commercial vessels. AD- *A. duboisii*, AE- *A. eydouxii*, AL- *A. laevis*, AS- *A. stokesii*, DK- *D. kingii*, DM- *D. major*, Hsp- *Hydrophis* spp., HE - *H. elegans*, HO- *H. ornatus*, HP- *H. pacificus*. The 'Sept-Oct 1996' (A), (B) and (C) cruises indicate different commercial vessel used by scientific observer for that cruise. Night (1830-0600) and dawn (0600-0700).

Cruise	Time	Trawl hours	Trawls	Depth range (m)	AD	AE	AL	AS	DK	DM	Hsp	HE	HO	HP	Snakes N	Mean catch rates ± se
Sept-Oct 1996 (A)	Night	53.0	19	41-47	-	-	-	1	-	1	-	1	1	-	4	1.4 ± 0.7
	Dawn	8.5	4	41-47	-	-	-	-	-	1	-	1	-	-	2	5.7 ± 3.4
Sept-Oct 1996 (B)	Night	18.3	6	39	1	-	1	-	-	-	1	-	-	-	3	3.3 ± 2.2
	Dawn	6.0	2	38-39	-	-	-	-	-	-	2	-	-	-	2	6.5 ± 6.5
Sept-Oct 1996 (C)	Night	133.0	40	26-45	1	1	1	-	-	-	1	2	2	-	8	1.4 ± 0.5
	Dawn	35.8	12	26-45	-	-	1	-	-	-	1	-	-	-	2	1.3 ± 0.8
May-Jun 97	Night	225.5	76	33-43	-	1	1	5	4	35	15	34	3	4	102	9.0 ± 1.0
	Dawn	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sept-Oct 97	Night	160.1	45	28-36	-	-	-	1	-	-	1	-	1	-	3	0.4 ± 0.3
	Dawn	36.8	15	28-36	-	1	-	-	-	-	-	-	-	-	1	0.6 ± 0.6
June 98	Night	17.3	6	14-23	-	-	-	-	1	-	-	2	1	-	4	3.8 ± 1.8
	Dawn	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	Night	607.1	192	14-47	2	2	3	7	5	36	18	39	8	4	124	4.3 ± 0.5
	Dawn	87.0	33	26-47	-	1	1	-	-	1	3	1	-	-	7	1.8 ± 0.7

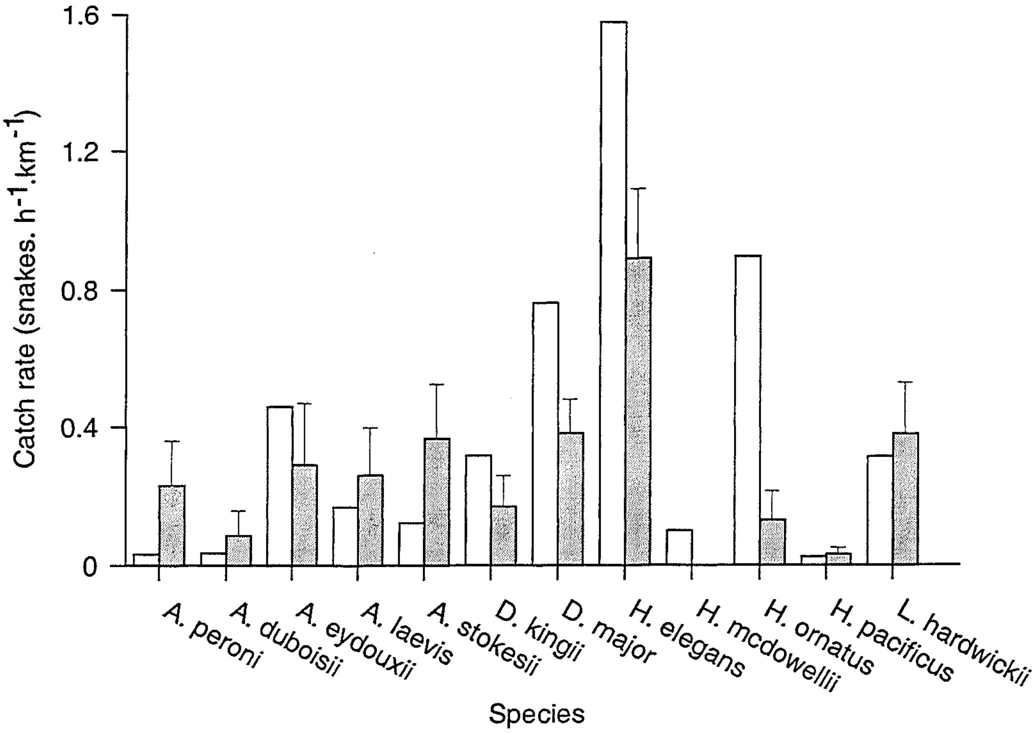


Figure 7.4.3.8 The catch rates of the 12 most abundant species of sea snake (in 1996-98) caught by prawn trawlers in the Gulf of Carpentaria in 1989 (Ward 2000) (open) and in 1996-98 (shaded). Vertical bars represent ± 1 se.

The fourth species, *H. mcdowelli*, had a very low catch rate during our study, but the change was highly significant (P<0.0001) and suggests that there may have been a real decline in the catch rate of this species. These results may have been affected by the distribution of trawl effort during our study. However, this is unlikely to have produced these results because our study concentrated in regions where the commercial trawl effort was highest.

The overall catch rates of sea snakes showed little change since 1989 in four of the regions of the NPF where we had sufficient data (Figure 7.4.3.9). The greatest decline was in the 'Weipa' region, where the mean catch rate was one half that recorded in 1989. The other regions ('Groote Eylandt', 'Mornington Island' and 'Limmen Bight' all showed similar mean overall catch rate to 1989.

The breakdown of the regional combined catch rates reveals that while the overall catch rates have remained stable, the species composition of the trawl catches have changed since 1989 in the three regions where we have sufficient data ('Groote Eylandt', 'Mornington Island' and 'Weipa') (Figure 7.4.3.10). The species composition and catch rates of sea snakes at 'Groote Eylandt' have undergone the greatest change since 1989 (Figure 7.4.3.10). The catch rate of the most commonly caught species in 1989, *H. elegans*, has remained unchanged, whereas the catches of the two species of *Disteira* (*D. kingii* and *D. major*) have declined.

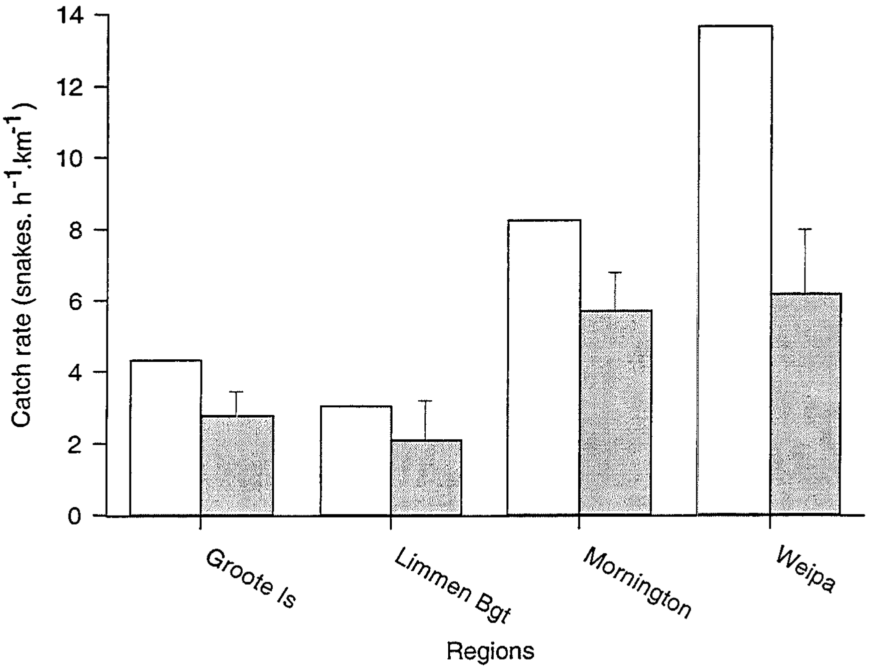


Figure 7.4.3.9 The combined catch rate of all species of sea snake caught in prawn trawls in four regions of the Gulf of Carpentaria in 1989 (Ward 2000) and 1996-98 (shaded). Vertical bars represent ± 1 se.

Although *A. eydouxii* had the second highest mean catch rate in 1996-98, its catch rate was similar to those of *A. laevis, H. ornatus* and *L. hardwickii* (*t-test*, $P>0.5$). The catch rates of *A. laevis* and *L. hardwickii* were significantly higher at 'Groote Eylandt' in 1996-98 than in 1989 ($P<0.05$). This suggests that the distribution or pattern of fishing effort has probably changed or conditions in this region have been modified to favour these species.

The catch rates of most species remained unchanged at 'Mornington Island' between 1989 and 1996-98 (Figure 7.4.3.10). The catch rates of some species, such as *A. eydouxii* and *D. kingii* were higher in 1996-98. The only species that showed a major change in catch rate was *H. ornatus*. Its catch rate dropped to about half that found in 1989 and it has been replaced by *H. elegans* as the most abundant species in the catch.

This differed from the pattern at 'Weipa' where the catch rate of *H. ornatus* has increased and it was the most common species. Catch rates of other species, such as the two *Disteira* species, appear to have declined and there has been a major change in species composition since 1976-79. The most commonly caught species in 1976-79 was *L. hardwickii* and this species was caught much less frequently in 1996-98. However, the catch rates of the common species at 'Weipa' are still higher than at either of the other two sites studied.

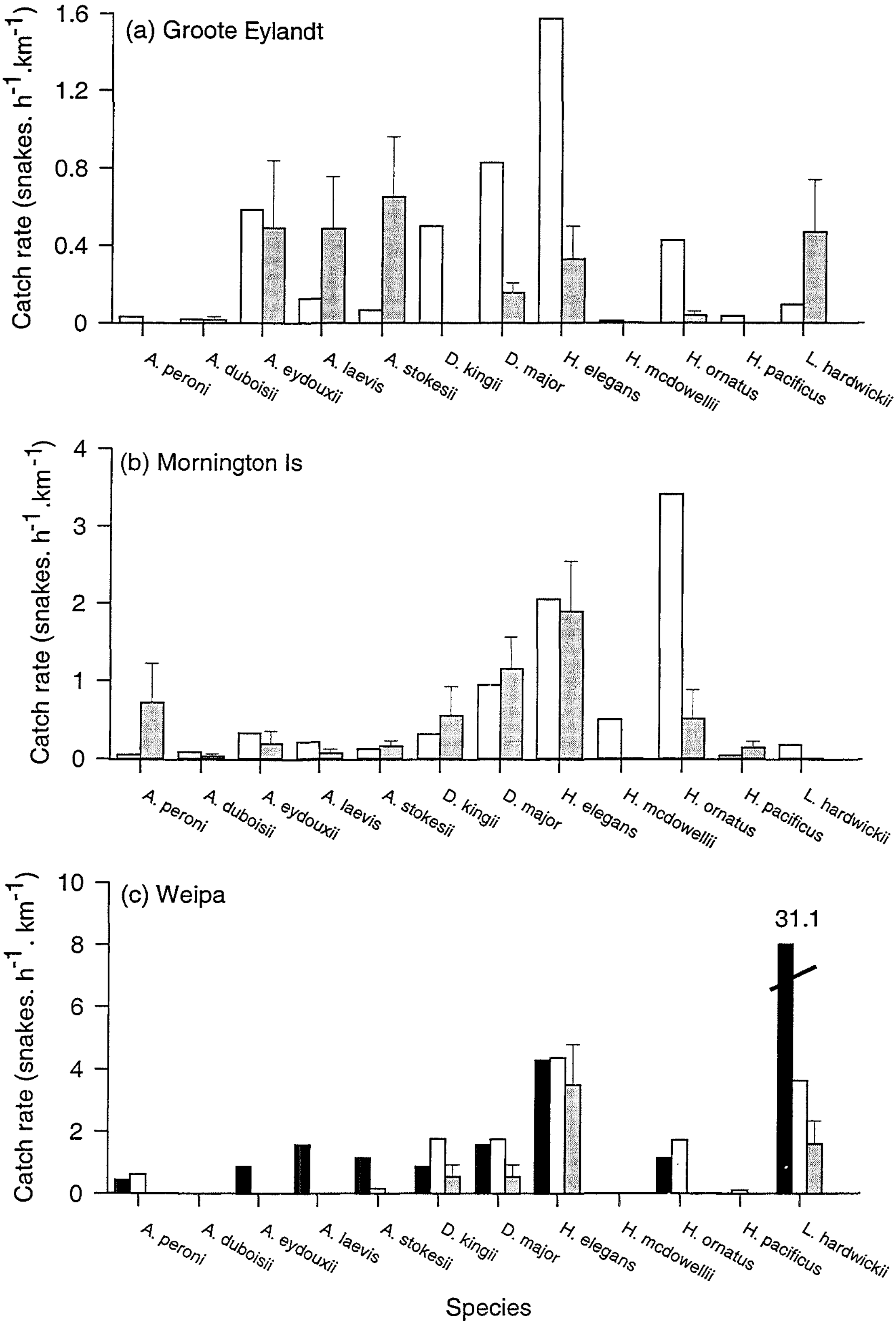


Figure 7.4.3.10 The mean catch rates of the 12 most abundant species of sea snake in prawn trawls from (a) 'Groote Eylandt' and (b) 'Mornington Island' in 1989 (Ward 2000) and 1996-98 (shaded). (c) catch rates at 'Weipa' of the same species in 1976-79 (black), 1989 (open) and 1996-98 (shaded). Data for 1976-79 are from Wassenberg *et al.* (1994) and 1989 from Ward (2000).

Some of these differences in species composition and changes in catch rates at 'Weipa' are probably related to the differences in depth that each study trawled. The maximum depth trawled in the study in 1976-79 was 26m (Wassenberg *et al.,* 1994). The commercial tiger prawn trawl grounds that were fished in 1989 and 1996-98 were mainly between 20 and 40m and located much further from the coast. Ward (2000) found a significant depth-related effect for *L. hardwickii* and *H. elegans*. He found trawlers caught more *L. hardwickii* in shallow water and more *H. elegans* in deeper water. Our data for *L. hardwickii* show a similar pattern, but it does not explain the results for the other species that have a lower catch rate in 1996-98 compared to 1976-79.

There is a declining trend in the overall catch rate of sea snakes in the Gulf of Carpentaria and at 'Weipa' since 1976-79 (Figure 7.4.3.11). The decline appears to be more dramatic at 'Weipa', but these data are biased by the distribution of trawls in each of the studies. Our data are most comparable with that of Ward (2000) and show a slight increase in catch rates at 'Weipa' since 1989. The overall catch rates in the Gulf of Carpentaria show a decline between 1989 and 1996-98, but the drop in catch rate was greatest between 1976-84 and 1989 and would also be biased by the differences in the regions surveyed.

Sea snake sustainability

Axis 1: Species susceptibility

Most species of sea snake had a weighted overall rank over two (Table 7.4.3.9). *Hydrophis pacificus* had the lowest rank, followed by *D. kingii*. Most species were caught throughout the NPF during the study of Ward (2000). The observations in the published literature suggest that the most commonly caught species tend to prefer open, unstructured habitats on soft sediments, characteristic of prawn trawl grounds. The diet of most species contained benthic fish species caught in prawn trawls and none ate species that did not occur in open, unstructured habitats. Three species of snake had higher catch rates during the night and most had higher catch rates during the day (Table 7.4.3.9). The survival index came from Section 7.4.2 and most species had above average survival.

Axis 2: Capacity to recover

The smallest length caught was less than the length at maturity for all species and the mean mortality index (Z) varied from 0.4 – 1.9 (Table 7.4.3.10). The mean length caught of most species was larger than the length at maturity (Table 7.4.3.10) indicating that the probability that most species had bred at least once was very high (P>0.98) (Table 7.4.3.11). The exceptions to this pattern were *A. laevis* and *E. schistosa*. The mean size of both species was less than the size at maturity and both had a low probability that, on average, they had bred before being caught in prawn trawls (P<0.05).

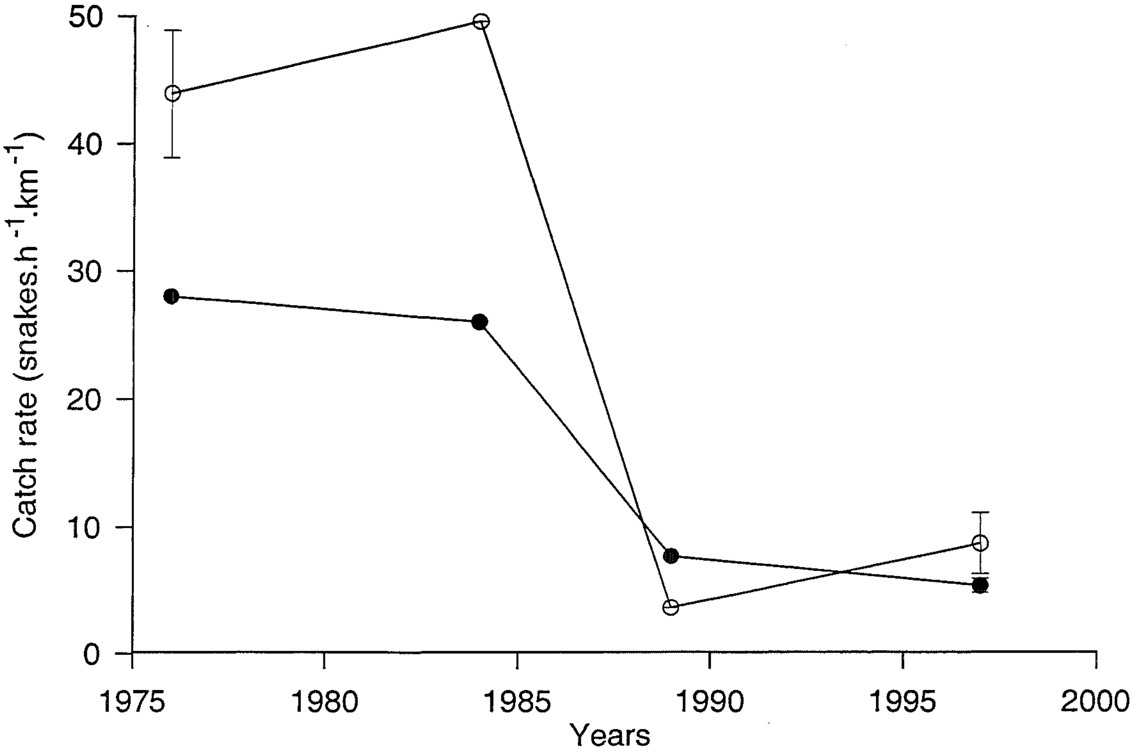


Figure 7.4.3.11 Changes in the overall catch rate of sea snakes in the Gulf of Carpentaria section of the NPF, including 'Weipa' (closed) and at 'Weipa' (open) between 1976-79 and 1996-98. Vertical bars represent ±1 se where calculable. Data for 1976-79 and 1984 are from Wassenberg *et al.* (1994) and 1989 from Ward (2000).

Table 7.4.3.9 The ranking of the relative susceptibility to trawling of sea snakes caught in the NPF during the current project. All measures of susceptibility have been range standardised and scored on a one to three scale with one being the most susceptibility. Overall rank is the based on the sum of the combined weighted ranks. Weightings are shown in bold beneath each criterion and are based on the relative importance of each given by the NPF Fisheries Advisory Group at their 11th November, 1999 meeting.

Species	**Preferred habitat**	**Survival**	**Range**	**Day/night**	**Diet**	**Overall Rank**
	3	**3**	**2**	**2**	**2**	
H. pacificus	1	3 ?	1	1	2	1.67
D. kingii	2	1	2	2	2	1.75
H. elegans	1	1	3	3	2	1.83
A. stokesii	3	1	3	2	1	2.00
A. laevis	3	2	2	2	1	2.08
E. schistosa	2	3	1	2	2	2.08
A. duboisii	3	3	1	1	2	2.17
D. major	1	3	3	2	2	2.17
H. ornatus	2	2	3	3	1	2.17
L. hardwickii	2	2	3	3	1	2.17
A. peronii	2	3	3	1	2	2.25
H. mcdowelli	2	3	1	3	2	2.25
A. eydouxii	2	3	3	3	2	2.58

Table 7.4.3.10 The length at first capture (L'), length at maturity (L_m) and its percentage of maximum length (in brackets), mean ($\bar{L}$) and maximum length of 14 species of sea snake and the mean mortality index (Z) of each species.

Species	L' (mm)	L_m (mm)	$\bar{L}$ ± se (mm)	Max. Length (mm)	Mortality index (Z)
A. peronii	702	716 (63)	879 ± 24	1140	1.5
A. duboisii	550	910 (78)	981 ± 34	1170	0.7
A. eydouxii	392	472 (56)	605 ± 10	850	1.1
A. laevis	640	1034 (80)	946 ± 30	1300	1.1
A. stokesii	595	817 (59)	933 ± 18	1380	1.3
D. kingii	620	823 (50)	1213 ± 39	1650	0.7
D. major	530	710 (43)	922 ± 12	1650	1.9
E. schistosa	386	790 (77)	760 ± 16	1024	0.7
H. elegans	430	1183 (52)	1372 ± 19	2270	1.0
H. mcdowelli	351	635 (70)	738 ± 37	912	0.4
H. ornatus	700	800 (49)	1046 ± 13	1630	1.7
H. pacificus	1350	1350 (82)	1453 ± 67	1650	1.9
L. hardwickii	311	677 (54)	783 ± 7	1250	1.0

Table 7.4.3.11 The ratio of length at maturity (L_m) to the mean length ($\bar{L}$) in the trawl catch during 1996-98 and the probability that these snakes have bred before capture.

Species	Ratio $\bar{L} / L_m$	Probability of breeding
A. peronii	1.28	> 0.9999
A. duboisii	1.08	> 0.98
A. eydouxii	1.28	> 0.9999
A. laevis	0.91	< 0.02
A. stokesii	1.14	> 0.9999
D. kingii	1.47	> 0.9999
D. major	1.30	> 0.9999
E. schistosa	0.96	< 0.03
H. elegans	1.16	> 0.9999
H. mcdowelli	1.16	> 0.997
H. ornatus	1.31	> 0.9999
H. pacificus	1.08	> 0.94
L. hardwickii	1.16	> 0.9999

Hydrophis elegans were caught at the smallest size of all species as a percentage of the length at sexual maturity (36%). The length at sexual maturity as a proportion of maximum length varied greatly between species (Table 7.4.3.10). *Disteira major* appear to mature earlier than other species and *A. laevis* and *H. pacificus* were latest maturing species, assuming growth rates are similar. Burns (1985) also suggested that *A. laevis* matured at more than 4 yrs of age.

The estimated number of sea snakes caught by prawn trawlers in the Gulf of Carpentaria has dropped from over 105,000 in 1989 to between 51,000 and 86,000 during 1993-97 (Figure 7.4.3.12). This represents 10-12% of the total population of sea snakes in the Gulf of Carpentaria and equates to a fishing mortality of 3.7-6.3% of the population (given a combined capture and post-capture mortality rate of 52%: Section 7.4.2). The decline in our estimate of the sea snake catch was due to a reduction in the level of fishing effort (boat days) between 1993 and 1997.

The population estimates of most species in the Gulf of Carpentaria varied from 1,200 to 100,000 in 1996-98 (Figure 7.4.3.13). These estimates were much smaller than those in 1989 for *Hydrophis* and *Disteira* species, but similar for the others. The common species (*H. elegans*, *H. ornatus* and *L. hardwickii*) appear to show a greater reduction in population size but these changes may be driven by changes in the current distribution and the level of fishing effort.

Hydrophis pacificus and *A. duboisii* had the lowest combined rank for their capacity to recover from trawling (Table 7.4.3.12). The species with the highest catch rates, *H. elegans,* had population and life history characteristics that ranked it as the most sustainable. No species scored a rank of one for all criteria, nor did any score an overall rank of three. This indicates that all species had at least one characteristic that would make them susceptible to trawling or reduce their capacity to recover.

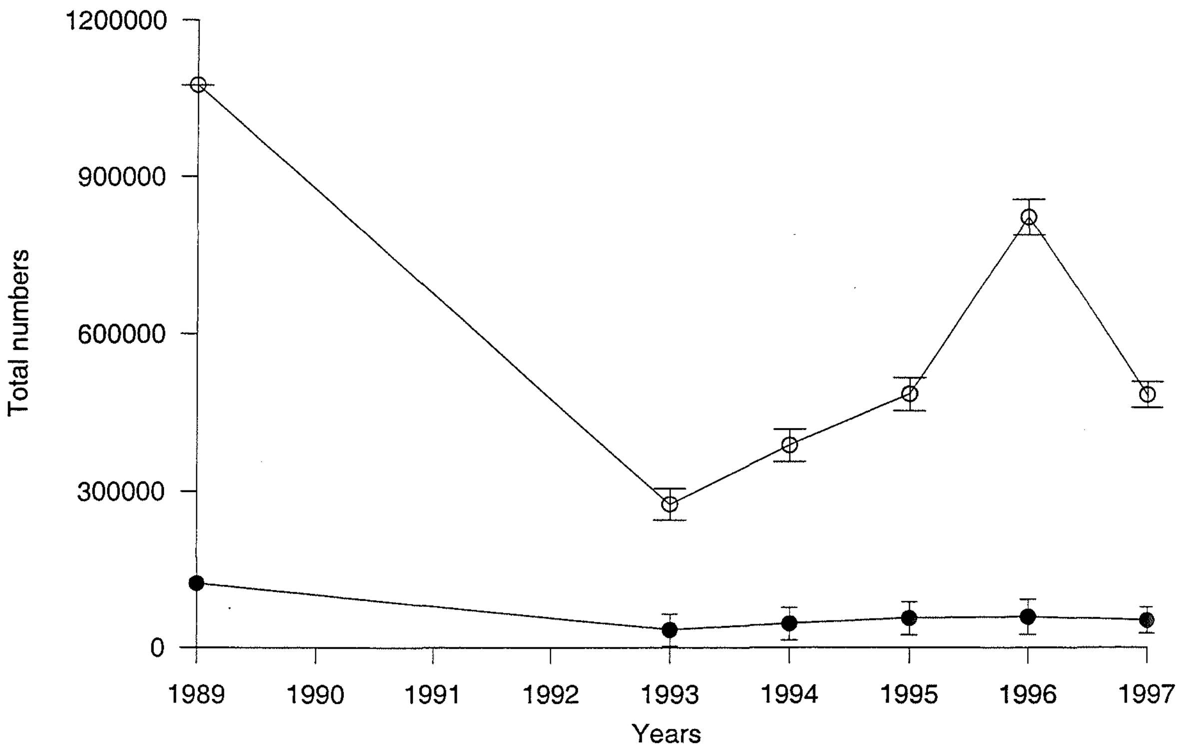


Figure 7.4.3.12 The estimated total catch of sea snakes by prawn trawlers (solid) and their total annual population estimate (open) in the Gulf of Carpentaria from 1989 to 1997. Vertical bars represent ± 1 se.

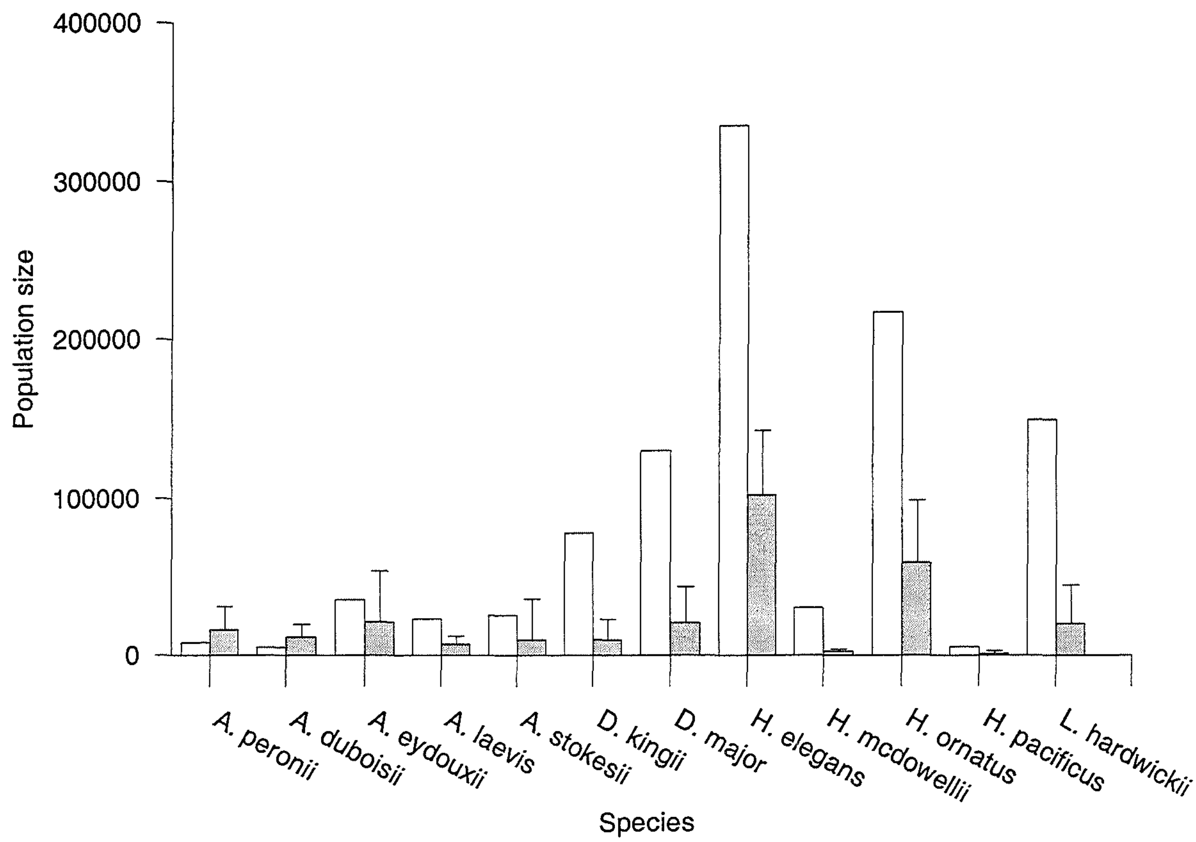


Figure 7.4.3.13 The estimated population size of twelve species of sea snake caught during 1989 and 1996-98 (shaded) in the Gulf of Carpentaria. Vertical bars represent ±1 se.

Table 7.4.3.12 The ranking of sea snakes caught in the NPF according to their capacity to recover from trawling. The ranking method is given in the text. The overall ranks are based on the sum of the weighted ranks, and are ordered from least to most sustainable. The relative weighting of each criterion is given in bold.

Species	Maximum size **3**	Percentage population removed **3**	Breeding **3**	Length at maturity **2**	Survival index **2**	Annual fecundity **2**	Overall Rank
A. duboisii	1	3	1	1	1	1	1.4
H. pacificus	2	1	2	1	1	1 ?	1.4
A. eydouxii	1	1	2	3	2	1	1.6
A. laevis	2	2	1	1	2	2	1.7
H. mcdowelli	1	1	2	2	3	1	1.8
A. peronii	1	3	1	2	3	1	1.8
E. schistosa	1	3	1	1	3	2	1.8
D. major	2	1	2	3	1	2	1.8
A. stokesii	2	1	2	2	2	3	1.9
H. ornatus	2	2	2	3	1	1	1.9
L. hardwickii	2	2	2	3	2	1	2.0
D. kingii	2	1	2	3	3	2	2.1
H. elegans	3	3	2	3	2	3	2.7

7.4.3.4 Discussion

The species composition and catch rates of sea snakes caught by prawn trawls differ between 1976 and 1998 in the Gulf of Carpentaria. For example, data from Wassenberg *et al.* (1994) indicated that *E. schistosa*, *H. mcdowelli* and *H. caerulescens* were caught in trawls during 1976-79. In our study, only two *H. mcdowelli* and no *E. schistosa* or *H. caerulescens* were caught in prawn trawls during 1996-98. Even the most common species, *D. major*, *H. elegans*, *H. ornatus* and *L. hardwickii* showed considerable variations in their catch rates over time and regions within the Gulf of Carpentaria.

These catch rate differences may have been caused by the continual changes in fishing practices between 1976 and 1998, such as changes in the level of fishing effort, fishing patterns and regions fished by prawn trawlers and the use of GPS. It can also be explained to some degree by the seasonal distribution of sea snakes as few studies were carried out in the same regions and times of the year. For example, Redfield *et al.* (1978) collected sea snake samples in the eastern Gulf of Carpentaria region and found *L. hardwickii* was the most common species, with a higher catch rate in shallow waters during spring to summer, whereas *H. elegans* was more abundant during June and December. Therefore it is difficult to verify if differences in sea snake catches are a result of actual changes in sea snake numbers over time, and if so, whether it is due to natural fluctuations or fishing pressures.

Life history

The life history characteristics of sea snakes, such as differences in their sex ratio in catches, suggest that they may be susceptible to trawling. There were significantly more females than males caught in trawls for the majority of sea snake species in northern Australia. The difference in numbers of females and males varied considerably between species and regions. For example, females outnumbered males by more than 2:1 around 'Mornington Island' and 'Weipa'. It is possible that females move to these regions to give birth, as there are large estuaries nearby that could act as nurseries (Wassenberg *et al.*, 1994). As these regions have high fishing effort, trawling would have a more significant effect on these sea snake populations.

Lemen and Voris (1981) reported differences in sex ratios between species, locations and months. However they suspected this was due to sexual differences in habitat selection or activity since sex ratios of *E. schistosa* embryos were not different from 1:1. If this is correct, females from the majority of species in our study showed some kind of behavioural difference. For example, it may be that remaining close to the bottom for greater food availability or protection from predators resulted in them being caught more frequently than males.

Female sea snakes from northern Australia appear to become mature at a smaller SVL than males. Voris and Jayne (1979) reported female *E. schistosa* from Malaysia were sexually mature at 730mm SVL. We found that *E. schistosa* females did not produce oviducal eggs or embryos until they reached 790mm SVL, which is larger than that reported by Voris and Jayne (1979). This difference may only indicate that we had small sample sizes for the months that females were pregnant, thereby overestimating length at maturity. Voris and Jayne (1979) also found that *E. schistosa* males became mature at a smaller size than females, although no data was available for *E. schistosa* males in our study.

The proportion of mature sea snakes caught was high, 67% for males and 89% for females. This indicated that there were very few juvenile sea snakes caught in prawn trawls. Wassenberg *et al.* (1994) reported that sea snake juveniles were scarce in NPF trawling grounds and suggested that they were probably inhabiting estuaries and rivers. Voris and Jayne (1979) and Voris (1985) found that juveniles made up over half of the total sea snakes caught in the Muar River, Malaysia. Most juvenile sea snakes probably remain in estuarine and riverine habitats for protection and only migrate into more open water when nearing maturity. This is significant in that NPF trawling would have little impact on sea snake recruits until they moved onto trawl grounds.

Sea snakes produced few offspring per clutch, between 3 and 20, but they invested a large amount of energy in developing these few large offspring. This would give each newborn a greater chance of survival. Lemen and Voris (1981) found that in all sea snakes, with the exception of *L. hardwickii* and *E. schistosa*, there was no change in embryo size as female size increased. Hence large females of most species opted for a greater number of young rather than producing larger young. This may not be surprising since small sea snakes produce quite large offspring already. Furthermore a maximum embryo size limit at birth may have been reached.

The reproductive cycle of sea snakes has been investigated for a number of species. Voris and Jayne (1979) reported that in *E. schistosa* females, egg size was found to increase between May to September, developing into term embryos by September to January. The births of offspring occurred during February and March and by May all females were spent. Results of our study suggest that female sea snakes from northern Australia also breed seasonally with the timing of offspring production closely following that reported by Voris and Jayne (1979). The only exception to this cycle was *A. eydouxii* whose females carried term embryos between May to August. Heatwole and Burns (1987) also found that female *A. eydouxii* from the Gulf of Carpentaria were pregnant in the dry season although for the same species in the Straits of Malacca, Malaysia females were carrying term embryos during January to April (Lemen and Voris, 1981).

We found that females of most species of sea snake produced young every year as the proportion of pregnant females in the months of January, February and March was close to 100%. Voris and Jayne (1979) reported similar findings with 100% of *E. schistosa* females pregnant in January. In contrast, Burns (1985) found that in an *A. laevis* population in north-eastern Queensland, only half of the females were pregnant at any one time thus suggesting that breeding occurred every two years. As this population was in a more temperate locality it was suggested that temperature may be an important factor for this variation, extending gestation time long enough to postpone ovulation to the following year. In Malaysia, gestation time for *E. schistosa* females was reported to be between four and six months (Voris and Jayne, 1979). This is slightly shorter than the six to seven months estimated for sea snakes in northern Australia, but their study was in a more tropical region.

The most vulnerable period for female sea snakes is likely to be when they are pregnant. Sea snakes may synchronise birth to coincide with the most favourable period of the year to minimise gestation time. In the Gulf of Carpentaria, the warmest months are during the wet season (November to February) and for most species of sea snakes, females gave birth during this time. This would decrease the time when they are at their most vulnerable to predators. In the majority of sea snake species, gestation is also largely outside the NPF fishing season (April to May then mid July to November). Pregnant females should give birth before the prawn trawling season starts when their fishing mortality might increase.

Aipysurus eydouxii females, on the other hand, were heavily pregnant during during winter, which is during the NPF fishing season and would be expected to be more susceptible to capture because of the reduced mobility of aquatic snakes during pregnancy (Shine, 1988). However, our data suggests that catch rates for this species have increased since previous studies. This may be due to changes in fishing patterns caused by the introduction of GPSs which have allowed fishers to trawl much nearer reefs where *Aipysurus* species are much more abundant (Cogger, 1992, Greer, 1997).

As expected, the male reproductive cycle was synchronised with the female breeding cycle. The males timed sperm production for the months shortly after females give birth. Voris and Jayne (1979) reported sperm production in *E. schistosa* males was also highly seasonal, occurring just prior to the appearance of pregnant females in the population during September.

Shine (1988) proposed that pregnant female sea snakes should have reduced locomotion compared with males and non-pregnant snakes. This suggests that pregnant females might have a greater chance of being caught in trawls. Also, pregnant females with the highest RCM may be caught with the greatest frequency. The ability of sea snakes to escape from trawls is not known, however catch rates from trawls using certain bycatch reduction devices (BRD) were found to be up to 50% lower than in standard prawn trawl nets (Brewer *et al.,* 1998). Therefore, it is possible that some sea snakes can either swim out of the way of nets or escape through the BRDs. It is also likely that pregnant females, being slower and larger in girth, would have a smaller chance of escaping from prawn trawls as they became more heavily pregnant late in the trawl season.

Our data do not support these predictions, as we did not catch more pregnant females than expected. In fact, nine of the 13 species had a lower proportion of pregnant females compared to non-pregnant females in the catches. This would suggest pregnant females either showed behavioural differences that caused a decrease in their catchability or that the difference was a sampling artefact. The latter is the most probable cause since we are assuming that in a population there is an equal number of pregnant and non-pregnant females at any one time. This is not the case since females were found to breed annually and within a fixed period of the year. *Aipysurus duboisii* was the only species where there was significantly more pregnant than non-pregnant females in catches and showed considerably higher RCM than any other species. It may be that females of this species are particularly susceptible to trawling when they are pregnant. However this species is known to prefer reef habitats (Cogger, 1992) and is not common on prawn trawl grounds.

Diets

The results of stomach content analysis indicated that most species of sea snakes preyed on a narrow range of prey species and consumed mainly benthic and substrate-associated fish species. This was similar to the results of Glodek and Voris (1982) where most sea snake species were found to prey predominantly on a few benthic fish species such as eels, burrowing gobies, ariid and plotosid catfish. Voris and Voris (1983) suggested that the swimming capability of fish species was important in prey suitability for most snakes. They found 36 sea snake species preying on 'sitting' fish species compared to 14 species consuming 'swimmers'.

Glodek and Voris (1982) and Voris and Voris (1983) classified *L. hardwickii* as a generalist feeder preying on more than 20 different families of fish. In our study *L. hardwickii* also showed the widest range of prey, feeding on 18 species from 12 families of benthic and pelagic fish. The reason for this is unclear and it may indicate opportunistic feeding. However, it suggests that the distribution of this species may be less dependent on specific prey distributions and abundances than other sea snake species. This also infers that for sea snakes that specialise on benthic prey species, trawling activities that potentially disturb benthic communities may significantly affect the food sources of sea snakes.

Voris *et al.* (1978) found that *E. schistosa* preferred specific species of fish during experiments and these species were an important part of the diet of wild caught specimens. This may have been a learned response by the sea snakes to favour prey species most commonly encountered and therefore most often preyed on in their natural environment. This has some significance if sea snakes are exposed to and learn to feed on discarded bycatch from trawlers. This may result in attracting sea snakes into regions with high trawling effort and increasing their chances of capture. However our data suggests that this is not occurring.

The similarity in the diet of *H. elegans*, *A. stokesii*, *H. ornatus* and *L. hardwickii* between areas open and closed to NPF trawling suggests prawn trawl bycatch comprise little or no part in the diet for these species of sea snakes. Although it is difficult to fully dismiss bycatch feeding as sea snakes caught in closed areas may have been consuming discards from our vessel.

A few *A. laevis* and *H. ornatus* had fresh non-benthic fish in their stomachs and possibly ate them while in the net, indicating they are opportunistic feeders and will take non-preferred species when available. Whether these fish were alive or dead when consumed was not known, but Heatwole *et al.* (1978) found some evidence of sea snakes feeding on dead fish. Also *L. hardwickii* has been observed feeding on discarded dead fish on the surface (Wassenberg pers. obs.). This suggests that although sea snakes may feed on bycatch, few did and so it is unlikely that discards would be attracting sea snakes into NPF trawl grounds.

Catch Rates

There has been little change in the mean SVL of most sea snake species between 1986 and 1998. It suggests that the length frequency distribution of most species have remained fairly stable during this period, as we would expect the mean SVL to decline under heavy fishing pressure. Trawling occurs in less than 20% of the Gulf of Carpentaria, so snakes living in similar habitats outside the trawl grounds would buffer populations from any effect of trawling on the mean SVL in the catch unless the mortality rate became extremely high.

Redfield *et al.* (1978) compared catch rates by time of day and found no significant difference between day and night trawling. Although they reported that *A. peronii, A. laevis, D. kingii, D. major* and *H. mcdowelli* were caught more frequently during the day than at night. Catch rates of sea snakes during research cruises in 1997 and 1998 were the highest at dawn (22.3 sea snakes h^{-1} km^{-1}) and overall catch rates during the day (10.7 sea snakes h^{-1} km^{-1}) were significantly higher than at night (3.3 sea snakes h^{-1} km^{-1}) ($P<0.001$).

Greer (1997) summarised data on sea snake activity and found some species more active at dawn and during the day, possibly searching for food. Since they are mostly bottom feeders, during the day they would be in the path of the trawl and have a greater chance of being caught. These species of sea snakes tend to sleep on the surface at night, thus making them less prone to being caught in night trawls. We have insufficient data to clearly demonstrate which species of sea snake in the NPF are nocturnal or diurnal but the data in Greer (1997) suggests that *Aipysurus* species are mainly diurnal and *Hydrophis* are probably mainly nocturnal. More study on their foraging behaviour will help to understand their relative catchability in prawn trawls. Our catch data (Table 7.4.3.7) do not support the pattern suggested by Greer, as species of both *Hydrophis* and *Aipysurus* were more catchable at night (*Aipysurus*) and during the day (*Hydrophis*).

Sustainability

There has been a clear decline in the catch rates of some species of sea snake during the last 20 years and these declines may or may not be the result of trawling (Figure 7.4.3.10 and 7.4.3.11). Biological and catch data collected during our study indicate that sea snakes could be potentially susceptible to trawling. However, the small proportion of the NPF that is trawled will reduce the effects on species' populations. We estimate that trawling is catching a maximum of 10-12% of the population of each species in the Gulf of Carpentaria and that over 50% of these will die. This means that approximately 5-7% of the population is killed by fishing in this region each year.

The population estimates of each species on which these figures are based should be considered minimum estimates because many species prefer reef habitats and estuarine areas and so are likely to be in higher densities in these habitats than estimated by trawl catch rates. Most of the sea snakes caught by trawling are adults that have probably bred at least once before capture and thus contributed recruits to the population. This will further reduce the effect of trawling on sea snake populations.

Despite these factors that act to reduce the effect of trawling on sea snake populations, the catch rates for many species have declined in regions where data are reasonably representative among studies. Our analysis suggests that the population size of species that prefer open habitats, such as most *Hydrophis* species and *Disteira* species, have declined by between 30 and 70% since 1989 (Figure 7.4.3.13). Whereas the catch rates (and population estimates) of the more reef-associated species (*Aipysurus* species and *A. stokesii*) have remained the same or increased.

The classification of sea snakes in terms of their sustainability (Figure 7.4.3.14) is supported by all our biological and catch data and suggests that a more detailed assessment of the status of *H. pacificus* should be of high priority. The current data on its habitat preferences and distribution (Cogger, 1992, Greer, 1997) shows that it is restricted to the Gulf of Carpentaria and nearby regions and favours potential trawl ground habitats. This species has always been relatively uncommon in trawl catches in the Gulf of Carpentaria, but the number of trawls during our study should have been sufficient to catch more of them if their abundance was similar to that in the late 1980s. Further data on its status is required to make a more detailed assessment.

Most other species appear to score higher than average (2) on the susceptible to trawling criteria and most had a score on that axis above 2 (Figure 7.4.3.14). Most of these same species scored lower than average for their capacity to recover. The second most susceptible species overall, *D. kingii*, had a higher score on the x-axis (capacity to recover) than many others, but its weighted score was still less than 2. This indicates that this species should be a higher priority species for study than other species examined.
The species with the lowest capacity to recover was *A. duboisii* and it appears to have less capacity to recover from trawling than *H. pacificus.* Fortunately, its populations are probably less susceptible because it prefers more structured habitats and so most of the population is not susceptible to trawling. Current trends in fishing patterns have resulted in fishers trawling much closer to reefs and there has been a significant increase in the catch of *A. duboisii* since 1989. We have no data by which to assess whether this increase in catch should be a cause of concern.
Given the results of the analysis of sustainability, what is the next step ?
More data are required on the highest priority species in order to increase the data reliability. This is feasible for *D. kingii* because it is still caught in much higher frequency than *H. pacificus*. We caught four *H. pacificus* in 1378 h of trawling and so the whole NPF fleet probably only catches about 200 during the entire fishing season. This makes any quantitative assessment of the status of this species extremely difficult. Monitoring all catches of this species may be an option and would allow a database to be accumulated on its distribution and relative abundance, information that would greatly contribute to understanding the effect of trawling and is currently lacking.

One of the major gaps in our knowledge of sea snake biology that affects our ability to estimate the impacts of trawling on populations is the lack of data on longevity of most species. Preliminary data are only available for two species – *E. schistosa* and *A. laevis* and these studies conflict. The study on *Enhydrina* (Voris and Jayne, 1979) suggested that there were five year classes, whereas Burns (1985) suggested that *A. laevis* took five years to reach sexual maturity and probably live for more than 10 years. These differences in potential longevity have a major influence on any assessment of the sustainability of current catch rates of any species.

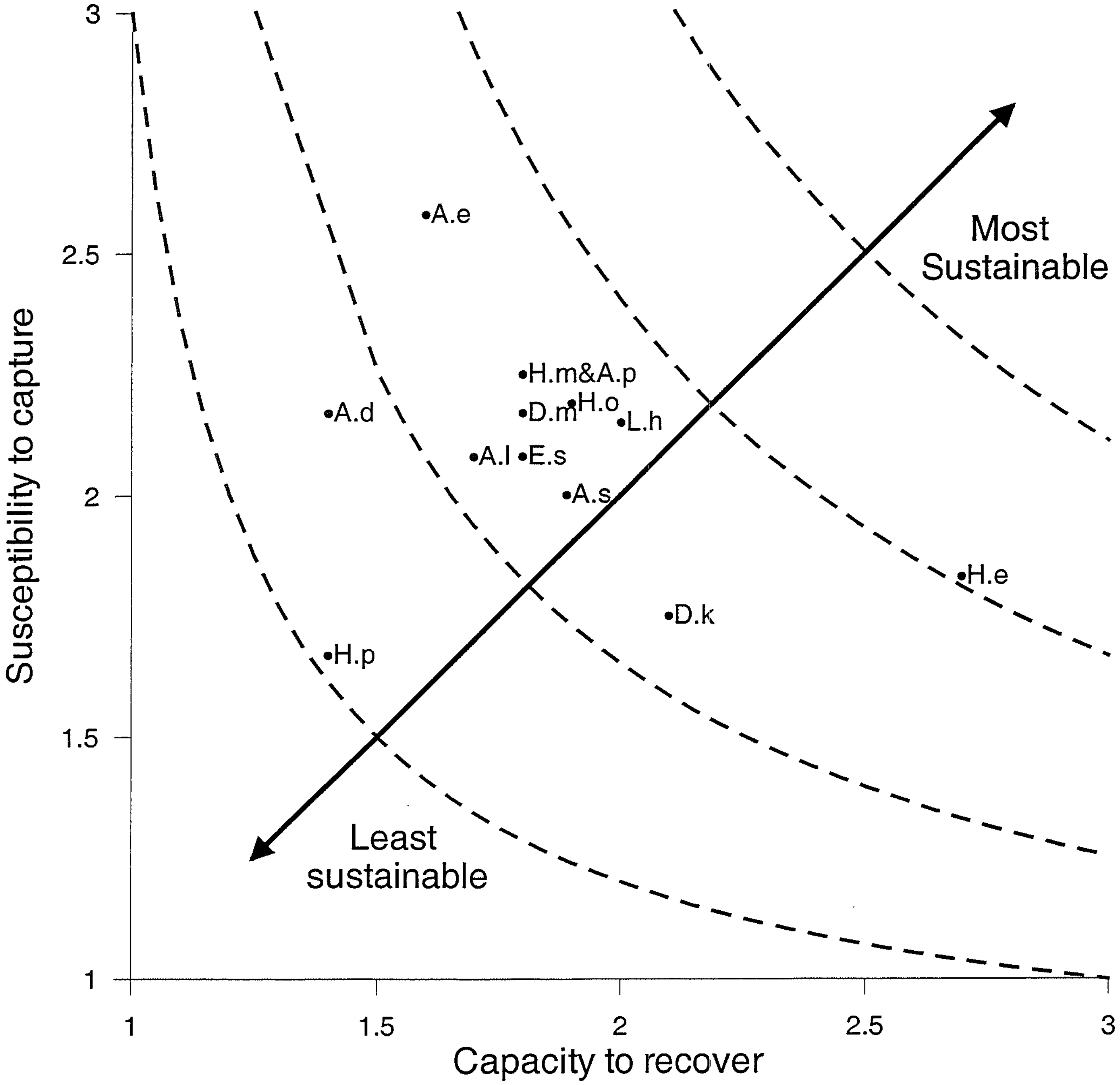


Figure 7.4.3.14 A matrix of the relative susceptibility of each species of sea snake and their relative capacity to recover. The lines separate regions of similar relative priority for further research or management action. The least sustainable species are in the lower left box of the figure. Values for each species are the sum of the ranks of each criterion shown in Tables 7.4.3.9 and 7.4.3.12. A.d = A. duboisii, A.e = A. eydouxii, A.l = A. laevis, A.p = A. peronii, A.s = A. stokesii, D.k = D. kingii, D.m = D. major, E.s = E. schistosa, H.e = H. elegans, H.m = H. mcdowellii, H.o = H. ornatus, H.p = H. pacificus, L.p = L. hardwickii.

7.4.3.5 Conclusions

- Female sea snakes showed significantly higher catch rates than males for the majority of species especially in high effort trawling regions such as 'Mornington Island' and 'Weipa'.
- The proportion of mature sea snakes in trawl catches in the Gulf of Carpentaria is high, reaching close to 100% in some cases, and juvenile sea snakes of most species were not caught on NPF trawling grounds.
- Female sea snakes breed annually and the young in most sea snake species are born during summer (closed season).
- Sea snakes produce only a few large young, suggesting a large investment in reproduction.
- Pregnant females of most species did not have a higher probability of capture by prawn trawls than non-pregnant females.
- Sea snakes had a specialised natural diet and most species fed on benthic fish species. Some ate pelagic and mid-water species that were common in trawl bycatch. However, they do not appear to be attracted into NPF trawl grounds by the availability of discarded bycatch as food.
- Sea snakes were caught more frequently at dawn and day than at night by research trawlers, but commercial vessels catch rates were higher at night than at dawn.
- Catches of most species of sea snake appear sustainable at current levels of fishing effort.
- Our estimates of the sea snake catch and the biomass of each species indicate that fishing mortality could be as high as 5-6% per year.
- TEDs and BRDs are very effective at reducing sea snake catch.
- Some species are more common around reefs and so are less susceptible to trawling, but changing fishing patterns may be altering this situation.
- Gulf of Carpentaria populations of two species of sea snake appear susceptible to trawling and are a high priority for further study of trawl effects.

References

Brewer, D., Rawlinson, N., Eayrs, S., Burridge, C., 1998. An assessment of bycatch reduction devices in a tropical Australian prawn trawl fishery. Fish. Res. 36, 195-215.

Burns, G.W. 1985. The female reproductive cycle of the olive sea snake, *Aipysurus laevis* (Hydrophiidae) pp. 339-341. In: Grigg, G., Shine, R. and H. Ehmann (Eds.) The biology of Australasian frogs and reptiles. Surrey Beatty and Sons, Sydney.

Beverton, R.J.H., Holt, S. J., 1956. A review of methods for estimating mortality rates in exploited fish populations, with special reference to sources of bias in catch sampling. Rapp. P.-V. Reun. CIEM 140, 67-83.

Cogger, H.G., 1975. Sea Snakes of Australia and New Guinea. In: Dunson, W.A. (Eds.), The Biology of Sea Snakes. University Park Press, Baltimore, pp. 59-139.

Cogger, H.G., 1992. Reptiles and Amphibians of Australia. 5th Edition. Reed, Sydney.

Die, D.J., Caddy, J.F., 1997. Sustainable yield indicators from biomass: are there appropriate reference points for use in tropical fisheries. Fish. Res. 32, 69-79.

Dunson, W.A., 1975. The Biology of Sea Snakes. University Park Press, Baltimore.

Glodek, G.S., Voris, H.K., 1982. Marine snake diets: prey composition, diversity and overlap. Copeia. 1982, 661-666.

Greer, A.E., 1997. The biology and evolution of Australian snakes. Surrey Beatty & Sons, Sydney.

Heatwole, H., 1975a. Predation on Sea Snakes. In: Dunson, W.A. (Eds.), The Biology of Sea Snakes. University Park Press, Baltimore, pp. 233-249.

Heatwole, H., 1975b. Sea Snakes of the Gulf of Carpentaria. In: Dunson, W.A. (Eds.), The Biology of Sea Snakes. University Park Press, Baltimore, pp. 145-149.

Heatwole, H., 1978. Adaptations of marine snakes. American Scientist. 66, 594-604.

Heatwole, H., Burns, G., 1987. Sea snake populations – 1984-1987 Report for ANPWS, Canberra. 64 pp.

Heatwole, H., Minton, S.A., Taylor, R., Taylor, V., 1978. Underwater observations on sea snake behaviour. Rec. Aust. Mus. 31, 737-761.

Lemen, C.A., Voris, H.K., 1981. A comparison of reproductive strategies among marine snakes. J. Animal Ecol. 50, 89-101.

Redfield, J.A., Holmes, J.C., Holmes, R.D., 1978. Sea snakes of the eastern Gulf of Carpentaria. Aust. J. Mar. Freshw. Res. 29, 325-334.

Shine, R., 1988. Constraints on reproductive investments: a comparison between aquatic and terrestrial snakes. Evolution 42, 17-27.

Thackway, R., Cresswell, I.D. 1997. Interim marine and coastal regionalisation for Australia: an ecosystem-based classification for marine and coastal environments. IMCRA Technical Grp., Version 3.2. Environment Australia, Canberra.

Voris, H.K., 1985. Population size estimates for a marine snake (*Enhydrina schistosa*) in Malaysia. Copeia. 1985, 955-961.

Voris, H.K., Jayne, B.C., 1979. Growth, reproduction and population structure of a marine snake, *Enhydrina schistosa* (Hydrophiidae). Copeia. 1979, 307-318.

Voris, H.K., Voris, H.H., 1983. Feeding strategies in marine snakes: an analysis of evolutionary, morphological, behavioural and ecological relationships. American Zool. 23, 411-425.

Voris, H.K., Voris, H.H., Lim, B.L., 1978. The food and feeding behaviour of a marine snake, *Enhydrina schistosa* (Hydrophiidae). Copeia. 1978, 134-146.

Ward, T.M., 1996. Sea snake by-catch of prawn trawlers on the northern Australian continental shelf. Mar. Freshw. Res. 47, 631-635.

Ward, T. M., 2000. Factors affecting the catch rates and relative abundance of sea snakes in the by-catch of trawlers targeting tiger and endeavour prawns on the northern Australian continental shelf. Mar. Freshw. Res. (in press).

Walpole, R.E., 1974. Introduction to Statistics. (Second Edition). MacMillan Publishing, New York.

Wassenberg, T.J., Salini, J.P., Heatwole, H., Kerr, J.D. 1994. Incidental capture of sea snakes (Hydrophiidae) by prawn trawlers in the Gulf of Carpentaria, Australia. Aust. J. Mar. Freshw. Res. 45, 429-443

8. TRAWLING IMPACTS ON VERTEBTRATE BIODIVERSITY

To assess the effects of prawn trawling on the biodiversity of key fish and other vertebrate communities.

8.1 General introduction

As part of the management of prawn trawling in an ecologically sustainable manner we require an understanding of how trawling impacts on biodiversity within the managed area. One way to address this issue is to compare communities in areas open and closed to trawling. This can provide insights into the impact on biodiversity. In this section therefore, we compared the composition of the vertebrate bycatch community in areas open and closed to trawling and also the size structure of individual species. This section focuses on the bycatch species as these are impacted directly by trawling. We might expect differences in the species composition of the bycatch community or differences in the diversity due to trawling. Individual species may show changes in abundance or size structure in relation to trawling. While proving a direct causal link between trawling and any observed differences is not possible from these comparisons, the results will increase our understanding of the complex interaction between trawling and biodiversity.

This study focused on the closure to the west of Groote Eylandt (Figure 8.1.1), which has been permanently closed to trawling since 1983. This closure was instigated to protect juvenile tiger prawns and their nursery habitats (Taylor, 1994). This closure was selected for the comparison as it contained areas that were previously part of the trawl grounds, increasing the likelihood that the environment would be similar to areas currently trawled. The majority of other permanent closures in the NPF cover shallow seagrass habitats (Taylor, 1994) that are likely to differ markedly from the main trawling grounds. In order to separate out possible trawling impacts, factors such as depth and bottom type of the open and closed areas should be as similar as possible. This also, therefore, influenced the choice of region for this comparison. Depth, sediment type and acoustic measures of bottom roughness and hardness were recorded in order to factor out their influence on any observed patterns in the fish community.

The specific objectives of this section were:
to compare the vertebrate bycatch species composition of areas open and closed to trawling,
to determine whether individual species showed a difference in size structure between areas open and closed to trawling.

This study was conducted in two stages, a pilot study undertaken in 1997 and a larger scale comparison in 1998. The pilot study was conducted to provide information for designing the 1998 survey. The results of the pilot study will be discussed briefly (Section 8.2), focusing on the key results which influenced the design of the 1998 survey. The full results of the 1998 and 1997 surveys will then be described (Section 8.3).

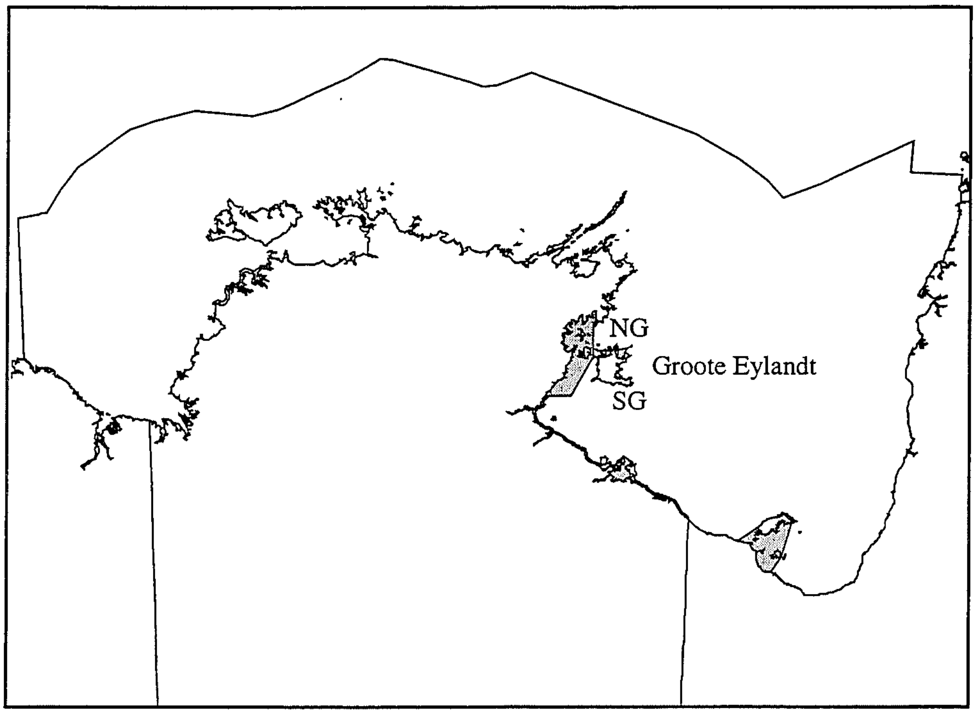


Figure 8.1.1 The areas in the Northern Prawn Fishery that are permanently closed to trawling (shaded). The regions examined in this study were 'South Groote' (SG) and 'North Groote' (NG).

References

Taylor, B., 1994. A delicate balancing act: management of the fishery. In Pownall, P.C. (ed.) Australia's Northern Prawn Fishery: the first 25 years. NPF25, Cleveland, Australia.

8.2 Pilot study

8.2.1 Methods

Survey Design

In October 1997 one area of the closure west of Groote Eylandt was surveyed (Figure 8.2.1), using the RV 'Southern Surveyor'. In order to minimise differences in depth and sediment between the open and closed areas, three 6 x 6 n. mile grids were sampled immediately inside and outside the closure boundary (Figure 8.2.1). One 6 x 6 n. mile grid was sampled for a day and night before moving to the next grid. The sampling started in an open grid (sampled for a day and night), then moved to a closed grid, then to an open grid until all grids had been sampled.

Trawls were conducted during the day and night, but not within half an hour of dusk or dawn. The trawls were towed where possible, along lines that were 2, 4, 5 and 6 n. miles from the closure boundary at night, and 2, 4 and 6 n. miles from the closure boundary during the day. The actual position of the trawls was governed by the presence of obstacles on the sea bed (Figure 8.2.1). When sampling a grid, the first of trawls of the day/night were closest to the closure boundary (2 n. mile). Three trawls parallel to the closure boundary were conducted before moving to the next distance from the closure boundary. A total of 95, 30 minute trawls were conducted during the day and night (Table 8.2.1).

The structure of the sampling design was aimed at maximising the efficiency of ship time primarily by minimising steaming time. This enabled the largest number of trawls to be completed. The sampling was also designed to enable us to examine whether distance from the closure boundary influenced bycatch composition. The trawls were sampled as described in Section 6.2.2.

Abiotic Measurements

Depth, acoustic roughness and hardness were recorded continuously by dataloggers during the sampling. The acoustic data were cleaned and summarised as described in Section 6.2.2

Data Analysis

All catches (of teleosts and elasmobranchs) were standardised by the duration of the trawl and data are presented as the number of individuals per hour (n h^{-1}) or weight per hour (kg h^{-1}).

The actual distance of each trawl from the closure boundary was calculated in the GSI program ArcView, with distances outside the closure, in the trawled area, labelled negative. The depth, roughness and hardness were summarised as mean values for each trawl.

Ordinations were used to examine the composition of the teleosts and elasmobranch bycatch from the trawls. The association matrix was formed using the Bray Curtis metric and the ordination was performed on a double centred matrix followed by principal component analysis (Williams, 1976).

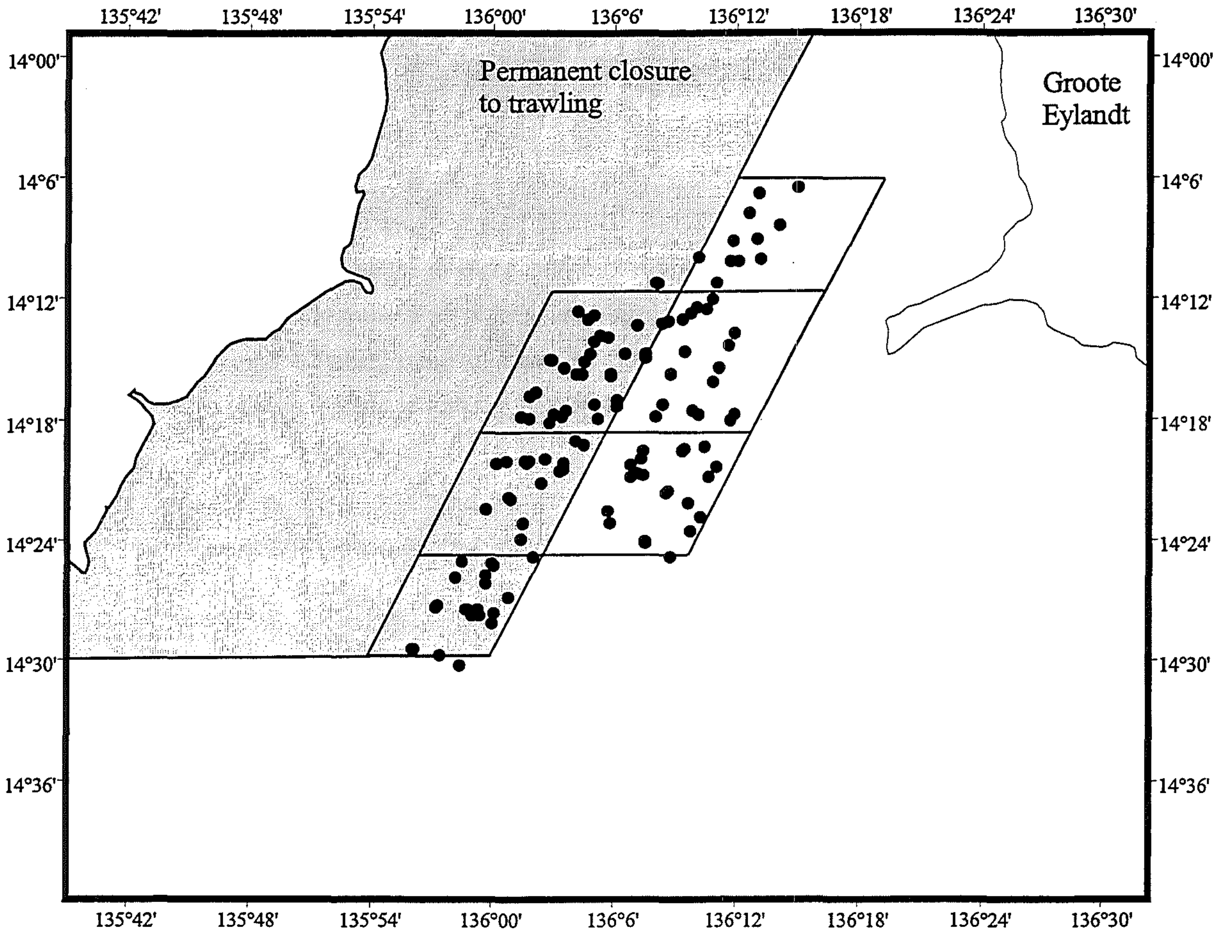


Figure 8.2.1 The trawl sites inside and outside the closure at 'South Groote' for the pilot study.

Table 8.2.1 The number of trawls conducted in the areas open and closed to trawling, during day and night, in the 1997 pilot survey.

Area	**Day**	**Night**
Closed	20	36
Open	16	23
Total	36	59

Day and night trawls combined

The first ordination included all trawls and was based on the abundance of teleost and elasmobranch species that occurred in more than 10% of trawls (60 species). The abundances were transformed (log ($n\ h^{-1}$ + minimum $n\ h^{-1}$)) to reduce heteroscedasticity.

Two-way ANOVAs, on the scores of trawls on the first three principal components from the ordination, were used to examine whether there were differences between the open and closed areas (A) and between night and day (T) as well as any interaction (A*T)

$$\mathbf{y = A + T + A{*}T + e} \qquad \text{(model 8.2.1)}$$

e represents the residual error. Two-way ANOVAs of the same design were applied to the transformed abundance of individual species. This examined the response of individual species to the factors, area and day/night.

Day and night trawls separated

The results of the first ordination and ANOVAs suggested that ordinations (following the procedure described above) should be performed separately on the night and day data sets. These ordinations were based on the abundance of species in more than 10% of trawls for each time. The influence of the abiotics (depth, roughness and hardness of trawls) along with distance from the closure line, on the ordination, was examined using Pearson's correlations (Sokal and Rohlf, 1996).

Two-way ANOVAs were performed on the scores of the trawls on the first three principal components

$$\mathbf{y = A + S + A{*}S + e} \qquad \text{(model 8.2.2)}$$

to examine the effect of area , open or closed (A). The effect of a blocking factor sample day (S) and the interaction between sample day and area (A*S) were included to partition out any variation due to these effects. Sample day refers to the pairs of consecutive days/nights during which one open and one closed grid were sampled. This takes into account the potential impact of time of the month. We would expect days/nights within each pair to be more similar than other pairs.

The influence of the abiotics on significant of effects in the ANOVAs (model 8.2.2) was examined using ANCOVAs applied to the scores of the trawls on the first three principal components. Firstly the effect of the covariates depth (D) and distance from the closure boundary (I) was examined. These covariates were available for all trawls

$$\mathbf{y = A + S + A{*}S + D + I + e} \qquad \text{(model 8.2.3)}$$

The effect of roughness (R) and hardness (H), which were not available for all trawls, were then included

$$\mathbf{y = A + S + A{*}S + D + I + R + H + e} \qquad \text{(model 8.2.4)}$$

The correlations between the covariates were examined prior to the ANCOVAs.

8.2.2 Results

Day and night trawls combined

The first ordination included day and night trawls (95 stations) and was based on 60 species that occurred in more than 10% of trawls. The first principal component explained 21.8% of the variation and the first three principal components explained 48.2%. The ordination showed separation between the day and night trawls as well as the open and closed areas (Figure 8.2.2).

In the ANOVA (model 8.2.1) the first and second principal components scores of the trawls showed significant differences between night and day and between open and closed areas (Table 8.2.2). There was, however, no interaction between these factors on the first two principal components. The size of the F ratios on the first principal component suggests that the majority of the variation among the trawls was due to differences between night and day. The third principal component showed a significant difference between night and day and a significant interaction.

Individual ANOVAs (model 8.2.1) preformed directly on species abundances resulted in 53 of the 60 species showing either a significant difference between night and day or a significant interaction (Table 8.2.3). Twenty-seven species showed a significant time effect and no interaction with region, with 16 species more abundant in night-time trawls and 11 species more abundant in day-time trawls. There were 27 species with a significant effect and interaction between the time and area or just a significant interaction. Of these, 14 species had a higher abundance in night-time trawls and 5 species had a higher abundance in day-time trawls, but the size of this difference varied between the open and closed areas. There were 8 species that were present in only one area, or where the time of highest catch rate differed between open and closed areas (Table 8.2.3).

The primary interest of this study was the difference between the open and closed areas rather than the difference between day and night. The fact that the major separation in the ordination was due to time of the trawls, suggested that if this factor was removed, variation due the area effect would be clearer. Therefore, the two times were separated for further analyses.

Day and night trawl separated

Night time trawls

There were 67 species that occurred in more than 10% of trawls during the night and so were included in the ordination. The most common species, in terms of the number of trawls in which they were present were *Caranx bucculentus* and *Leiognathus moretoniensis*, which occurred in 91.5% of trawls. The most abundant in terms of n h^{-1} were and *L. moretoniensis* 376.4 ($\pm$ 58.59 se) n h^{-1} and *Leiognathus leuciscus*, 374.5 ($\pm$ 67.65 se) n $h^{-1.}$ In terms of kg h^{-1} *C. bucculentus* (7.3$\pm$ kg h^{-1}) and *Pomadasys maculatum* (6.0 $\pm$ kg h^{-1}) were the most abundant.

The first principal component of the ordination explained 30.9% of the variation and the first three explained 54.8%. The ordination shows separation between the open and closed areas, although there is some overlap

(Figure 8.2.3). The first principal component was strongly correlated with roughness and hardness of the bottom but not depth or distance from the closure boundary (Table 8.2.4).

The ANOVAs (model.8.2.2) on the first three principal components scores of the trawls showed that there was a significant difference between open and closed areas on the first and third principal components (Table 8.2.5). The size of the F ratio for area on the first principal component suggests a substantial amount of the variation is due to this effect. The sample day effect was significant on the first and second principal components (Table 8.2.5).

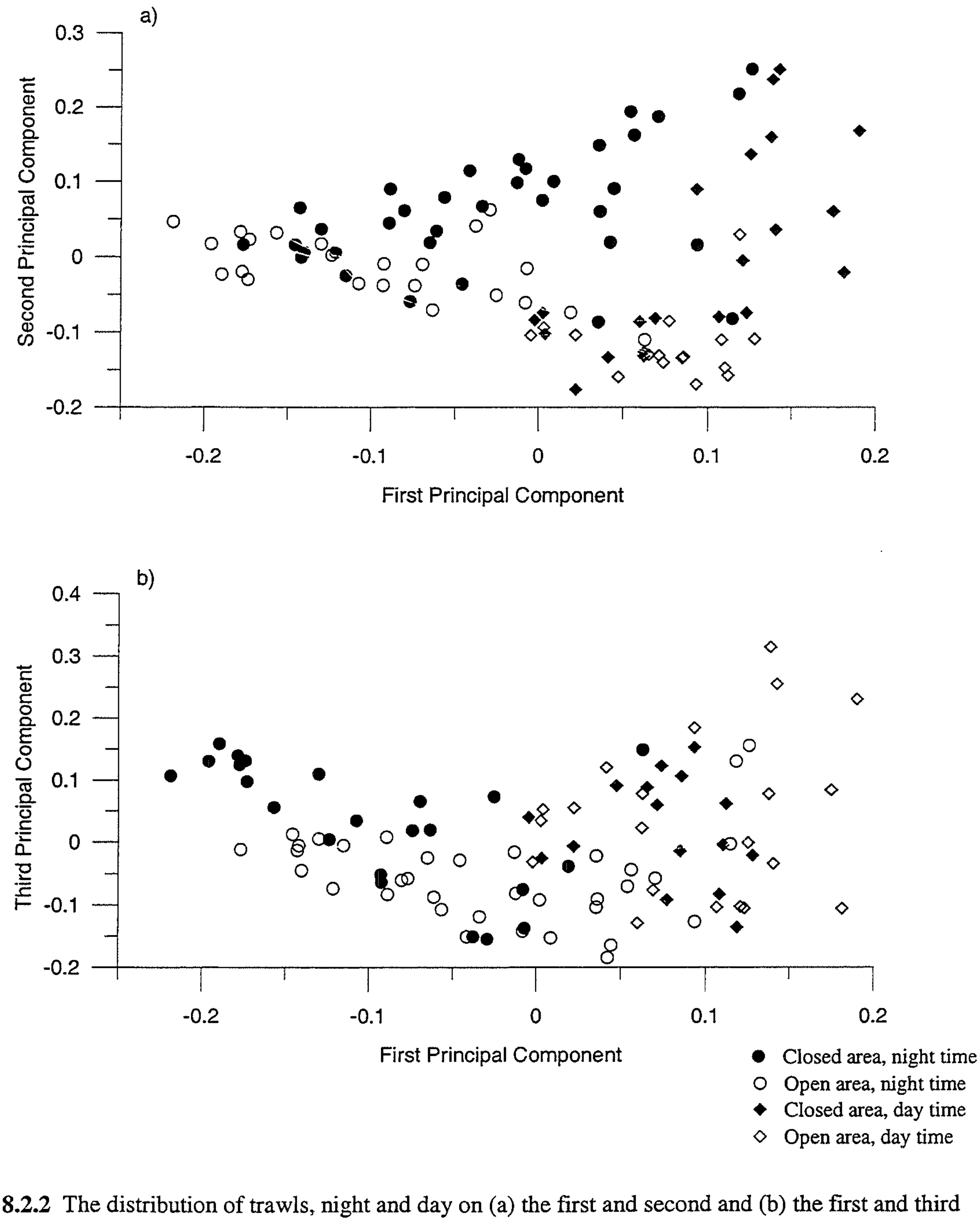


Figure 8.2.2 The distribution of trawls, night and day on (a) the first and second and (b) the first and third principal components.

Table 8.2.2 The results from the ANOVAs (model 8.2.1) on the scores of the trawls (day and night) on the first three principal components.

Principal component	Factor	df	F	P
First	Area	1,91	8.65	*0.0042*
	Time	1,91	82.79	*< 0.0001*
	Interaction	1,91	3.1	*0.0816*
Second	Area	1,91	28.3	*< 0.0001*
	Time	1,91	25.4	*< 0.0001*
	Interaction	1,91	0.69	*0.4077*
Third	Area	1,91	2.58	*0.1114*
	Time	1,91	4.08	*0.0465*
	Interaction	1,91	6.59	*0.0119*

Table 8.2.3 The significant effects, at p = 0.05 (*), in the ANOVAs (model 8.2.1) on the abundance of each species. Where there was a significant time effect or interaction, the time of highest catch rate is given for the species.

		Effect			Highest
Family	**Species**	**Time**	**Area**	**Interaction**	**catch**
Apogonidae	*Apogon elliotti*				
	Apogon fasciatus		*	*	night
	Apogon poecilopterus			*	
Bathysauridae	*Saurida micropectoralis*	*	*	*	night
	Saurida sp. 2	*			night
Callionymidae	*Callionymus grossi*	*			night
Carangidae	*Alepes sp.*	*			day
	Carangoides caeruleopinnatus				
	Carangoides hedlandensis	*	*	*	day
	Carangoides humerosus				
	Carangoides talamparoides	*	*	*	day
	Caranx bucculentus	*		*	day
	Carcharhinus dussumieri	*			day
	Parastromateus niger	*		*	day
	Selaroides leptolepis	*	*	*	night
	Ulua aurochs	*	*	*	night
Clupeidae	*Dussumieria elopsoides*	*			day
	Herklotsichthys koningsbergeri	*			night
	Herklotsichthys lippa	*			day
	Pellona ditchela	*	*		day
	Sardinella gibbosa	*			day
Engraulididae	*Thryssa setirostris*	*			night
Gerreidae	*Gerres macrosoma*	*		*	night
	Pentaprion longimanus	*			night
Gobbiidae	*Yongeichthys nebulosus*	*		*	night
Haemulidae	*Diagramma pictum*		*		day
	Pomadasys maculatus	*		*	night
Labridae	*Choerodon cephalotes*	*			night
Leiognathidae	*Gazza minuta*			*	
	Leiognathus bindus	*			day
	Leiognathus leuciscus		*	*	day
	Leiognathus moretoniensis			*	

Table 8.2.3 The significant effects, at p = 0.05 (*), in the ANOVAs (model 8.2.1) on the abundance of each species. Where there was a significant time effect or interaction, the time of highest catch rate is given for the species.

		Effect			Highest
Family	**Species**	**Time**	**Area**	**Interaction**	**catch**
	Leiognathus sp.	*			day
	Leiognathus splendens	*			day
	Secutor insidiator	*			day
Lethrinidae	*Lethrinus laticaudis*	*	*	*	night
	Lethrinus lentjan	*			night
Mullidae	*Upeneus luzonius*			*	
	Upeneus sundaicus	*	*	*	night
	Upeneus tragula	*	*	*	night
Nemipteridae	*Nemipterus furcosus*	*	*		night
	Nemipterus hexodon			*	
	Nemipterus peronii	*			night
	Pentapodus paradiseus			*	
	Scolopsis taeniopterus	*			night
Platycephalidae	*Elates ransonnetii*	*			night
	Inegocia japonica		*		night
Scombridae	*Scomberomorus queenslandicus*			*	
Scorpaenidae	*Apistus carinatus*	*		*	night
Sillaginidae	*Sillago burrus*			*	
	Sillago ingenuua	*	*		night
Sphyraenidae	*Sphyraena flavicauda*	*	*	*	night
Terapontidae	*Pelates quadrilineatus*			*	
	Terapon jarbua	*			night
	Terapon theraps				
Tetraodontidae	*Chelonodon patoca*	*			night
	Torquigener pallimaculatus	*			night
	Torquigener whitleyi	*	*	*	night
Triacanthidae	*Trixiphichthys weberi*	*			night
Trichiuridae	*Trichiurus lepturus*	*			day

The depth, distance from the closure boundary, roughness and hardness of each trawl were included in the ANCOVAs (model 8.2.3 and 8.2.4). The correlations among these covariates, although some were significant, were not particularly strong (Table 8.2.6) and so all were included in the models.

The first ANCOVA (model 8.2.3) showed a significant result for the covariate, distance from the closure, on the first principal component (Table 8.2.5) and once the covariates were included the difference between areas was no longer significant. The second ANCOVA model (model 8.2.4) showed a significant result for roughness and hardness on the first principal component scores, with hardness also significant on the second principal component scores. Distance from the closure was not significant once the other covariates were included. The second ANCOVA showed no effect of area or sample day but a significant interaction. Roughness and hardness were significant covariates on the first principal component and hardness on the second. Figure 8.2.4 shows the ordination results with symbols representing the degree of roughness and hardness of the trawls and Figure 8.2.5 shows the distribution of these variables spatially. The ordination results appear to be influenced by the characteristics of the seabed.

Day time trawls

There were 49 species that occurred in more than 10% of trawls during the day, which were included in the ordination. The most common species, in terms of the number of trawls in which they were present were *Selaroides leptolepis* and *L. leuciscus*, which occurred in 94.4% and 91.7% of trawls respectively. The most abundant in terms of n h^{-1} were *L. leuciscus* 785.5 (± 145.7 se) n h^{-1} and *Leiognathus splendens* 201.1 (± 78.9 se) n h^{-1}. The most abundant in terms of kg h^{-1} were *Galeocerdo cuvier* , 17.2 (± 17.2 se) kg h^{-1} , the result of capturing a single animal in one trawl, *L. leuciscus* 12.9 (± 2.41 se) kg h^{-1} and *C. bucculentus* 11.9 (± 3.3 se) kg h^{-1}.

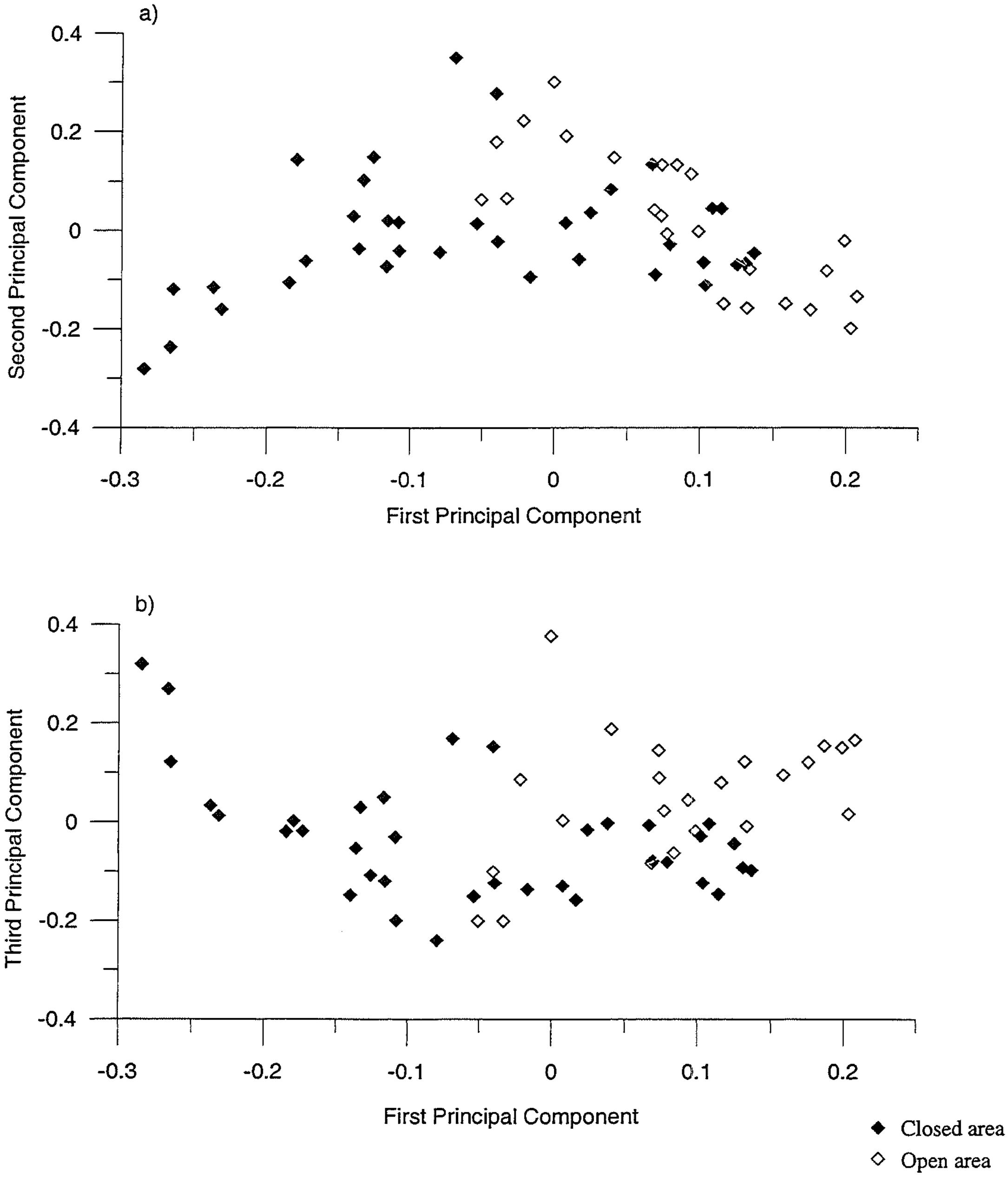


Figure 8.2.3 The distribution of night-time trawls on (a) the first and second, and (b) the first and third principal components.

Table 8.2.4 The correlations between the abiotic variables (depth, distance from the closure boundary, roughness and hardness) and the first three principal components from the ordination on the night time trawls

		Principal Component		
		First	**Second**	**Third**
Depth	r	-0.26	0.07	0.08
	P	*0.047*	*0.6052*	*0.5273*
	n	59	59	59
Distance	r	0.38	0.2	0.28
	P	*0.0027*	*0.1292*	*0.0325*
	n	59	59	59
Roughness	r	-0.85	-0.03	0.004
	P	*< 0.0001*	*0.8632*	*0.9783*
	n	44	44	44
Hardness	r	-0.63	-0.36	0.10
	P	*< 0.0001*	*0.0176*	*0.517*
	n	44	44	44

The ordination on the daytime trawls, showed some separation of trawls between the closed and open areas, but there was substantial overlap (Figure 8.2.6). The first principal component explained 35.2% of the variation and the first three explained 60% of the variation. The hardness and roughness of the bottom were the strongest variables correlated with the first principal component. Depth and the distance from the closure were also correlated with this component (Table 8.2.7). Hardness correlated with the second principal component and distance from the closure with the third (Table 8.2.7).

The ANOVAs (model 8.2.2) on the first three principal components suggested significant differences among the open and closed areas and a significant effect of sample day and the interaction (Table 8.2.8). The size of the F ratio indicates that the effect of area contributed most to the variation (Table 8.2.8).

The depth, distance from the closure and roughness and hardness were included in the ANCOVAs (model 8.2.3 and 8.2.4). The correlations among these covariates, although some were significant were not particularly strong (Table 8.2.9) and so all were included in the models

The first ANCOVAs (model 8.2.3) on the first three principal components showed a that distance from the closure boundary was a significant covariate. The second ANCOVAs (model 8.2.4) showed no significant covariates but this model was weak due to only 24 trawls containing all covariates. Figure 8.2.7 shows the ordination results in relation to the roughness and hardness of the sites, suggesting these contribute to the pattern observed.

Overall, the results suggest that the observed differences between open and closed areas were driven by differences in seabed characteristics. This highlights the importance of measuring these characteristics and integrating them into the analysis.

Table 8.2.5 The F ratio and associated probabilites from the ANOVAs and ANCOVAs on the scores of the nigh-time trawls on the first three principal components from the ordination Distance = for the distance from the closure boundary.

ANOVA (model 8.2.2)

Principal component		Effects: Open/Closed	Sample day	Interaction
First	F	70.59	48.53	3.84
	P	*< 0.0001*	*< 0.0001*	*0.0277*
Second	F	0.39	3.24	10.1
	P	*0.5344*	*0.0478*	*0.0002*
Third	F	8.79	0.48	7.61
	P	*0.0045*	*0.6232*	*< 0.0001*

ANCOVA (model 8.2.3)

		Effects			Covariates	
Principal component		**Open/Closed**	**Sample day**	**Interaction**	**Depth**	**Distance**
First	F	0.48	49.63	2.19	0.79	15.34
	P	*0.4913*	*0.0001*	*0.1224*	*0.3785*	*0.0003*
Second	F	0.00	1.9	9.89	0.85	0.05
	P	*0.9749*	*0.1604*	*0.0002*	*0.3604*	*0.8303*
Third	F	2.12	0.93	8.52	2.42	0.00
	P	*0.152*	*0.4009*	*0.0006*	*0.1261*	*0.9848*

ANCOVA (model 8.2.4)

		Effects			Covariates			
Principal component		**Open/Closed**	**Sample day**	**Interaction**	**Depth**	**Distance**	**Roughness**	**Hardness**
First	F	1.85	0.97	11.58	0.09	0.66	10.06	12.08
	P	*0.1826*	*0.3883*	*0.0001*	*0.7703*	*0.4205*	*0.0032*	*0.0014*
Second	F	1.52	0.22	8.33	0.23	0.67	0.31	5.18
	P	*0.226*	*0.8015*	*0.0011*	*0.6351*	*0.4203*	*0.5801*	*0.0292*
Third	F	5.22	1.87	9.78	3.33	0.48	0.45	2.8
	P	*0.0286*	*0.1691*	*0.0004*	*0.0766*	*0.4934*	*0.5079*	*0.1032*

Table 8.2.6 The correlation coefficients between the abiotic variables: depth, roughness, hardness and the distance from the closure boundary, for the night-time trawls only. Probabilities are given in italics.

	Distance	Roughness	Hardness
Depth	0.3	0.42	0.07
	0.0215	*0.0042*	*0.6738*
Distance		-0.21	-0.45
		0.1765	*0.0023*
Roughness			0.51
			0.0005

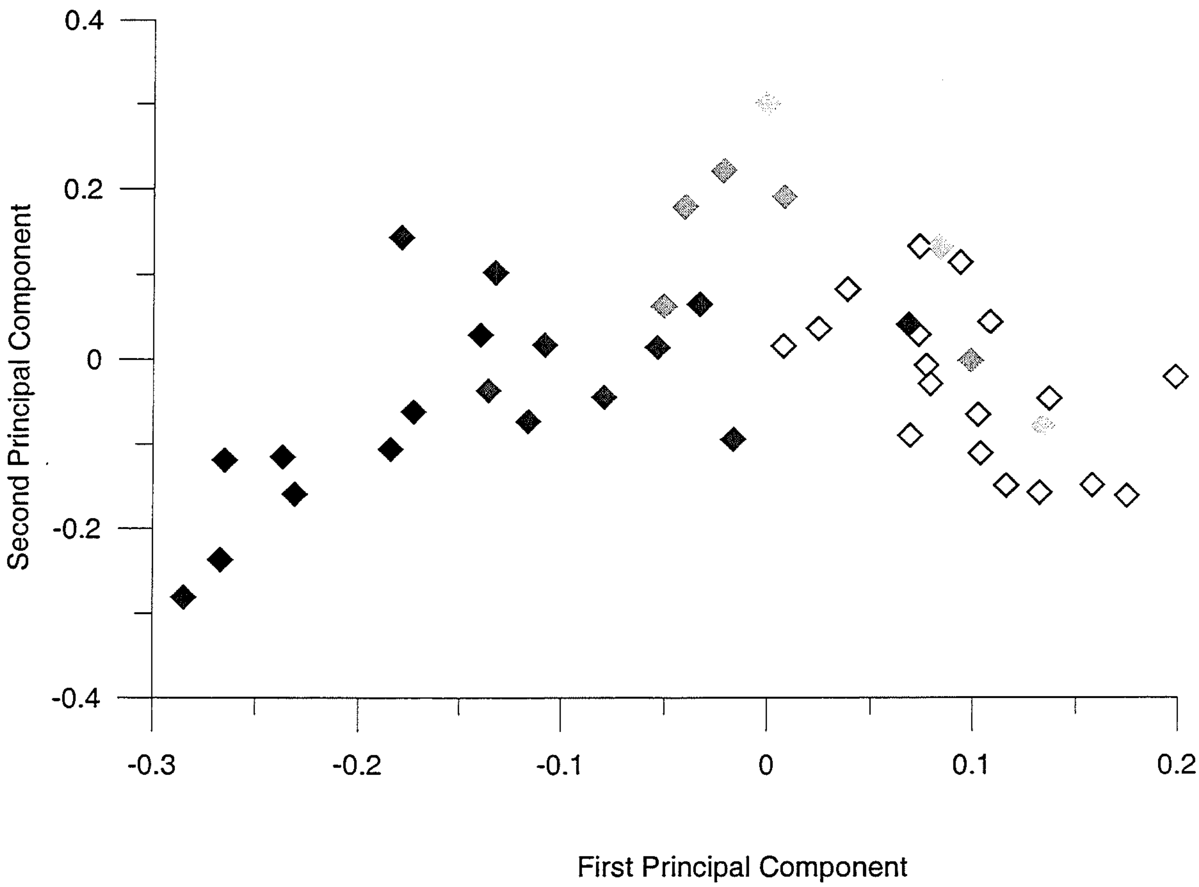


Figure 8.2.4 The scores of the night-time trawls on the first and second principal components from the ordination. The points are shaded in relation to the roughness and hardness of the trawl sites, roughness and hardness increase as the points darken.

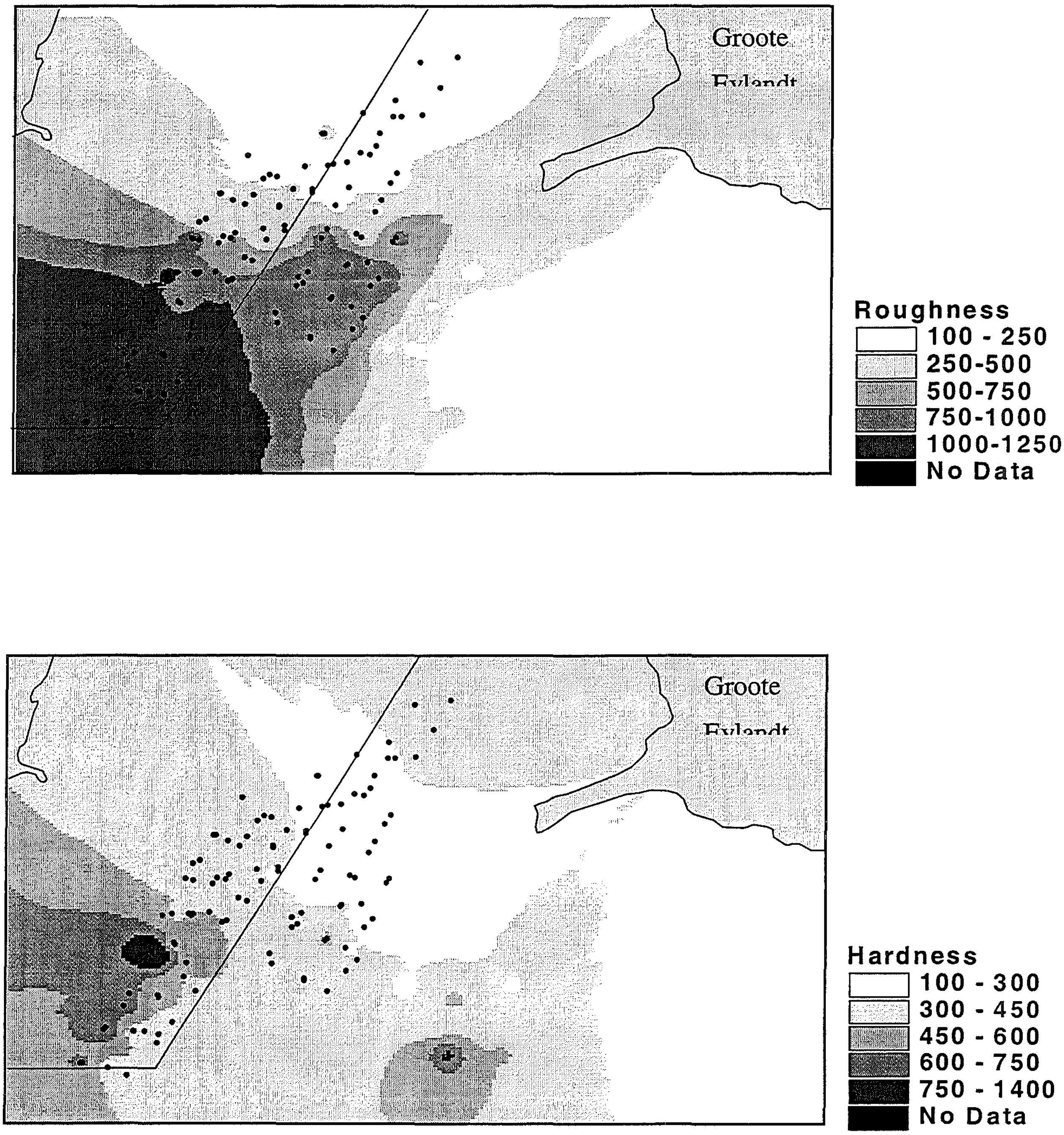


Figure 8.2.5 The acoustic roughness and hardness in the areas of the trawls at 'South Groote'.

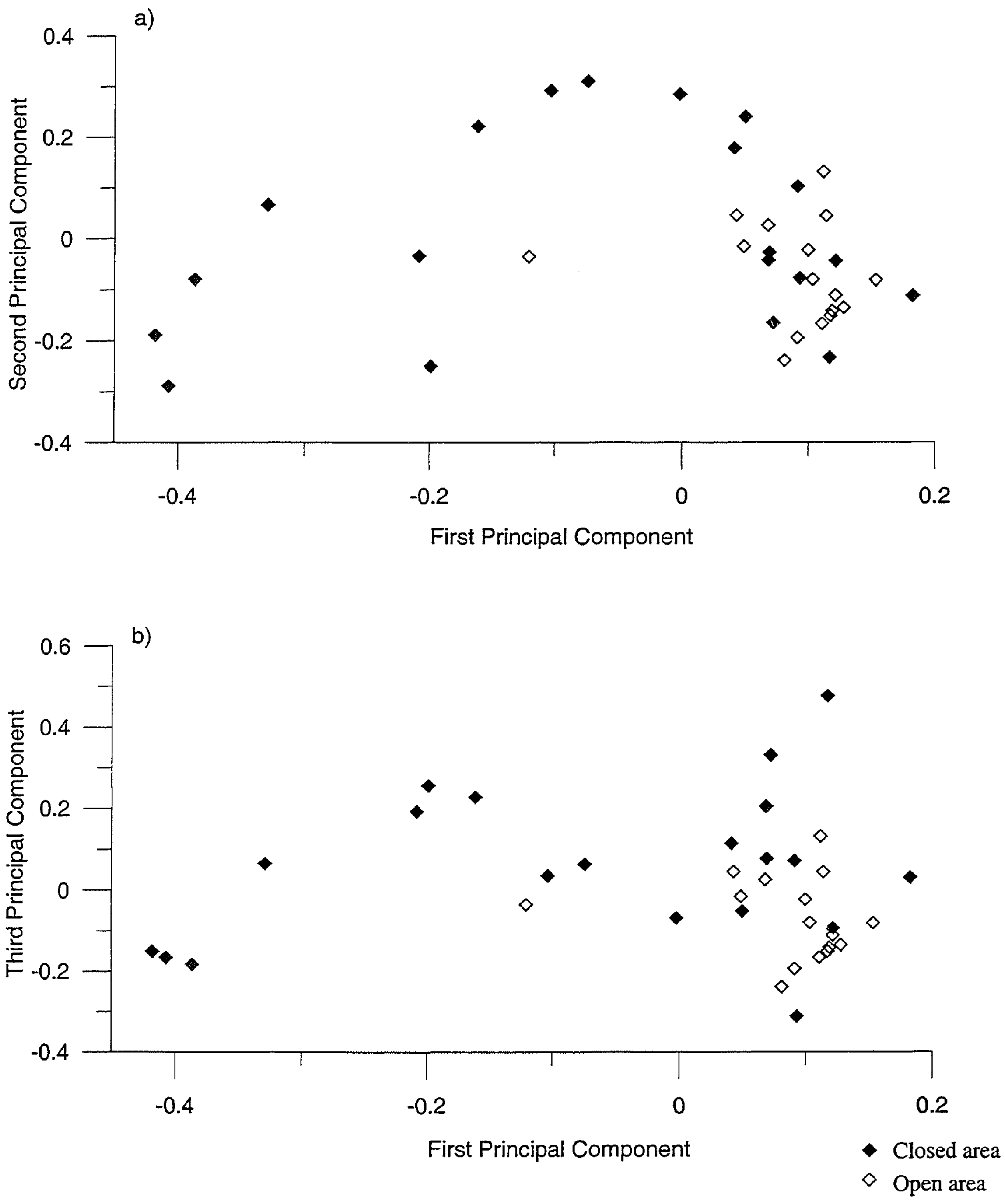


Figure 8.2.6 The distribution of day-time trawls on (a) the first and second, and (b) the first and third principal components.

Table 8.2.7 The correlations between the abiotic variables (depth, distance from the closure boundary, roughness and hardness) and the first three principal components from the ordination, for the day-time trawls.

		Principal Component		
		First	**Second**	**Third**
Depth	r	-0.43	0.18	-0.14
	P	*0.0092*	*0.288*	*0.4212*
	n	36	36	36
Distance	r	0.45	0.002	-0.45
	P	*0.0056*	*0.9912*	*0.0054*
	n	36	36	36
Roughness	r	-0.74	0.19	-0.37
	P	*< 0.0001*	*0.3724*	*0.0742*
	n	24	24	24
Hardness	r	-0.75	-0.45	0.01
	P	*< 0.0001*	*0.0272*	*0.9551*
	n	24	24	24

Table 8.2.8 The F ratios and associated probabilities from the ANOVAs and ANCOVAs on the scores of the day-time trawls on the first three principal components from the ordination. Distance = distance the closure boundary

ANOVA (model 8.2.2)

		Effects		
Principal component		**Open/Closed**	**Sample day**	**Interaction**
First	F	76.38	50.35	23.17
	P	*< 0.0001*	*< 0.0001*	*< 0.0001*
Second	F	2.25	3.90	30.23
	P	*0.1433*	*0.0309*	*< 0.0001*
Third	F	1.88	2.44	0.52
	P	*0.1797*	*0.1034*	*0.4754*

ANCOVA (model 8.2.3)

		Effects			Covariates	
Principal component		**Open/Closed**	**Sample day**	**Interaction**	**Depth**	**Distance**
First	F	4.63	49.68	18.26	0.00	16.16
	P	*0.04*	*< 0.0001*	*0.0002*	*0.9591*	*0.0004*
Second	F	0.52	3.58	34.87	1.33	2.87
	P	*0.4773*	*0.0408*	*< 0.0001*	*0.2583*	*0.101*
Third	F	0.08	1.91	0.09	0.03	1.37
	P	*0.776*	*0.1667*	*0.7618*	*0.8536*	*0.2512*

ANCOVA (model 8.2.4)

		Effects			Covariates			
Principal component		**Open/Closed**	**Sample day**	**Interaction**	**Depth**	**Distance**	**Roughness**	**Hardness**
First	F	0.54	0.48	0.13	0.00	0.17	0.51	0.00
	P	*0.4725*	*62.75*	*72.78*	*0.9857*	*0.6841*	*0.0389*	*0.9538*
Second	F	0.38	2.40	2.55	0.00	8.96	0.69	0.05
	P	*0.5486*	*0.1245*	*0.1314*	*0.9931*	*0.0091*	*0.4193*	*0.8326*
Third	F	0.95	0.39	0.35	0.15	0.16	0.80	0.92
	P	*0.3445*	*0.6851*	*0.5603*	*0.7079*	*0.6956*	*0.3856*	*0.3525*

Table 8.2.9 The correlation coefficients between the abiotic variables; depth, roughness, hardness of trawls and the distance of trawls from the closure boundary, for the day-time trawls only. Probabilities are given in italics.

	Distance	Roughness	Hardness
Depth	0.19	0.59	0.07
	0.2488	*0.0022*	*0.7423*
Distance		0.19	-0.5
		0.3735	*0.0133*
Roughness			0.51
			0.0112

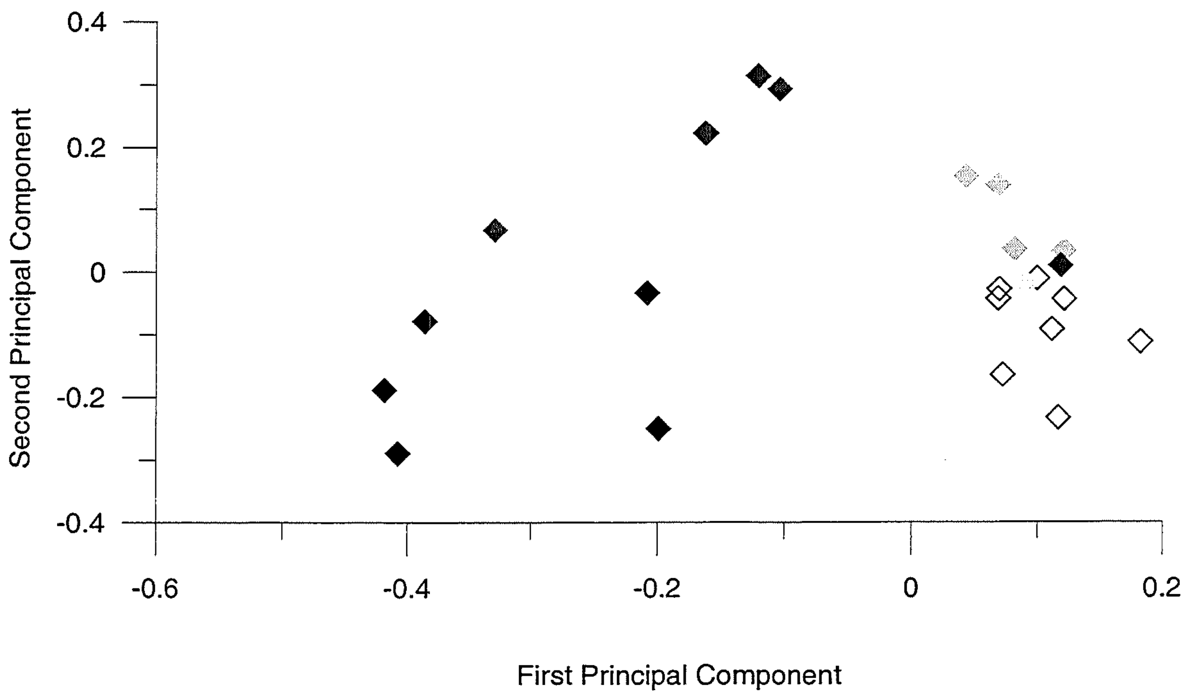


Figure 8.2.7 The scores of the day-time trawls on the first and second principal components from the ordination. The points are shaded in relation to the roughness and hardness of the trawl sites, the roughness and hardness increase as the points darken.

8.2.3 Conclusions

The results of the pilot study show that:

- night time and daytime trawls should be examined separately as the strong day/night signal may overwhelm other effects.
- the inclusion of the blocking factor that accounted for the potential impact of time of the month, and the interaction was successful in removing variation due to these factors.
- the distance from the closure boundary appeared to reflect changes in roughness and hardness and so did not add value to the interpretation. The sampling design also confounded this factor with time of night or day.

There were differences in the fish community of the areas open and closed to trawling but differences in the roughness and hardness characteristics of the sea bottom appeared to explain the observed differences.

8.3 Comparison between areas open and closed to trawling

8.3.1 Methods

Survey Design

In October 1998 two regions ('North Groote', 'South Groote') of the closure west of Groote Eylandt (Figure 8.1.2) were surveyed, using the RV 'Southern Surveyor'. In order to include areas of high effort, in each region three areas were surveyed, an area closed to trawling (closed), an area open to trawling near the closure boundary (near) and an area open to trawling further from the closure (far) (Figures 8.3.1 and 8.3.2).

In each area (closed, near and far) three 6 x 6 n. mile grids were sampled (Figure 8.3.3 and 8.3.4). In the 'South Groote' region the choice of grids was influenced by where sampling occurred in 1997, so that comparisons could be made between the two years. The southern most grid inside the closure sampled in 1997 (Figure 8.2.1) was not resampled in 1998 (Figure 8.3.3). This grid was very rough and hard (Figure 8.2.5), differing greatly from areas outside the closure.

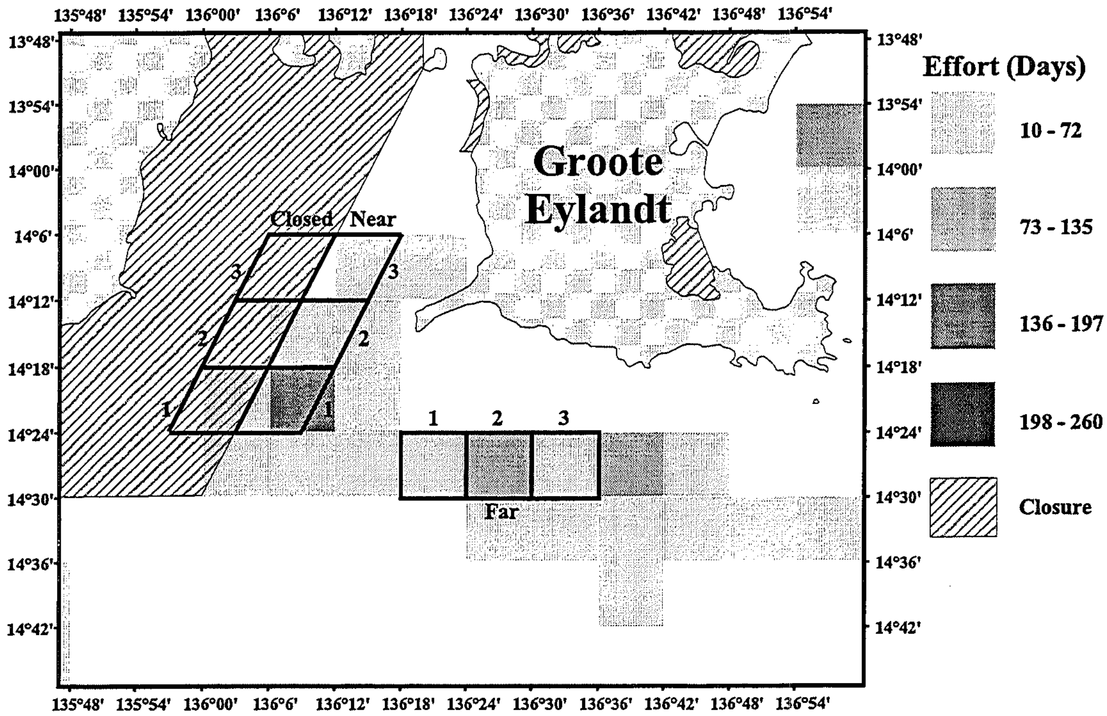
The 'North Groote' region was sampled for 12 nights and 9 days and then the 'South Groote' region for 12 nights and 9 days. The results of the pilot study (Section 8.2.3) suggested that the time of month contributed significant variation to the bycatch composition. The sampling was, therefore, blocked with respect to this factor. In each region the sampling time was broken into blocks of three days/nights. During each block each area (closed, near and far) was visited for one day/night. The sampling was also blocked with respect to the time of day/night. The time of day/night was broken into three time periods, the first three trawls, the second three and the third three trawls. These did not always correspond to distinct times of day/night, due to logistic constraints. Sampling in each time period was conducted in one 6 x 6 n. mile grid. Trawls were 0.5 h in duration.

The aim was to have the sampling distributed randomly with respect to both blocking factors, in Latin Square designs (Sokal and Rolf, 1996). However, due to logistics and steaming constraints the design was compromised and consisted of sampling the areas and the grids within areas as shown in Table 8.3.1. We aimed to carry out three trawls within each grid each day/night and this was accomplished unless there was gear failure. The trawls were sampled as described in Section 6.2.2. We also recorded the standard length of up to 20 randomly selected individuals of each species from each trawl.

Abiotic Measurements

The depth and acoustic roughness and hardness were monitored continuously and the data was checked and summarised as described in Section 6.2.2.

a)



b)

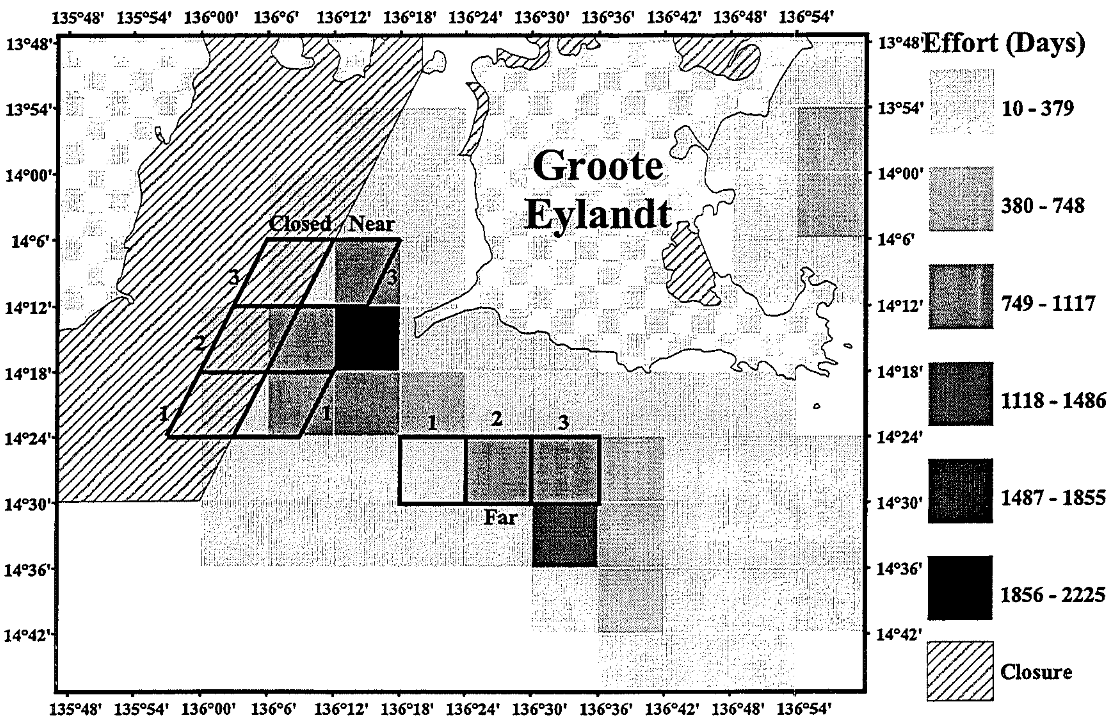
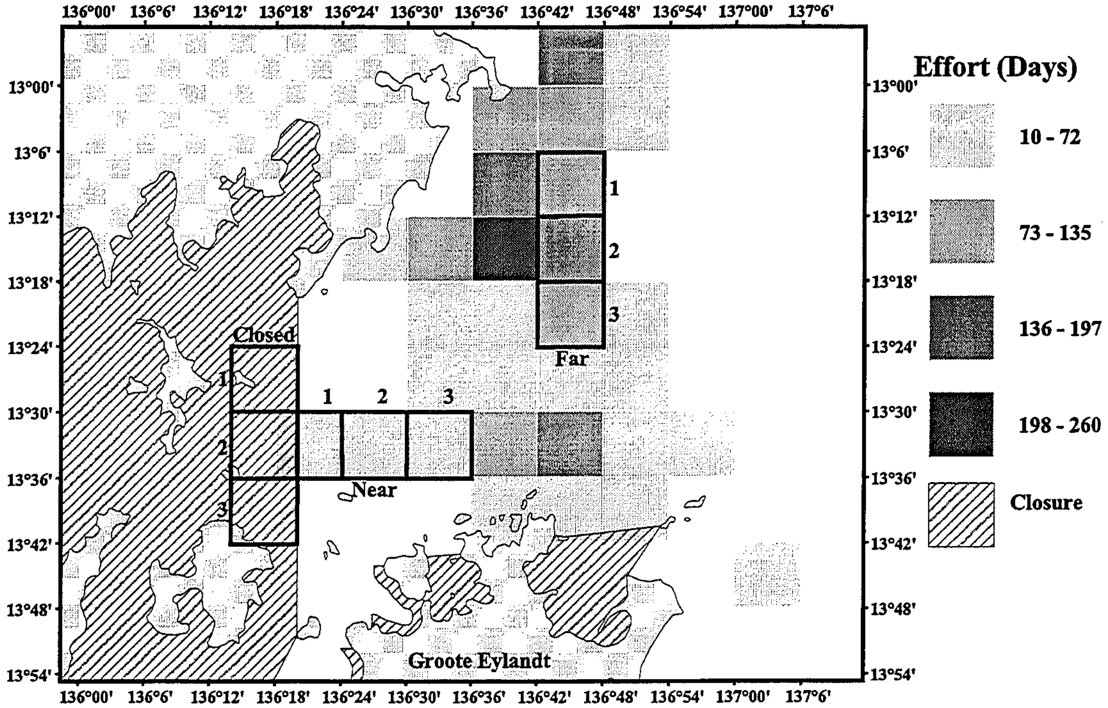


Figure 8.3.1 The areas sampled (outlined grids) at 'North Groote' 1998, and the commercial effort in this region a) in 1997 and b) cumulative from 1987 - 1996

a)



b)

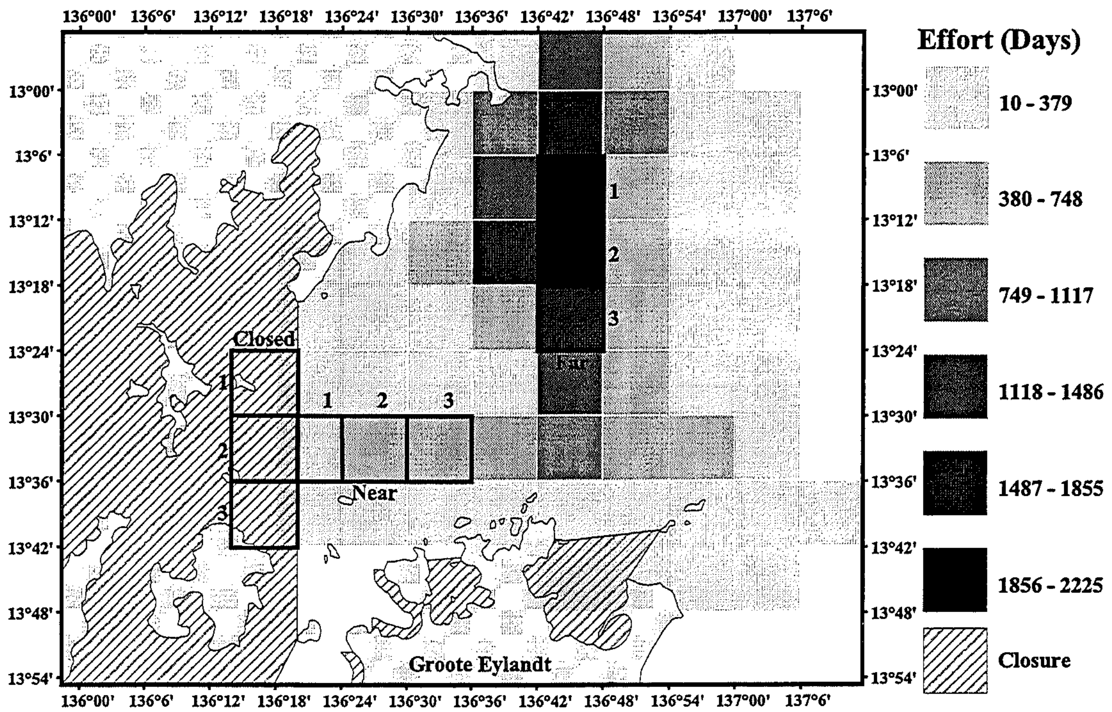
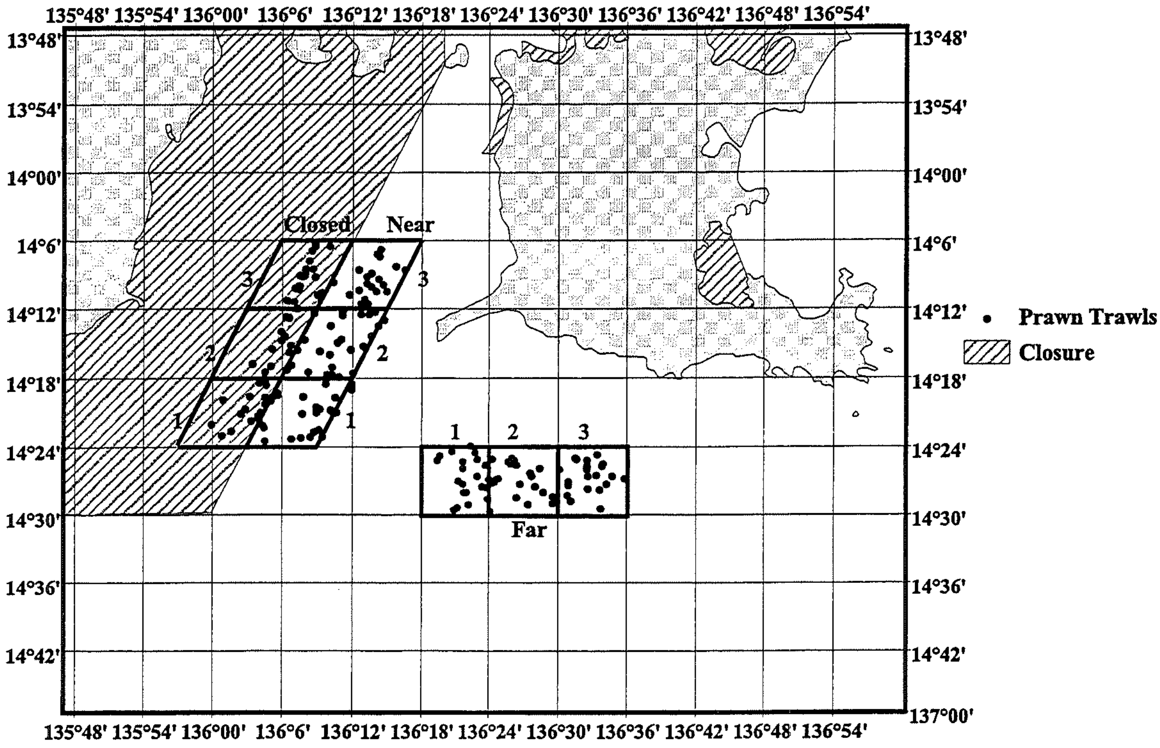


Figure 8.3.2 The areas sampled (outlined grids) at 'South Groote' 1998, and the commercial effort in this region a) in 1997 and b) cumulative from 1987 - 1996

a)



b)

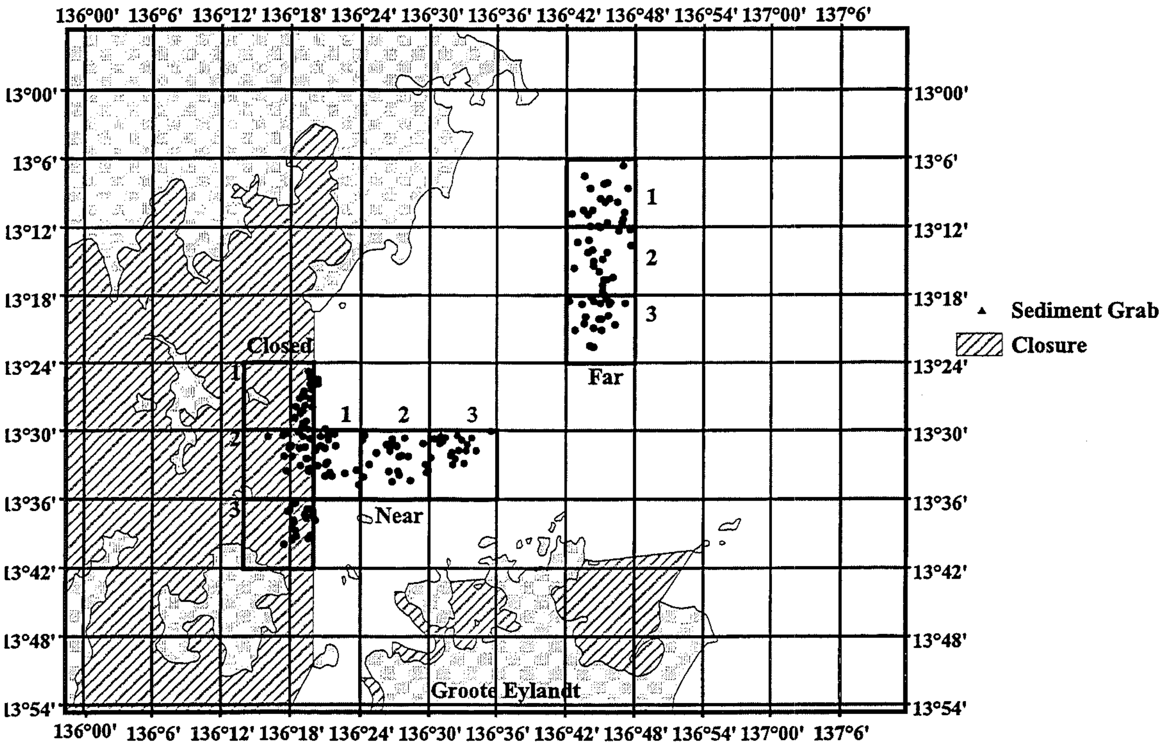
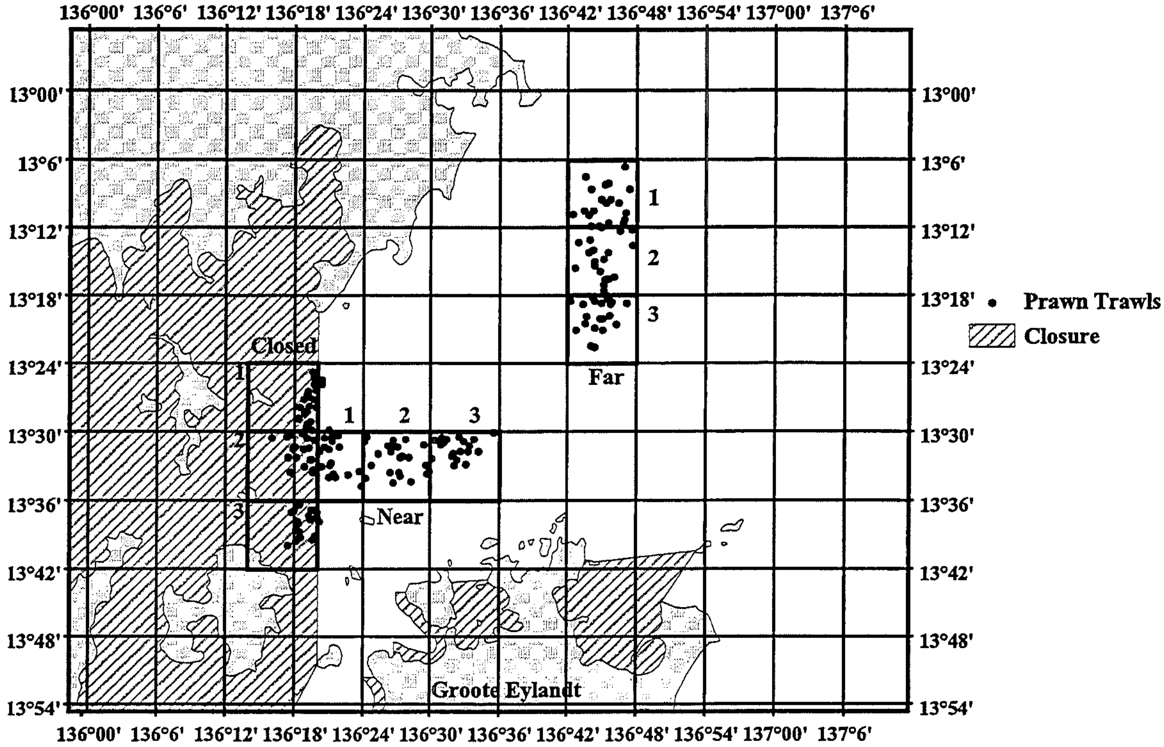


Figure 8.3.3. The sites of (a) trawls and (b) sediment grabs in 'South Groote' 1998.

a)



b)

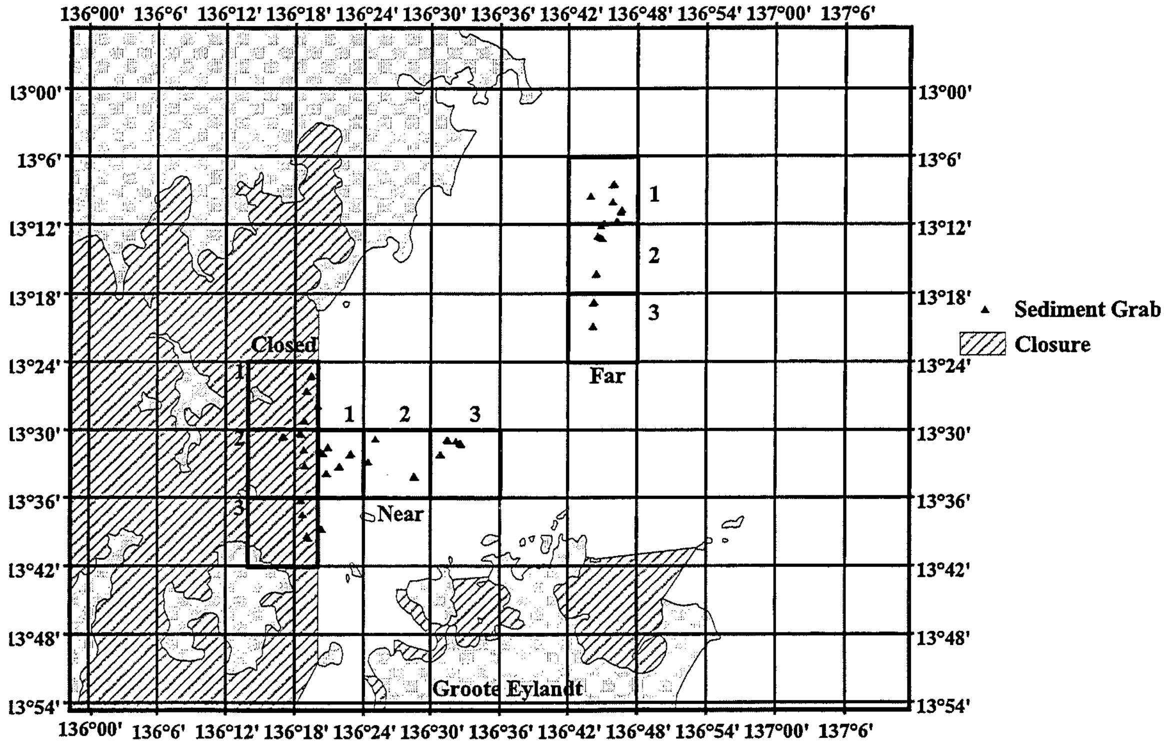


Figure 8.3.4. The sites of (a) trawls and (b) sediment grabs in 'North Groote' 1998.

In 1998 sediment samples were collected in both regions (Figures 8.3.3 and 8.3.4). There were 261 sediment grabs performed, spread across the grids. At each station three replicate grabs were taken in close proximity. The samples were dried at 50°C and then passed through sieves and weighed to determine the proportion of sediment in each size class. The size classes used were mud (< 0.063 mm), very fine sand (0.063 – 0.125 mm), fine sand (0.125 – 0.25 mm), medium sand (0.25 – 0.50 mm), coarse sand (0.50 – 1.00 mm), very coarse sand (1.00 – 2.00 mm), gravel (2.00 – 4.00 mm) and pebbles (> 4.00 mm). Only the percentage of mud in each sample was used in the analysis here. A estimate of the percent mud in the sediment in the area of each trawl was taken from the nearest sediment sample. The data was used to make estimates of the mud content in the areas of the 1997 trawls, assuming that sediment composition did not change significantly between the two years.

An estimate of the commercial effort in the region of each trawl was made as described in Section 6.2.2.

Data Analysis
Catch rates of teleosts and elasmobranchs were standardised by the duration of the trawl and so data are presented as the number of individuals per hour (n h^{-1}) or weight per hour (kg h^{-1}).

The data for each region and time were analysed separately. The 'South Groote' 1997 data were reanalysed to include trawls that were originally sampled for the bycatch description (Section 6.2). These trawls were in the same area as the 'South Groote' 1998 far area (Figure 8.3.3).

Both multivariate and univariate analyses were used. The multivariate analyses examined differences in the overall bycatch composition among the sites, while the univariate analyses examined the patterns shown by individual species.

Multivariate Analysis
Ordinations were performed on the abundance (log (n h^{-1} + minimum n h^{-1}) of teleost and elasmobranch species that occurred in more than 5% of trawls. The association matrix was formed using the Bray Curtis metric and the ordination was performed on a double centred matrix followed by principal component analysis (Williams, 1976).

The two regions in 1998 were analysed initially together in a single ordination. The regions were then separated.

Pearson's correlations (Sokal and Rohlf, 1996) were used to examine the relationship between the principal components from the ordination and the abundance of individual species and the abiotic measurements (depth, roughness, hardness, percent mud and commercial effort).

Univariate Analysis
The patterns shown in the catch rates of individual species were examined using ANCOVAs. This would help identify species that contributed to the patterns observed in the ordinations. ANCOVAs were used to enable the

potential influence of the covariates, depth, percent mud and commercial effort, to be taken out before the treatment effects were assessed.

1998 Surveys

The 1998 data were analysed with an ANCOVA which included the factor area which had three levels (closed, near and far). The patterns seen in the ordination suggested that two specific contrasts between the areas should be investigated. The first contrast compared the far area with the combined closed and near and the second contrast compared the closed and near areas. The effect of the block of sample days/nights and the block of time of day/night were also included. The block of sample days/nights had four levels in the night analyses and three levels in the day analyses (Table 8.3.1). The block of time had three levels. The interactions between the area contrasts and the time were also examined. The effect of grid within area was also included to partition variation due to this factor. The analysis was performed in PROC GLM (SAS Institute, 1989). Due to the unbalanced nature of the design the appropriate error terms to test the various effects were formulated from the table of expected mean squares.

Table 8.3.1 The sampling design for the 1998 survey, showing the two regions sampled ('South Groote' = SG and 'North Groote' = NG), during day and night, the blocks of days/nights within each region and the blocks of time within day/night. The areas within the regions are denoted F = far, N = near, C = closed. The numbers in the cells refer to the grid number within each area, from Figures 8.3.3 and 8.3.4.

	Day/	**Time**	**Block of Days**											
Region	**Night**	**Block**	**1**			**2**			**3**			**4**		
NG	**Night**		**F**	**N**	**C**	**N**	**F**	**C**	**C**	**N**	**F**	**F**	**N**	**C**
		1	1	1	1	3	1	3	2	2	2	3	1	1
		2	2	2	2	2	2	2	3	3	3	2	2	2
		3	3	3	3	1	3	1	1	1	1	1	3	3
	Day		**F**	**N**	**C**	**N**	**F**	**C**	**C**	**N**	**F**			
		1	1	1	1	3	3	3	2	2	2			
		2	2	2	2	2	2	2	3	3	1			
		3	3	3	3	1	1	1	1	1	3			
SG	**Night**		**C**	**N**	**F**	**N**	**C**	**F**	**F**	**N**	**C**	**C**	**F**	**N**
		1	1	1	1	2	2	2	3	3	3	3	3	3
		2	2	2	2	3	3	3	1	1	1	2	2	2
		3	3	3	3	1	1	1	2	2	2	1	1	1
	Day		**F**	**N**	**C**				**F**	**N**	**C**	**C**	**F**	**N**
		1	1	1	1				3	3	3	1	1	1
		2	2	2	2				1	1	1	2	2	2
		3	3	3	3				2	2	2	3	3	3

A second ANCOVA model was run to examine the contrasts between the groups of near and closed sites which separated on the first principal component of the ordination. This aimed to identify which species showed the differences between the groups that occurred in the ordination. In this model only closed and near sites were used. The model examined the contrast between closed and near, between the two groups on the first principal component and the interaction between these two factors.

Table 8.3.3 The correlations between the abiotics in each region, separately for night and day.

'North Groote', 1998

Night

		Effort	% Mud	Roughness	Hardness
% Mud	**r**	0.6543			
	P	*< 0.0001*			
	n	100			
Roughness	**r**	-0.2374	-0.1783		
	P	*0.0403*	*1397*		
	n	75	70		
Hardness	**r**	*0.7766*	*0.3869*	*0.09395*	
	P	*< 0.0001*	*0.0009*	*0.42227*	
	n	75	70	75	
Depth	**r**	0.8633	0.5283	-0.2254	0.81781
	P	*< 0.0001*	*< 0.0001*	*0.052*	*< 0.0001*
	n	105	100	75	75

Day

		Effort	% Mud	Roughness	Hardness
% Mud	**r**	0.5825			
	P	*< 0.0001*			
	n	77			
Roughness	**r**	0.6496	0.2629		
	P	*< 0.0001*	*0.033*		
	n	67	66		
Hardness	**r**	0.8496	0.5723	0.6674	
	P	*< 0.0001*	*< 0.0001*	*< 0.0001*	
	n	67	66	67	
Depth	**r**	0.81902	0.4915	0.56368	0.81771
	P	*< 0.0001*	*< 0.0001*	*< 0.0001*	*< 0.0001*
	n	78	77	67	67

Table 8.3.4 The mean total catch rate of teleost and elasmobranch bycatch in each area in each region, separately for night and day.

Night

Variable		**'South Groote' 1997**			**'South Groote' 1998**			**'North Groote' 1998**		
		Closed	**Near**	**Far**	**Closed**	**Near**	**Far**	**Closed**	**Near**	**Far**
Trawls	n	36	23	20	35	34	35	35	33	35
n h^{-1}	mean	2299.6	2015.2	1819.6	3343.4	2954.4	2427.6	4455.4	5481.7	1787.9
	se	222.43	471.29	272.77	500.05	448.01	337.13	731.68	929.91	173.63
kg h^{-1}	mean	76.4	66.3	60.3	109.0	93.5	87.8	107.0	142.9	34.9
	se	7.76	21.32	6.54	14.23	11.32	10.32	13.02	17.12	3.33

Day

Variable		**'South Groote' 1997**			**'South Groote' 1998**			**'North Groote' 1998**		
		Closed	**Near**	**Far**	**Closed**	**Near**	**Far**	**Closed**	**Near**	**Far**
Trawls	n	20	16	16	26	26	26	26	25	27
n h^{-1}	mean	1976.5	2414.0	1782.0	4390.9	6454.6	5976.3	2030.7	8166.9	3612.3
	se	411.28	415.99	488.85	800.89	2766.51	1137.77	840.92	4364.38	1027.45
kg h^{-1}	mean	93.0	82.7	63.3	153.8	218.6	214.5	74.3	207.8	84.3
	se	31.21	10.02	13.53	24.65	86.88	38.10	27.39	96.71	19.61

Table 8.3.5 The number of fish and elasmobranch bycatch species detected in each area within the regions, separately for night and day.

		Night		**Day**	
		species (n)	**trawls (n)**	**species (n)**	**trawls (n)**
'South Groote'	**Closed**	153	36	94	20
1997	**Near**	102	23	64	16
	Far	119	20	83	16
'South Groote'	**Closed**	182	35	135	26
1998	**Near**	141	34	123	26
	Far	164	35	134	26
'North Groote'	**Closed**	113	35	92	26
1998	**Near**	115	33	77	25
	Far	117	35	75	27

'South Groote' 1998 Night

The ordination was based on the abundance of 123 species in 104 trawls. The first principal component explained 21% of the variation, with the first three accounting for 45% of the variation. The ordination showed a clear separation on the second principal components of the far area from near/closed. The trawls within the later areas formed two groups (A & B, Figure 8.3.7). The separation of trawls along the first principal component appears to reflect an effect of the block of nights sampled, with the first two blocks of nights grouping together, separated from the second two blocks of nights (Figure 8.3.8). There was no clear pattern observed on the ordination in relation to the time of night (Figure 8.3.8).

There were 23 species which correlated positively with the first principal component (Table 8.3.9). The second principal component correlated negatively with 7 species and positively with 14 species (Table 8.3.9). The third principal component correlated negatively with 7 species and positively with 8 species (Table 8.3.9). Depth and percent mud were correlated strongly and positively with the second principal component, while roughness was correlated negatively (Table 8.3.7).

'South Groote' 1998 Day

The ordination was based on the abundance of 117 species in 79 trawls. The first principal component explained 25% of the variation, with the first three accounting for 49% of the variation. The separation was not as strong as the night time pattern (Figure 8.3.7) however the far area did appear to be separated from near/closed areas on the second principal component (Figure 8.3.9). The trawls in the near and closed areas which grouped together (groups A & B, Figure 8.3.9) were not spatially similar to the groups from the night (Figure 8.3.10). Similarly to the pattern at night there was an effect of the block of days, with the first block of days separating out from the second two blocks (Figure 8.3.11). There was no clear pattern observed in relation to time of day (Figure 8.3.11).

There were 22 species which correlated positively with the first principal component (Table 8.3.10). The second principal component correlated negatively with 7 species and positively with 12 species (Table 8.3.10). The third principal component correlated negatively with 5 species and positively with 9 species (Table 8.3.7). The second principal component was correlated positively with depth and percent mud and negatively with roughness (Table 8.3.7).

'North Groote' 1998 Night

The ordination was based on the abundance of 89 species in 105 trawls. The first principal component explained 30% of the variation, with the first three accounting for 55% of the variation. There was clear separation on the first two components of the far area from the near and closed areas (Figure 8.3.12). The near and closed trawls overlapped but separated into two groups, A and B (Figure 8.3.12). There was no clear pattern of groupings of sites in the ordination with respect to the block of days or time of night (Figures 8.3.13).

There were 25 species that correlated negatively and two positively with the first principal component (Table 8.3.11). The second principal component correlated negatively with 7 species and positively with 18 species (Table 8.3.11). The third principal component correlated negatively with one species and positively with four species (Table 8.3.11). Depth, hardness and commercial effort correlated strongly and positively with the first principal component (Table 8.3.7). The second principal component correlated positively with percent mud, commercial effort and depth and negatively with roughness (Table 8.3.7).

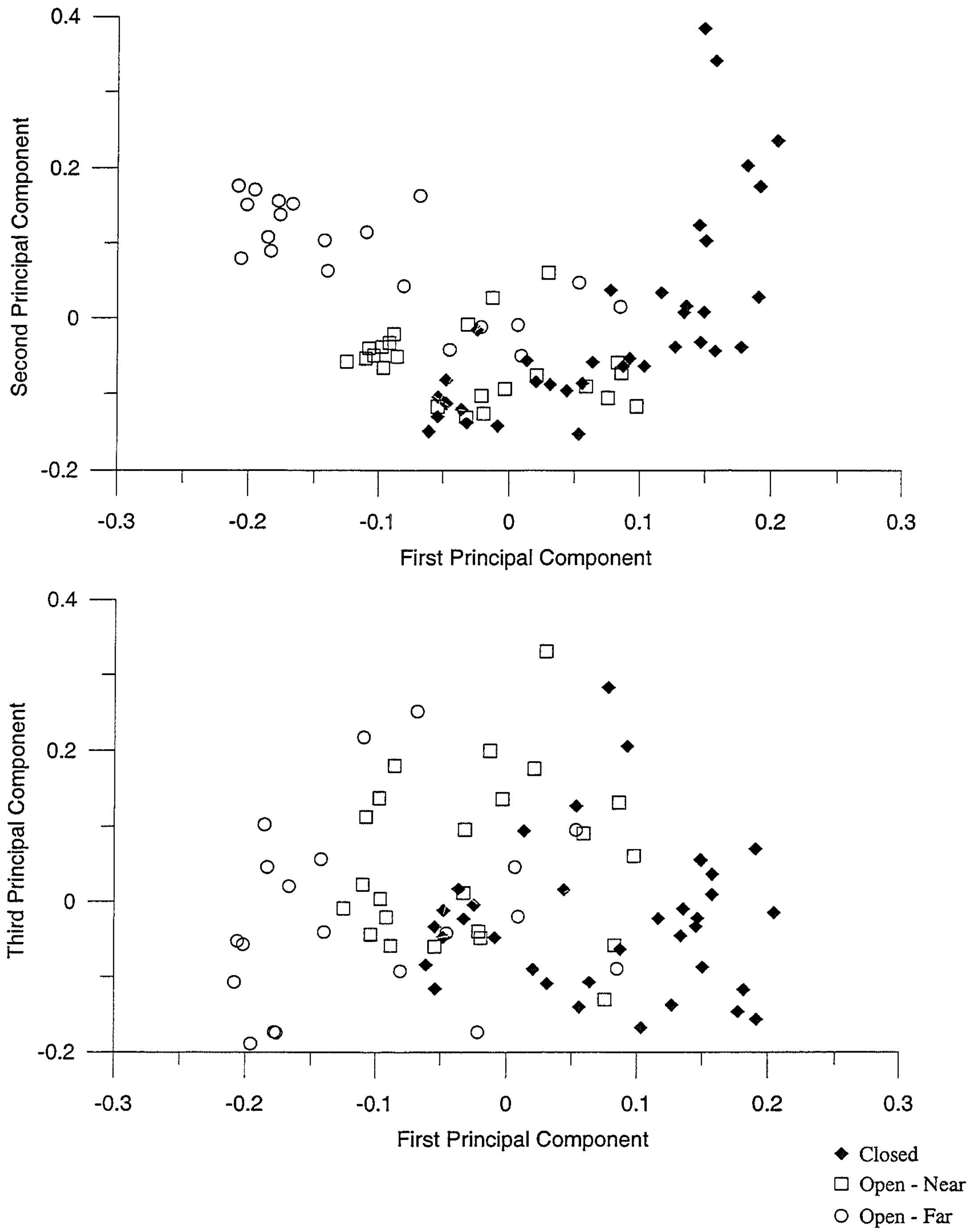


Figure 8.3.5 The ordination results for 'South Groote' 1997 during the night-time, showing the three areas sampled.

Table 8.3.6 The species with strong correlations ($p < 0.05$) with the principal components from the ordination on the trawls at 'South Groote' 1997 night-time (Figure 8.3.7)

First Principal Component Species	r	**Second Principal Component** Species	r	**Third Principal component** Species	r
Nemipterus hexodon	-0.81	*Leiognathus moretoniensis*	-0.76	*Inegocia japonica*	-0.73
Apogon poecilopterus	-0.78	*Torquigener whitleyi*	-0.61	*Scolopsis taeniopterus*	-0.60
Apogon fasciatus	-0.72	*Upeneus sundaicus*	-0.59	*Nemipterus peronii*	-0.55
Saurida micropectoralis	-0.71	*Caranx bucculentus*	-0.59	*Torquigener pallimaculatus*	-0.44
Pentaprion longimanus	-0.71	*Sardinella gibbosa*	-0.58	*Yongeichthys nebulosus*	-0.40
Elates ransonnetii	-0.68	*Trixiphichthys weberi*	-0.50	*Leiognathus bindus*	0.45
Priacanthus tayenus	-0.62	*Leiognathus leuciscus*	-0.49		
Suggrundus macracanthus	-0.60	*Terapon theraps*	-0.47		
Saurida sp. 2	-0.57	*Nemipterus nematopus*	0.40		
Paramonacanthus filicauda	-0.55	*Dactyloptena papilio*	0.41		
Nemipterus nematopus	-0.52	*Lutjanus vitta*	0.43		
Callionymus goodladi	-0.50	*Suggrundus macracanthus*	0.43		
Pseudorhombus elevatus	-0.49	*Pentapodus paradiseus*	0.48		
Apogon ellioti	-0.48	*Fistularia petimba*	0.54		
Sirembo imberbis	-0.47	*Tragulichthys jaculiferus*	0.54		
Euristhmus nudiceps	-0.45	*Choerodon cephalotes*	0.57		
Suggrundus rodericensis	-0.44	*Dasyatis leylandi*	0.58		
Dactyloptena papilio	-0.42	*Centrogenys vaigiensis*	0.58		
Selar crumenophthalmus	-0.41	*Parachaetodon ocellatus*	0.58		
Psettodes erumei	-0.40	*Lethrinus laticaudis*	0.59		
Lutjanus carponotatus	0.42	*Lutjanus carponotatus*	0.64		
Lethrinus laticaudis	0.42	*Diagramma pictum*	0.64		
Upeneus luzonius	0.46	*Siganus canaliculatus*	0.66		
Choerodon cephalotes	0.46				
Thryssa setirostris	0.47				
Dasyatis leylandi	0.47				
Pomadasys maculatus	0.47				
Torquigener pallimaculatus	0.49				
Sphyraena flavicauda	0.52				
Nemipterus furcosus	0.53				
Gazza minuta	0.54				
Leiognathus sp.	0.54				
Selaroides leptolepis	0.54				
Carangoides hedlandensis	0.55				
Callionymus grossi	0.57				
Gerres macrosoma	0.58				
Pentapodus paradiseus	0.62				
Sillago burrus	0.64				
Leiognathus leuciscus	0.67				
Upeneus tragula	0.77				

Table 8.3.7 The correlations between the abiotic measurements and the principal components (PC) from the ordinations for each region separately for each time.

			Depth			**Roughness**			**Hardness**			**Effort**			**% Mud**		
Region/ year	**Time**	**PC**	**r**	***P***	**n**	**r**	***P***	**n**	**r**	***P***	**n**	**r**	***P***	**n**	**r**	***P***	**n**
'South Groote' 1997	**Night**	**1**	-0.60	< *0.0001*	79	0.81	< *0.0001*	64	0.59	< *0.0001*	64	0.39	*0.001*	79	-0.86	< *0.0001*	78
		2	0.54	< *0.0001*	79	0.16	*0.204*	64	0.30	*0.0154*	64	-0.22	*0.0761*	79	0.07	*0.5502*	78
		3	-0.06	*0.5937*	79	-0.09	*0.4617*	64	-0.10	*0.413*	64	0.12	*0.1474*	79	0.17	*0.1428*	78
	Day	**1**	-0.65	< *0.0001*	52	-0.05	*0.7804*	38	-0.18	*0.2904*	38	0.50	*0.00023*	52	-0.04	*0.7686*	52
		2	0.66	< *0.0001*	52	0.71	< *0.001*	38	-0.77	<*0.0001*	38	0.24	*0.0833*	52	0.68	< *0.0001*	52
		3	-0.06	*0.6652*	52	0.06	*0.7073*	38	-0.12	*0.479*	38	-0.14	*0.3169*	52	-0.21	*0.139*	52
'South Groote' 1998	**Night**	**1**	0.14	*0.1595*	104	-0.29	*0.0201*	66	-0.08	*0.5009*	66	-0.01	*0.9568*	104	0.01	*0.9573*	104
		2	0.87	< *0.0001*	104	-0.51	< *0.0001*	66	0.34	*0.0054*	66	0.39	< *0.0001*	104	0.52	< *0.0001*	104
		3	0.14	*0.1552*	104	0.36	*0.0029*	66	0.03	*0.7973*	66	-0.05	*0.5925*	104	-0.49	< *0.0001*	104
	Day	**1**	-0.17	*0.1254*	79	-0.05	*0.0472*	47	0.26	*0.0813*	47	-0.05	*0.6666*	79	-0.04	*0.7033*	79
		2	0.68	< *0.0001*	79	-0.59	< *0.0001*	47	-0.21	*0.154*	47	0.29	*0.0084*	79	0.53	< *0.0001*	79
		3	-0.40	*0.0002*	79	0.15	*0.3103*	47	-0.28	*0.0596*	47	-0.16	*0.149*	79	0.03	*0.7938*	79
'North Groote' 1998	**Night**	**1**	0.65	< *0.0001*	105	0.15	*0.1916*	75	0.64	< *0.0001*	75	0.65	< *0.001*	105	0.14	*0.1771*	100
		2	0.54	< *0.0001*	105	-0.47	< *0.0001*	75	0.34	*0.0032*	75	0.63	< *0.001*	105	0.74	< *0.0001*	100
		3	0.11	*0.244*	105	0.21	*0.0762*	75	0.11	*0.3624*	75	0.20	*0.0455*	105	0.28	*0.0041*	100
	Day	**1**	-0.10	*0.3705*	78	-0.17	*0.9526*	67	-0.18	*0.0986*	67	-0.15	*0.2048*	78	-0.44	< *0.0001*	77
		2	0.38	< *0.0001*	78	-0.73	< *0.0001*	67	-0.76	< *0.001*	67	0.85	< *0.0001*	78	0.52	< *0.0001*	77
		3	0.01	*0.9513*	78	0.12	*0.4275*	67	0.25	*0.2435*	67	0.09	*0.4578*	78	-0.14	*0.2321*	77

Table 8.3.9 The species with strong correlations ($p < 0.05$) with the principal components from the ordination on the trawls from 'South Groote' 1998 night-time (Figure 8.3.7).

First Principal Component		**Second Principal Component**		**Third Principal component**	
Species	**r**	**Species**	**r**	**Species**	**r**
Apogon ellioti	0.41	*Terapon theraps*	-0.76	*Upeneus sundaicus*	-0.63
Pegasus volitans	0.43	*Trixiphichthys weberi*	-0.74	*Leiognathus leuciscus*	-0.53
Leiognathus moretoniensis	0.43	*Leiognathus leuciscus*	-0.57	*Leiognathus bindus*	-0.46
Pseudorhombus arsius	0.45	*Torquigener whitleyi*	-0.56	*Gazza minuta*	-0.45
Callionymus grossi	0.46	*Pegasus volitans*	-0.50	*Leiognathus moretoniensis*	-0.45
Grammatobothus polyophthalmus	0.47	*Pomadasys maculatus*	-0.50	*Leiognathus splendens*	-0.44
Saurida micropectoralis	0.48	*Choerodon cephalotes*	-0.46	*Bregmacerotidae*	-0.42
Apistus carinatus	0.48	*Leiognathus bindus*	0.41	*Choerodon cephalotes*	0.44
Pseudorhombus elevatus	0.48	*Carangoides caeruleopinnatus*	0.42	*Upeneus tragula*	0.44
Sillago ingenuua	0.49	*Gerres macracanthus*	0.42	*Callionymus grossi*	0.45
Callionymus goodladi	0.50	*Pentaprion longimanus*	0.43	*Pseudorhombus argus*	0.45
Scolopsis taeniopterus	0.50	*Nemipterus nematopus*	0.44	*Scolopsis taeniopterus*	0.45
Sillago burrus	0.53	*Upeneus sulphureus*	0.45	*Torquigener tuberculiferus*	0.47
Yongeichthys nebulosus	0.56	*Trichiurus lepturus*	0.48	*Sillago ingenuua*	0.52
Sardinella gibbosa	0.56	*Pseudorhombus elevatus*	0.49	*Nemipterus furcosus*	0.61
Nemipterus hexodon	0.61	*Apogon ellioti*	0.49		
Apogon poecilopterus	0.62	*Carangoides talamparoides*	0.50		
Pseudorhombus spinosus	0.65	*Nemipterus hexodon*	0.56		
Euristhmus nudiceps	0.71	*Priacanthus tayenus*	0.62		
Apogon fasciatus	0.74	*Saurida* sp. 2	0.65		
Nemipterus peronii	0.83	*Suggrundus macracanthus*	0.73		
Elates ransonnetii	0.86				
Inegocia japonica	0.91				

Summary of the multivariate analysis

The patterns seen in the bycatch composition were similar between the regions in 1998 ('North Groote' and 'South Groote') and between the two years in 'South Groote'. Both regions showed separation between the far and the combined near and closed areas. The near and closed trawls were mixed, but showed distinct structure. In 'South Groote' 1998 the groupings of the closed and near sites appeared to reflect an effect of the block of days/nights sampled (Figure 8.3.8 and 8.3.11). The first block of days/nights sampled in 'South Groote' 1998 coincided with a full moon. The sampling at 'North Groote' took place around the waxing moon. The grouping of closed and near trawls in 'North Groote' does not appear to reflect any effect of the block of days/nights sampled (Figure 8.3.13 and 8.3.16). 'South Groote' 1997 showed some indication of a separation between the far area and the closed but the pattern was much weaker than that seen in 1998.

The ordinations for each region and both times showed strong correlations with the abiotic measurements. Depth, percent mud, roughness and hardness showed significant correlations with all ordinations (Table 8.2.7). In general depth correlated strongly with the second principal component, on which most of the separation between far and closed/near areas was seen. This is not surprising as the far areas were deeper (Table 8.3.2). Roughness and the percentage of mud showed a similar pattern with strong correlations with the second principal component on most ordinations. Hardness did not show a consistent pattern across the ordinations (Table 8.3.7).

Univariate Analyses

'South Groote' 1997 Night

The contrasts from the ANCOVA showed that 14 species had a significant difference between the far area and combined closed and near areas but no significant interaction with time (Table 8.3.13). While 5 species showed a significant interaction but not the contrast. Of these, 6 were higher in catch rate in the far area, 7 in the combined closed near areas, and 4 species with interactions showed no consistent area with higher catch rate across the times (Table 8.3.13). There were 5 species that showed a significant difference in catch rate between the closed and near areas, but no significant interaction with time. Four species showed a significant interaction, but not the contrast (Table 8.3.13). Two species had higher catch rates in the closed area and 4 in the near. Three of the species with significant interactions showed no consistent direction across the times. There were 5 species that showed a significant effect of the block of nights, 3 had higher catch rates in the first block, and 1 in the second and third blocks (Table 8.3.13).

'South Groote' 1997 Day

The contrasts from the ANCOVA found no species with significant contrasts between the far area and the combined closed and near areas and one species (*Upeneus asymmetricus*) with a significant interaction between this contrast and time. This species showed a no difference in catch rate at time 1, but had a higher catch rate in the far area at times 2 and 3. Only 1 species (*Carangoides humerosus)* showed a significant contrast between the closed and near areas. This species had a higher catch rate in the near area. There were 2 species with significant interactions between this contrast and time. These species, (*Gazza minuta* and *Sillgo ingenuua)*, showed different patterns, *G. minuta* was higher in the near area at all times, but the magnitude of the difference varied, while *S. ingenuua* was higher in the closed area in times 1 and 3, but there was no difference in time 2. There were no species that showed a difference between the block of days.

'South Groote' 1998 Night

Twenty-one species had a significant contrast between the far area and the combined closed and near areas, with 1 also having a significant interaction with time. There were 7 species that did not have a significant contrast, but had a significant interaction (Table 8.3.14). Sixteen species had higher catch rates in the far area and 9 species had a higher catch rate in the combined closed and near areas (Table 8.3.14). The interaction for 4 species indicated a difference in the magnitude of the difference but the direction was consistent across times. There were 4 species which had a significant interaction that indicated the region with the highest catch rate was not consistent across times.

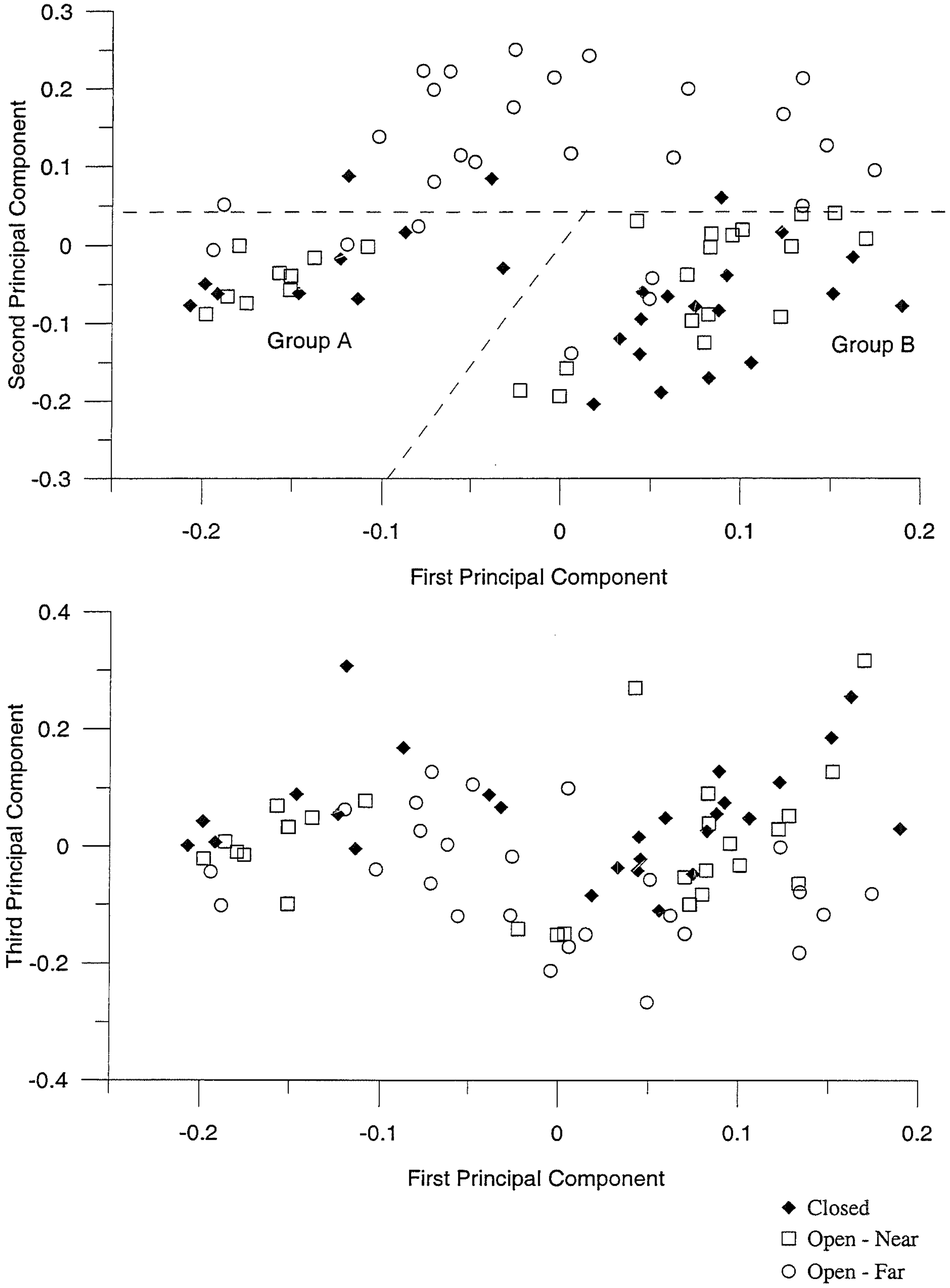


Figure 8.3.9 The ordination results for 'South Groote' during the day-time, showing the three areas sampled.

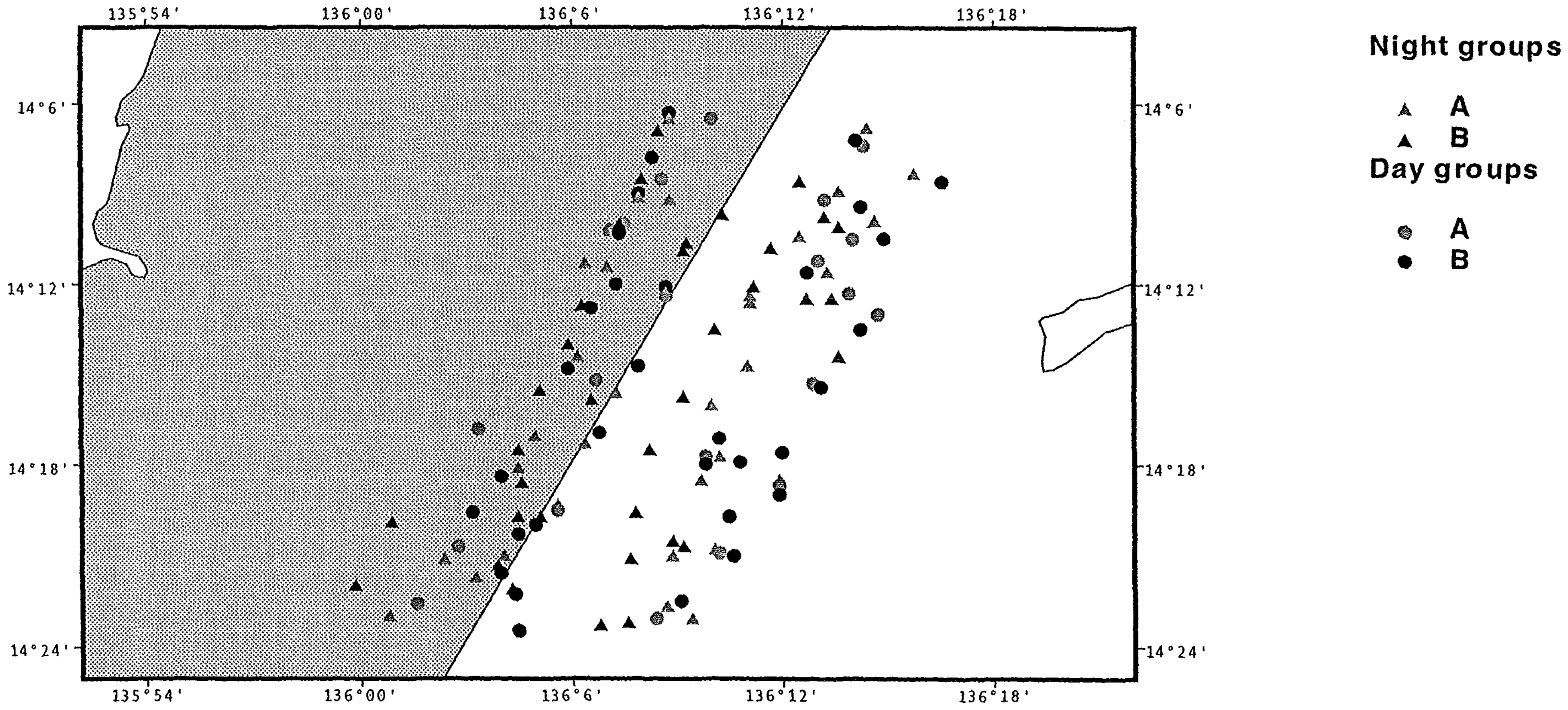


Figure 8.3.10 The location of trawls in the near and closed areas at 'South Groote', the symbols indicate which ordination group the trawls occurred in from Figures 8.3.7 and 8.3.9.

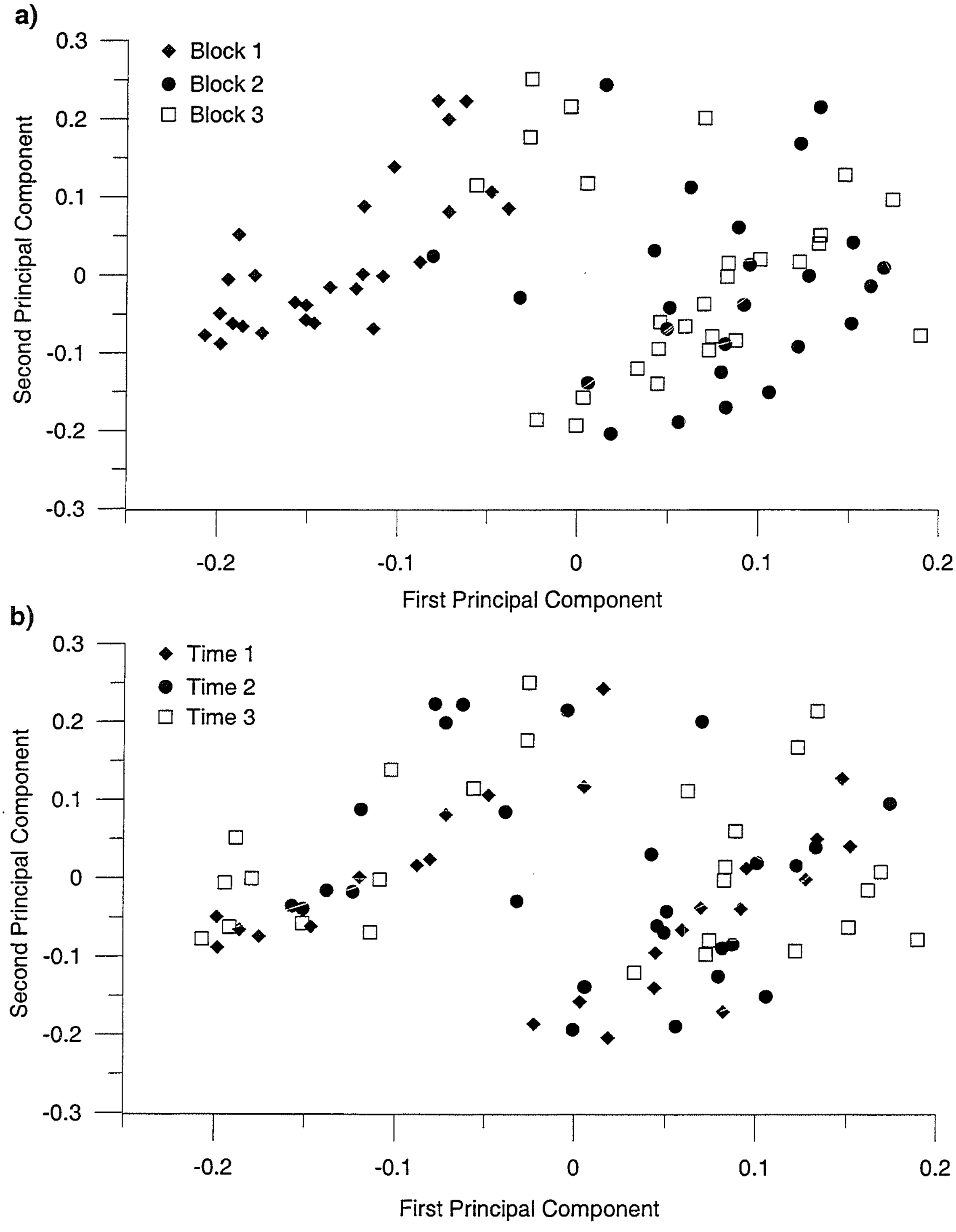


Figure 8.3.11 The ordination results for 'South Groote' during the day-time, showing (a) the blocks of sampling days and (b) the time of day.

Table 8.3.10 The species with strong correlations ($p < 0.05$) with the principal components from the ordination on the trawls from 'South Groote' 1998 day-time (Figure 8.3.9.).

First Principal Component		Second Principal Component		Third Principal component	
Species	**r**	**Species**	**r**	**Species**	**r**
Sillago burrus	0.40	*Scolopsis taeniopterus*	-0.48	*Nemipterus hexodon*	-0.55
Sillago ingenuua	0.40	*Nemipterus peronii*	-0.44	*Saurida* sp. 2	-0.51
Caranx bucculentus	0.41	*Trixiphichthys weberi*	-0.42	*Priacanthus tayenus*	-0.51
Secutor insidiator	0.41	*Pentapodus paradiseus*	-0.42	*Sphyraena forsteri*	-0.46
Apogon fasciatus	0.43	*Choerodon cephalotes*	-0.42	*Nemipterus furcosus*	-0.42
Leiognathus sp.	0.43	*Sillago ingenuua*	-0.41	*Rhizoprionodon acutus*	0.40
Psettodes erumei	0.44	*Torquigener whitleyi*	-0.41	*Caranx kleinii*	0.41
Leiognathus bindus	0.45	*Psenopsis humerosa*	0.41	*Carcharhinus dussumieri*	0.45
Himantura toshi	0.45	*Nemipterus nematopus*	0.42	*Scomberoides tol*	0.45
Nemipterus hexodon	0.50	*Trichiurus lepturus*	0.44	*Pellona ditchela*	0.48
Sardinella gibbosa	0.52	*Scomberoides tala*	0.44	*Sardinella gibbosa*	0.48
Saurida sp. 2	0.59	*Priacanthus tayenus*	0.45	*Leiognathus decorus*	0.51
Scolopsis taeniopterus	0.59	*Leiognathus* sp.	0.49	*Terapon theraps*	0.53
Saurida micropectoralis	0.62	*Pentaprion longimanus*	0.49	*Leiognathus splendens*	0.57
Trixiphichthys weberi	0.64	*Gerres macracanthus*	0.62		
Gazza minuta	0.70	*Leiognathus bindus*	0.63		
Leiognathus leuciscus	0.74	*Carangoides talamparoides*	0.68		
Inegocia japonica	0.74	*Carangoides caeruleopinnatus*	0.70		
Upeneus sundaicus	0.76	*Selar boops*	0.71		
Leiognathus moretoniensis	0.79	*Secutor insidiator*	0.73		
Nemipterus peronii	0.79				
Elates ransonnetii	0.80				

The contrast between the near and closed areas showed 15 species had a significant effect, 1 also had a significant interaction with time (Table 8.3.14). There were 7 species that did not have a significant contrast, but that had a significant interaction. Nine species were higher in the near area and 6 species

higher in the closed area (Table 8.3.14). The interaction term for 1 species indicated a difference in the magnitude of the difference but the direction was consistent. However, for 7 species the direction was not consistent.

There were 23 species with a significant difference among the blocks of days sampled. Of these 12 had a higher catch rate in the fourth block of days, and 10 species in the third block and one species in the first block (Table 8.3.14). The species that showed strong differences between the two groups of closed and near sites on the first principal component coincided with species that showed a significant effect of the block of days (Table 8.3.14). There were 21 of the 23 species with significant block of days effects that showed a significant difference between the groups (Table 8.3.14). There were 11 species which showed a higher abundance in Group A and 62 species with a higher abundance in Group B (Table 8.3.14).

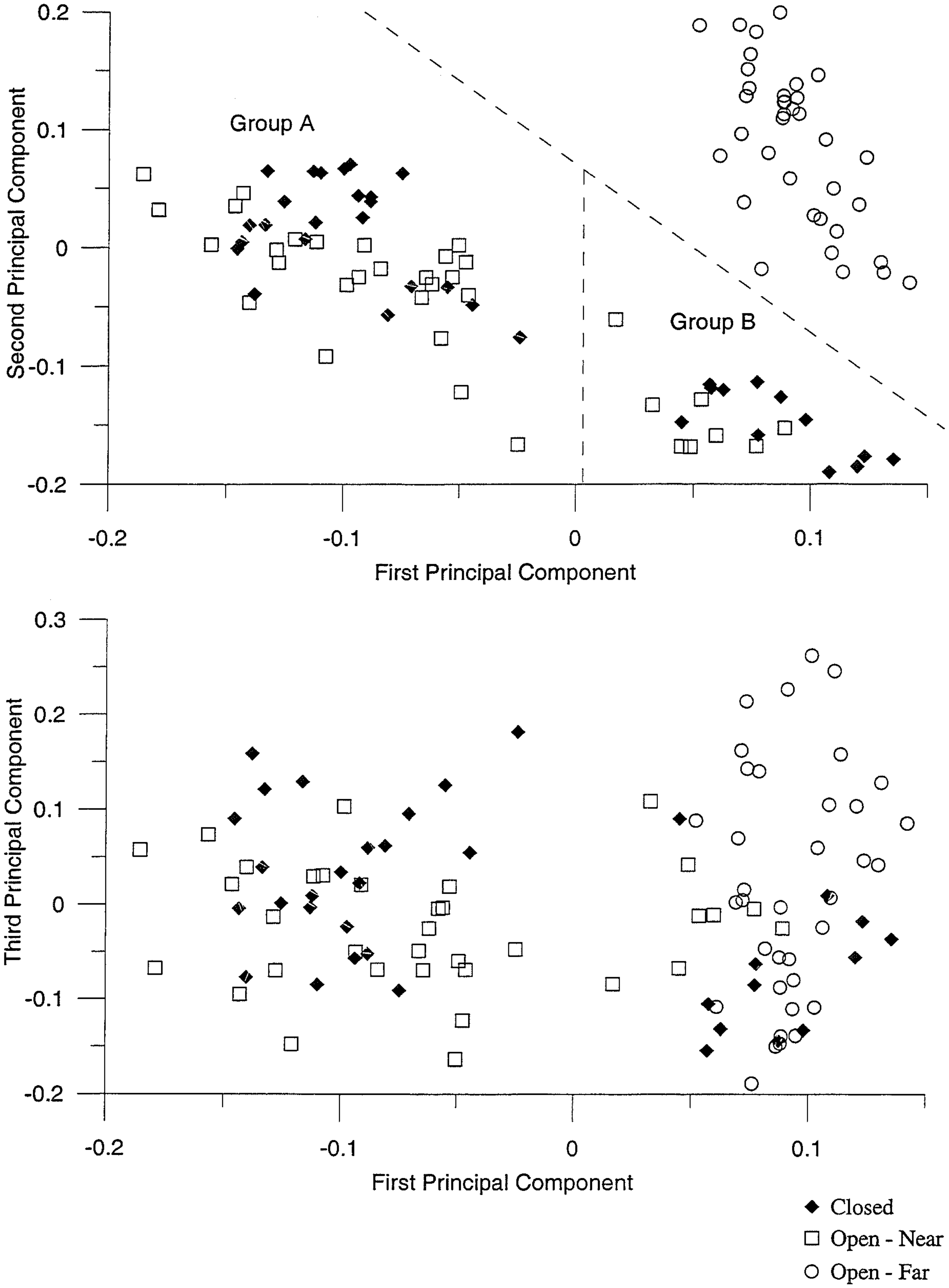


Figure 8.3.12 The ordination results for 'North Groote' during the night-time, showing the three areas sampled.

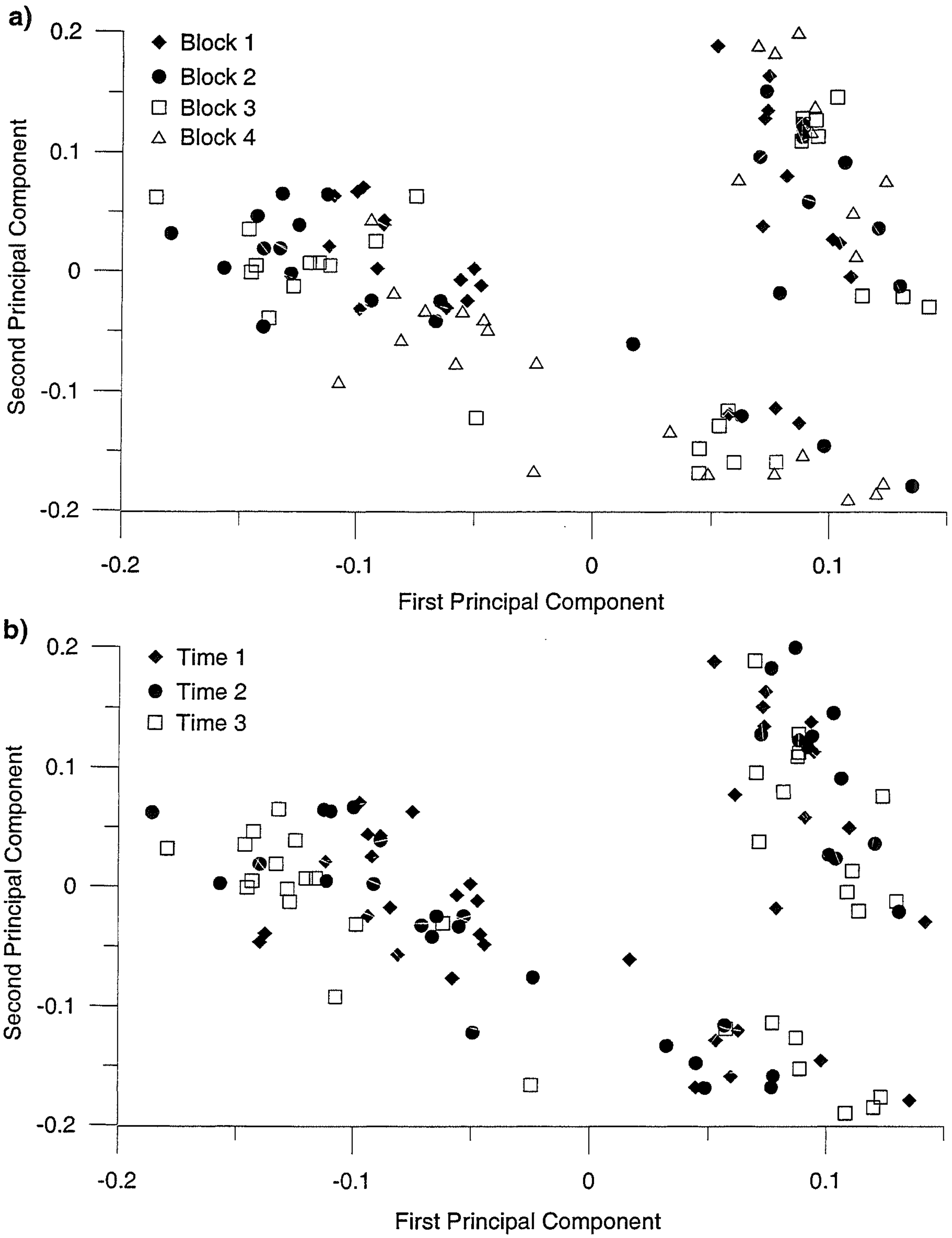


Figure 8.3.13 The ordination results for 'North Groote' 1998, during the night-time, showing (a) the blocks of sampling nights and (b) the time of night.

Table 8.3.11 The species with strong correlations (p < 0.05) with the principal components from the ordination of the trawls from 'North Groote' 1998 night-time (Figure 8.3.12).

First Principal Component		Second Principal Component		Third Principal component	
Species	**r**	**Species**	**r**	**Species**	**r**
Leiognathus splendens	-0.91	*Carangoides hedlandensis*	-0.63	*Apogon ellioti*	-0.45
Pomadasys trifasciatus	-0.88	*Scomberomorus queenslandicus*	-0.62	*Trichiurus lepturus*	0.42
Upeneus sundaicus	-0.87	*Caranx bucculentus*	-0.58	*Carangoides malabaricus*	0.48
Leiognathus decorus	-0.85	*Ulua aurochs*	-0.56	*Leiognathus bindus*	0.63
Trixiphichthys weberi	-0.81	*Atule mate*	-0.56	*Secutor insidiator*	0.65
Scolopsis taeniopterus	-0.75	*Selaroides leptolepis*	-0.48		
Anodontostoma chacunda	-0.73	*Leiognathus leuciscus*	-0.44		
Terapon theraps	-0.69	*Pseudorhombus elevatus*	0.40		
Nemipterus hexodon	-0.64	*Dexillus muelleri*	0.40		
Centriscus scutatus	-0.60	*Psettodes erumei*	0.44		
Carangoides humerosus	-0.59	*Priacanthus tayenus*	0.51		
Engraulididae	-0.58	*Uranoscopus cognatus*	0.52		
Caranx bucculentus	-0.58	*Apistus carinatus*	0.52		
Terapon puta	-0.57	*Euristhmus nudiceps*	0.53		
Pomadasys maculatus	-0.55	*Elates ransonnetii*	0.55		
Polydactylus multiradiatus	-0.52	*Nemipterus hexodon*	0.56		
Thryssa setirostris	-0.52	*Suggrundus macracanthus*	0.61		
Apogon ellioti	-0.52	*Leiognathus moretoniensis*	0.63		
Pelates quadrilineatus	-0.51	*Upeneus sulphureus*	0.64		
Leiognathus ruconius	-0.49	*Paramonacanthus filicauda*	0.64		
Nemipterus peronii	-0.47	*Saurida* sp. 2	0.66		
Gerres macrosoma	-0.45	*Apogon fasciatus*	0.70		
Gerres macracanthus	-0.44	*Pentaprion longimanus*	0.74		
Elates ransonnetii	-0.42	*Saurida micropectoralis*	0.75		
Apogon poecilopterus	-0.42	*Apogon poecilopterus*	0.81		
Upeneus sulphureus	0.51				
Paramonacanthus filicauda	0.53				

'South Groote' 1998 Day

The contrast from the ANCOVA between the far area and the combined closed and near areas showed that19 species had this contrast significant, 3 of which also had a significant interaction with time (Table 8.3.15). There were 10 species that had only a significant interaction. Of these species 15 species had significantly higher catch rates in the far area and 6 species were higher in the combined closed and near areas (Table 8.3.15). Only 2 species had a significant interaction which showed a change in the magnitude but not the direction of the contrast. There were 11 species that had a significant interaction term, indicating that the direction was not consistent (Table 8.3.15). Eight of these species were in common with the night.

The contrast between the near and closed areas showed 5 species with a significant contrast, one of which also had a significant interaction with time (Table 8.3.15). There were also 9 species that had no significant contrast, but a significant interaction. Of these species, 5 had higher catch rates in the closed area higher in the near area (Table 8.3.15). The interactions all indicated that the direction of the contrast was not consistent among the times. Five of these species had this contrast or interaction significant at night.

Table 8.3.12 The species with strong correlations (p < 0.05) with the principal components from the ordination on the trawls from 'North Groote' 1998 day-time (Figure 8.3.14).

First Principal Component		Second Principal Component		Third Principal component	
Species	**r**	**Species**	**r**	**Species**	**r**
Secutor insidiator	-0.86	*Carcharhinus dussumieri*	-0.54	*Upeneus sundaicus*	0.4
Leiognathus splendens	-0.81	*Carangoides hedlandensis*	-0.52	*Gerres macrosoma*	0.4
Pellona ditchela	-0.80	*Leiognathus decorus*	-0.46	*Carangoides caeruleopinnatus*	0.4
Gazza minuta	-0.73	*Scomberomorus queenslandicus*	-0.43	*Leiognathus leuciscus*	0.4
Sardinella gibbosa	-0.71	*Caranx bucculentus*	-0.43	*Gerres macracanthus*	0.5
Leiognathus ruconius	-0.69	*Anodontostoma chacunda*	-0.42	*Selaroides leptolepis*	0.6
Caranx bucculentus	-0.68	*Gerres macrosoma*	-0.42		
Herklotsichthys lippa	-0.68	*Leiognathus leuciscus*	-0.41		
Anodontostoma chacunda	-0.67	*Herklotsichthys lippa*	0.41		
Leiognathus decorus	-0.63	*Selar boops*	0.48		
Thryssa setirostris	-0.60	*Pentaprion longimanus*	0.50		
Pomadasys trifasciatus	-0.59	*Rastrelliger kanagurta*	0.50		
Trichiurus lepturus	-0.57	*Selar crumenophthalmus*	0.55		
Pomadasys maculatus	-0.57	*Saurida* sp. 2	0.60		
Pelates quadrilineatus	-0.54	*Carangoides talamparoides*	0.70		
Leiognathus bindus	-0.54	*Carangoides malabaricus*	0.72		
Herklotsichthys koningsbergeri	-0.47	*Upeneus sulphureus*	0.77		
Terapon theraps	-0.44				
Psenopsis humerosa	-0.43				
Carangoides talamparoides	-0.43				
Leiognathus equulus	-0.41				
Carangoides humerosus	-0.41				
Rhizoprionodon acutus	-0.41				

There were 19 species with a significant difference among the blocks of days, 8 that had a higher catch rate in the fourth block of days, 3 of these showed the same pattern at night, and 11 species in the third block, 5 of these showed the same pattern at night (Table 8.3.15). In a similar pattern to that seen in the night trawls, the majority of species which showed a strong effect of block of days, 15 out of the 19 species, showed a significant difference between groups on the first principal component (Table 8.3.15). There were 3 species with a higher catch in group A and 40 with a higher catch in group B (Table 8.3.15). Of the 40 species with a higher catch in group B, 26 also showed a higher catch in group B at night. Four other species with a higher catch in group B had higher catches in group A at night.

'North Groote' 1998 Night

There were 14 species with a significant contrast between the far area and combined closed and near areas and no significant interaction between this and time (Table 8.3.16). There was one species with the significant contrast and a significant interaction and 5 species with just the interaction significant. Of these species, 5 had higher catch rates in the far area and 13 in the combined closed and near areas. The interactions for 4 species indicated a difference in the magnitude of the difference within the contrast but the direction was the consistent. There were 2 species where the interaction indicated that the area with the highest catch rate was not consistent among the times (Table 8.3.16).

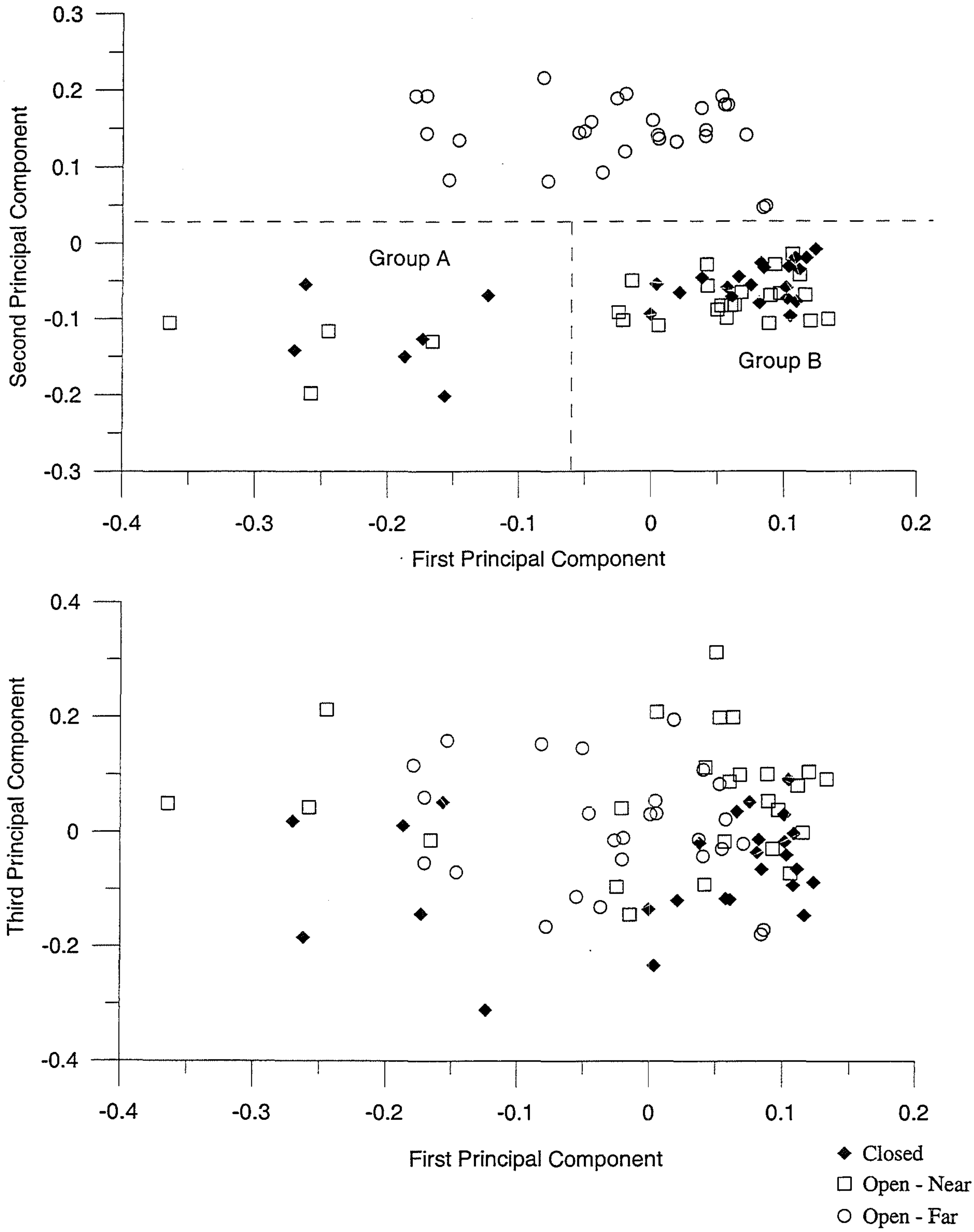


Figure 8.3.14 The ordination results for 'North Groote' 1998, during the day-time, showing the three areas sampled.

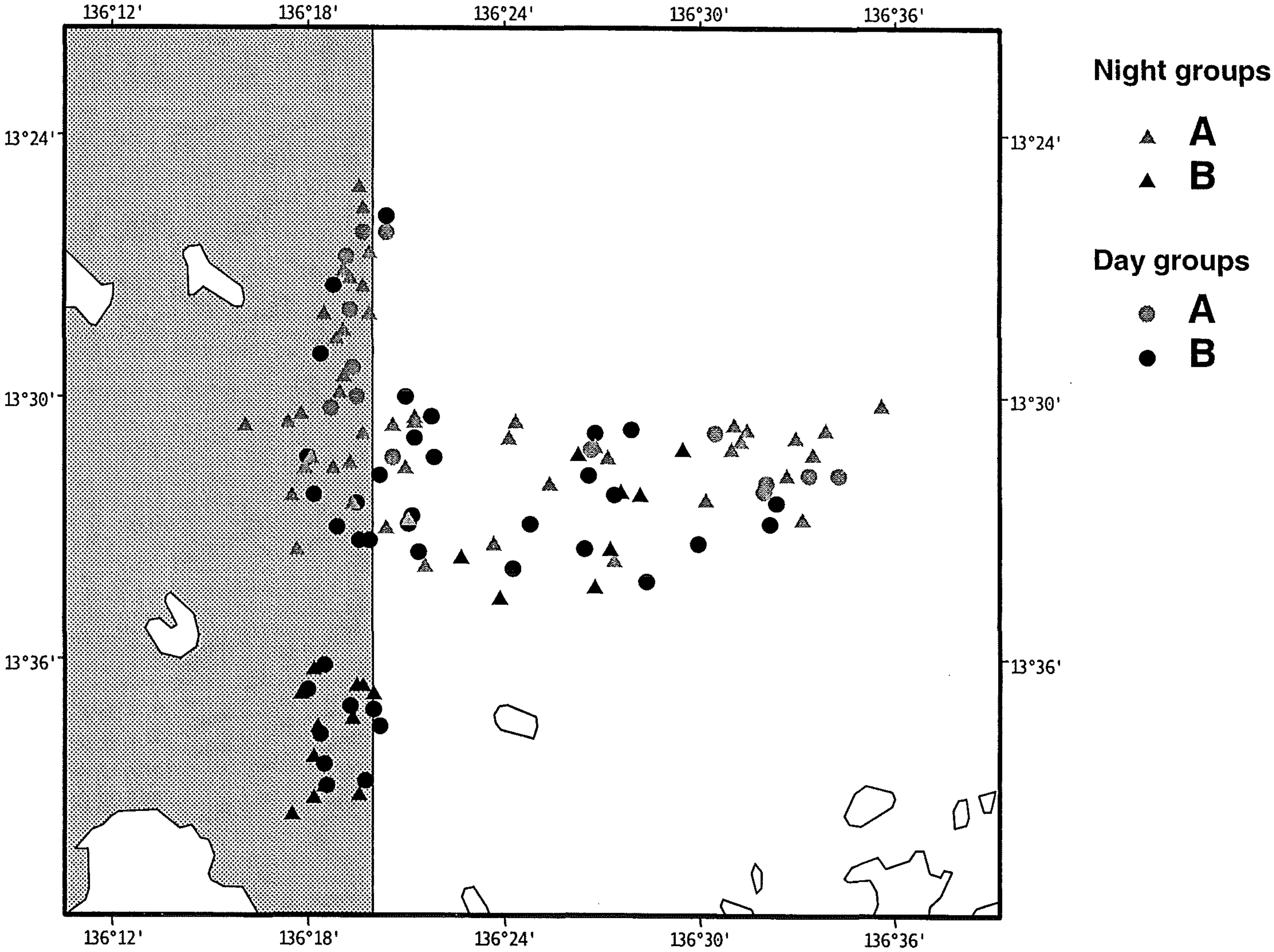


Figure 8.3.15 The location of trawls in the near and closed areas at 'North Groote', the symbols indicate which ordination group the trawls occurred in from Figures 8.3.12 and 8.3.14.

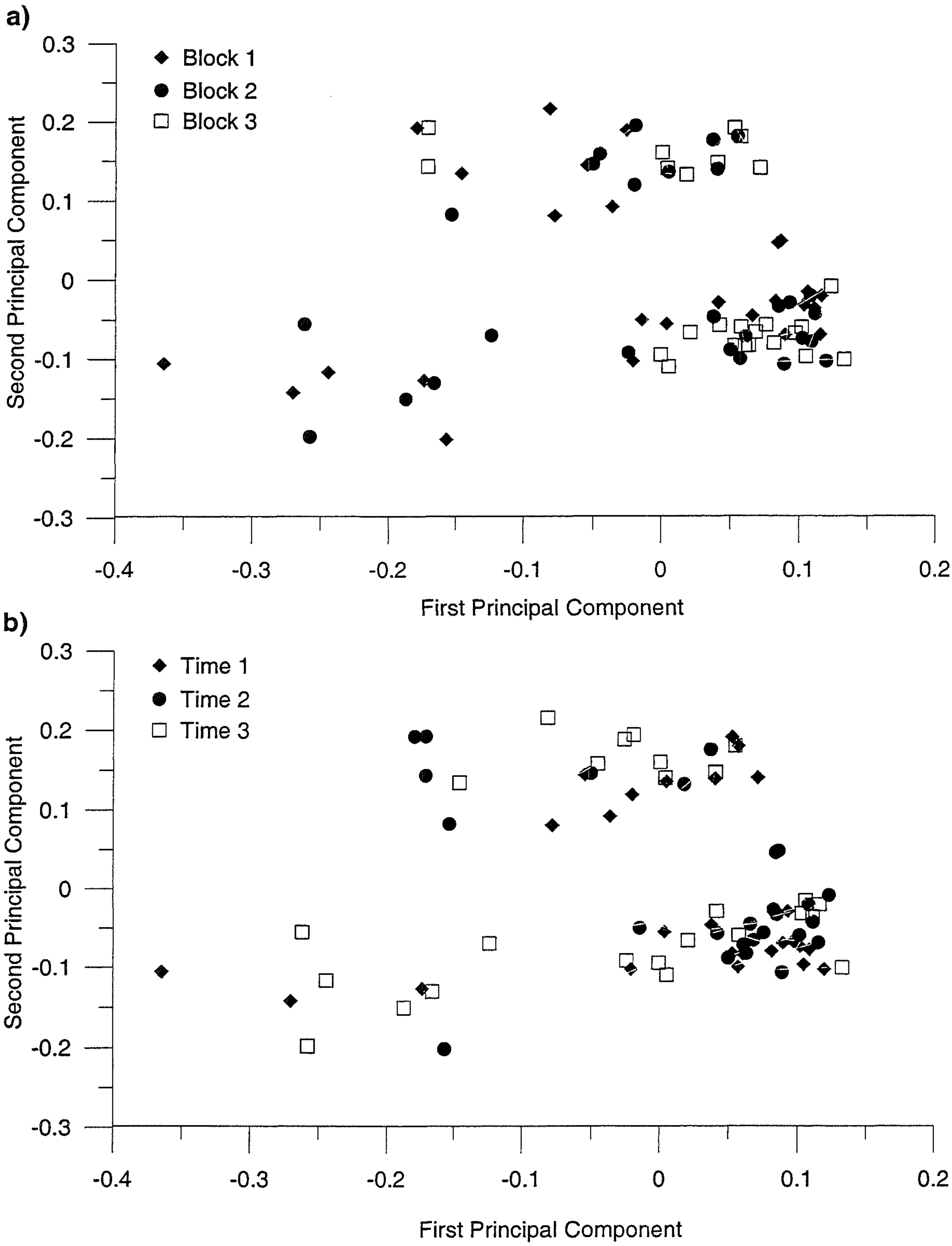


Figure 8.3.16 The ordination results for 'North Groote' 1998, during the day-time, showing (a) the blocks of sampling days and (b) the time of day.

Table 8.3.13 The species at 'South Groote' 1997, during the night, that showed significant results for the contrasts and effects from the ANCOVA, the area or block of days of highest catch rate is shown. f = far, cn = closed and near, c = closed, n = near, the numbers refer to blocks of days (Table 8.3.1).

Significant contrasts and effects	Species	Highest catch rate	Time 1	Time 2	Time 3
Far vs closed/near	*Apogon fasciatus*	cn			
	Carangoides caeruleopinnatus	f			
	Dussumieria elopsoides	cn			
	Gymnura australis	cn			
	Inegocia japonica	f			
	Nemipterus hexodon	f			
	Pomadasys maculatus	cn			
	Sardinella gibbosa	cn			
	Sillago ingenuua	f			
	Terapon theraps	cn			
	Upeneus asymmetricus	f			
	Upeneus sulphureus	cn			
(Far vs closed/near)* Time	*Fistularia petimba*		cn	f	f=cn
	Gerres filamentosus		f	cn	f
	Lagocephalus spadiceus		cn	f	f=cn
	Selar boops		f	f=cn	f=cn
	Upeneus asymmetricus		f	f	f
Closed vs near	*Dussumieria elopsoides*	n			
	Inegocia japonica	c			
	Secutor insidiator	n			
	Upeneus asymmetricus	n			
	Yongeichthys nebulosus	c			
(Closed vs near) * Time	*Chelonodon patoca*		n	n	c
	Himantura toshi		n=c	cn	n
	Nemipterus peronii		c	c	n
	Saurida micropectoralis		n	n	n
Block of days	*Pomadasys maculatus*	1			
	Saurida micropectoralis	3			
	Selaroides leptolepis	1			
	Sphyraena flavicauda	2			
	Torquigener pallimaculatus	1			

Fourteen species had a significant contrast between the closed and near area, 4 of these also showed a significant interaction with time (Table 8.3.16). There were 11 other species that did not have a significant contrast but showed a significant interaction. Of these species, 5 had higher catch rates in the near area and 5 in the closed. The 13 species with significant interactions had catch rates which were not consistently high in one area for the 3 times (Table 8.3.16).

Only one species showed a significant contrast between the blocks of days and it was highest in the first block (Table 8.3.16). The species that showed the separation between the two groups of near/closed sites in the ordination (Figure 8.3.10) are shown in Table 8.3.16. There were 35 species with higher catch rates in the Group A and 9 species higher in Group B (Table 8.3.16).

Table 8.3.14 The species at 'South Groote' 1998, during the night, that showed signficant results for the contrasts and effects from the ANCOVA the area and block of days of highest catch rate is shown. f = far, cn = closed and near, c = closed, n = near, the numbers refer to blocks of days (Table 8.3.1) A and B refer to the groups from the ordination (Figure 8.3.7.)

Significant contrasts and effects	Species	Highest catch rate	Time 1	Time 2	Time 3
Far vs closed/near	*Alectis indicus*	f			
	Callionymus goodladi	f			
	Carangoides caeruleopinnatus	f			
	Carangoides talamparoides	f			
	Carcharhinus dussumieri	cn			
	Choerodon cephalotes	cn			
	Gazza minuta	f			
	Lagocephalus spadiceus	cn			
	Leiognathus bindus	f			
	Leiognathus sp.	f			
	Nemipterus furcosus	f			
	Priacanthus tayenus	f			
	Pseudorhombus elevatus	f			
	Saurida sp. 2	f			
	Selaroides leptolepis	cn			
	Suggrundus macracanthus	f			
	Synodus sageneus	cn			
	Terapon puta	cn			
	Terapon theraps	cn			
	Tragulichthys jaculiferus	cn			
	Upeneus tragula	cn			
(Far vs closed/near) * Time	*Echeneis naucrates*		f	f	f
	Elates ransonnetii		f	cn	cn
	Apistus carinatus		cn	f	f
	Nemipterus nematopus		f	f	f
	Secutor insidiator		f	f	f
	Suggrundus macracanthus		f	f	f
	Suggrundus rodericensis		f	f=cn	f=cn
	Tetrabrachium ocellatum		f	f=cn	f=cn
Closed vs near	*Callionymus goodladi*	n			
	Carangoides hedlandensis	c			
	Carangoides malabaricus	c			
	Inegocia japonica	n			
	Leiognathus sp.	n			
	Nemipterus peronii	n			
	Pomadasys trifasciatus	c			
	Psettodes erumei	?			
	Pseudorhombus elevatus	n			
	Saurida sp. 2	n			
	Scolopsis taeniopterus	c			
	Selaroides leptolepis	n			
	Sillago ingenuua	n			
	Terapon theraps	c			
	Yongeichthys nebulosus	n			

Table 8.3.14 The species at 'South Groote' 1998, during the night, that showed signficant results for the contrasts and effects from the ANCOVA the area and block of days of highest catch rate is shown. f = far, cn = closed and near, c = closed, n = near, the numbers refer to blocks of days (Table 8.3.1) A and B refer to the groups from the ordination (Figure 8.3.7.)

		Highest catch rate		
		Time		
Significant contrasts and effects	**Species**	**1**	**2**	**3**
(Closed vs near) * Time	*Echeneis naucrates*	n	n	c
	Gymnura australis	c	c	n
	Johnius borneensis	c	n	c=n
	Paramonacanthus japonicus	c=n	c	n
	Parapercis nebulosa	c	c=n	c
	Polydactylus multiradiatus	n	c	n
	Pomadasys trifasciatus	n	c	c
	Upeneus tragula	c	c	c
Block of days	*Alepes sp.*	4		
	Apogon ellioti	4		
	Apogon fasciatus	4		
	Apogon poecilopterus	4		
	Arnoglossus waitei	3		
	Bregmacerotidae	4		
	Callionymus goodladi	4		
	Callionymus grossi	3		
	Elates ransonnetii	4		
	Engraulididae	4		
	Euristhmus nudiceps	3		
	Fistularia petimba	4		
	Apistus carinatus	4		
	Inegocia japonica	3		
	Leiognathus moretoniensis	4		
	Nemipterus peronii	3		
	Psettodes erumei	3		
	Pseudorhombus spinosus	3		
	Sardinella gibbosa	4		
	Scolopsis taeniopterus	3		
	Selaroides leptolepis	1		
	Tragulichthys jaculiferus	3		
	Yongeichthys nebulosus	3		
Ordination groups (A vs B)	*Alectis indicus*	A		
	Alepes sp.	A		
	Dasyatis leylandi	B		
	Apogon ellioti	B		
	Apogon fasciatus	B		
	Apogon poecilopterus	B		
	Arnoglossus waitei	B		
	Atule mate	A		
	Bregmacerotidae	B		
	Callionymus goodladi	B		
	Callionymus grossi	B		
	Callionymus meridionalis	B		
	Carangoides caeruleopinnatus	B		
	Carangoides talamparoides	A		
	Carcharhinus dussumieri	A		
	Centriscus scutatus	B		
	Choerodon cephalotes	A		

Table 8.3.14 The species at 'South Groote' 1998, during the night, that showed signficant results for the contrasts and effects from the ANCOVA the area and block of days of highest catch rate is shown. f = far, cn = closed and near, c = closed, n = near, the numbers refer to blocks of days (Table 8.3.1) A and B refer to the groups from the ordination (Figure 8.3.7.)

Significant contrasts and effects	Species	Highest catch rate	Time 1	2	3
Ordination groups (A vs B)	*Cymbacephalus nematophthalmus*	B			
	Cynoglossidae	B			
	Dexillus muelleri	B			
	Diagramma pictum	B			
	Echeneis naucrates	A			
	Elates ransonnetii	B			
	Engraulididae	B			
	Euristhmus nudiceps	B			
	Gazza minuta	A			
	Grammatobothus polyophthalmus	B			
	Gymnura australis	B			
	Himantura toshi	B			
	Apistus carinatus	B			
	Inegocia japonica	B			
	Johnius borneensis	B			
	Lagocephalus spadiceus	B			
	Leiognathus bindus	B			
	Leiognathus leuciscus	B			
	Leiognathus moretoniensis	B			
	Leiognathus sp.	B			
	Lutjanus lutjanus	A			
	Minous versicolor	B			
	Nemipterus furcosus	A			
	Nemipterus hexodon	B			
	Nemipterus peronii	B			
	Parapercis nebulosa	B			
	Pegasus volitans	B			
	Pentaprion longimanus	B			
	Pomadasys maculatus	B			
	Pomadasys trifasciatus	B			
	Zebrias quagga	B			
	Priacanthus tayenus	B			
	Psettodes erumei	B			
	Pseudorhombus arsius	B			
	Pseudorhombus elevatus	B			
	Pseudorhombus spinosus	B			
	Ostracion nasus	B			
	Sardinella gibbosa	B			
	Saurida micropectoralis	B			
	Saurida sp. 2	B			
	Scolopsis taeniopterus	B			
	Selaroides leptolepis	B			
	Sillago burrus	B			
	Sillago ingenuua	B			
	Sillago lutea	B			
	Suggrundus macracanthus	B			
	Synodus sageneus	B			
	Terapon puta	B			

Table 8.3.14 The species at 'South Groote' 1998, during the night, that showed signficant results for the contrasts and effects from the ANCOVA the area and block of days of highest catch rate is shown. f = far, cn = closed and near, c = closed, n = near, the numbers refer to blocks of days (Table 8.3.1) A and B refer to the groups from the ordination (Figure 8.3.7.)

		Highest catch rate			
Significant contrasts and effects	**Species**		**Time** 1	2	3
Ordination groups (A vs B)	*Terapon theraps*	B			
	Thryssa setirostris	B			
	Torquigener whitleyi	B			
	Tragulichthys jaculiferus	B			
	Upeneus asymmetricus	B			
	Upeneus sundaicus	B			
	Upeneus tragula	B			
	Yongeichthys nebulosus	B			

'North Groote' 1998 Day

There were 6 species with a significant contrast between the far area and combined closed and near areas and no significant interaction between this and time (Table 8.3.17). There were two species with the significant contrast and a significant interaction and 3 species with just the interaction significant. Of these species, 8 had higher catch rates in the far area and 5 in the combined closed and near areas. The interactions for 3 species indicated a difference in the magnitude of the difference within the contrast, but the direction was the consistent. There were 2 species where the interaction indicated that the area with the highest catch rate was not consistent among the times (Table 8.3.17). Of the species that were significant here 3 also had this contrast or interaction significant during the night.

Nine species had a significant contrast between the closed and near area, none of which showed a significant interaction with time (Table 8.3.17). There were 8 species that did not have a significant contrast, but showed a significant interaction. Of these species, 7 had higher catch rates in the near area and 2 in the closed. The 8 species with significant interactions had catch rates which were not consistently high in one area for the 3 times (Table 8.3.17). Four of these species showed the same contrast or the interaction in the night time trawls.

Two species showed a significant contrast between the blocks of days and they were highest in the second block (Table 8.3.17). The species which showed the separation between the two groups (A and B) of near and closed sites are shown in Table 8.3.18. There were 29 species with higher catch rates in the sites in group A and 4 species higher in group B (Table 8.3.17). Some of the species that had the highest catch rates in Group A during the day, also showed the highest catch rate in Group A from the night ordination. The species with the highest catch rate in Group B did not grouped similarly in the night ordination, one had the highest catch rate in Group B at night and 2 in Group A.

Table 8.3.15 The species at 'South Groote' 1998, during the day, that showed significant results for the contrasts and effects from the ANCOVAs and the area or block of days with the highest catch rate. f = far, cn = combined closed and near, c = closed, n = near, the numbers refer to blocks of days (Table 8.3.1), A and B refer to the groups from the ordination (Figure 8.3.9.)

		Highest catch rate			
			Time		
Significant contrasts and effects	**Species**		**1**	**2**	**3**
Far vs closed/near	*Callionymus grossi*	f			
	Carangoides caeruleopinnatus	f			
	Centriscus scutatus	f			
	Gazza minuta	f			
	Gerres macracanthus	f			
	Herklotsichthys koningsbergeri	cn			
	Lagocephalus lunaris	f			
	Leiognathus bindus	f			
	Leiognathus moretoniensis	cn			
	Leiognathus sp.	f			
	Nemipterus furcosus	f			
	Nemipterus hexodon	f			
	Nemipterus peronii	cn			
	Pantolabus radiatus	cn			
	Priacanthus tayenus	f			
	Secutor insidiator	f			
	Selar boops	f			
	Trachinocephalus myops	f			
	Upeneus tragula	cn			
(Far vs closed/near)*Time	*Callionymus goodladi*		f	cn=f	cn
	Carangoides chrysophrys		cn=f	f	f
	Herklotsichthys lippa		f	f	cn
	Lagocephalus lunaris		cn	f	cn=f
	Leiognathus splendens		cn	cn	cn
	Nemipterus furcosus		cn	f	f
	Pellona ditchela		f	cn	cn
	Polydactylus multiradiatus		cn	cn=f	cn
	Secutor insidiator		cn	f	cn
	Sphyraena forsteri		cn	f	f
	Sphyraena obtusata		f	cn	f
	Ulua aurochs		cn	f	f
	Upeneus tragula		cn	f	cn
Closed vs near	*Caranx kleinii*	c			
	Carangoides caeruleopinnatus	n			
	Carangoides malabaricus	c			
	Carangoides talamparoides	c			
	Megalaspis cordyla	c			
(Closed vs near)* Time	*Caranx kleinii*		c=n	c	c
	Callionymus goodladi		c=n	c	c
	Callionymus grossi		c	c=n	n
	Chirocentrus dorab		c	n	n
	Cymbacephalus nematophthalmus		c	c	n
	Leiognathus splendens		n	c	n
	Parapercis nebulosa		c	n	c
	Pomadasys trifasciatus		n	c	c
	Ostracion nasus		n	c	c
	Upeneus tragula		c	n	c

Table 8.3.15 The species at 'South Groote' 1998, during the day, that showed significant results for the contrasts and effects from the ANCOVAs and the area or block of days with the highest catch rate. f = far, cn = combined closed and near, c = closed, n = near, the numbers refer to blocks of days (Table 8.3.1), A and B refer to the groups from the ordination (Figure 8.3.9.)

		Highest catch rate				
Significant contrasts and effects	**Species**			**Time**		
				1	**2**	**3**
Block of days	*Apogon fasciatus*		3			
	Carangoides humerosus		2			
	Elates ransonnetii		3			
	Gerres macrosoma		3			
	Gymnura australis		2			
	Himantura toshi		2			
	Inegocia japonica		2			
	Johnius borneensis		2			
	Leiognathus leuciscus		2			
	Leiognathus moretoniensis		2			
	Nemipterus hexodon		3			
	Nemipterus peronii		2			
	Psettodes erumei		2			
	Saurida micropectoralis		3			
	Saurida sp. 2		3			
	Scolopsis taeniopterus		2			
	Upeneus sundaicus		3			
	Upeneus tragula		2			
	Zabidius novaemaculatus		3			
Ordination groups (A vs B)	*Apogon fasciatus*	B				
	Callionymus grossi	B				
	Carangoides caeruleopinnatus	B				
	Carangoides humerosus	B				
	Carcharhinus dussumieri	B				
	Centriscus scutatus	B				
	Elates ransonnetii	B				
	Gazza minuta	B				
	Gerres macracanthus	B				
	Herklotsichthys koningsbergeri	B				
	Himantura toshi	B				
	Inegocia japonica	B				
	Lagocephalus lunaris	B				
	Leiognathus bindus	B				
	Leiognathus leuciscus	B				
	Leiognathus moretoniensis	B				
	Leiognathus sp.	B				
	Nemipterus furcosus	B				
	Nemipterus hexodon	B				
	Nemipterus peronii	B				
	Pantolabus radiatus	A				
	Parastromateus niger	A				
	Priacanthus tayenus	B				
	Psettodes erumei	B				
	Pseudorhombus spinosus	B				
	Sardinella gibbosa	B				
	Saurida micropectoralis	B				
	Saurida sp. 2	B				

Table 8.3.15 The species at 'South Groote' 1998, during the day, that showed significant results for the contrasts and effects from the ANCOVAs and the area or block of days with the highest catch rate. f = far, cn = combined closed and near, c = closed, n = near, the numbers refer to blocks of days (Table 8.3.1), A and B refer to the groups from the ordination (Figure 8.3.9.)

		Highest catch rate			
Significant contrasts and			**Time**		
effects	**Species**		**1**	**2**	**3**
Ordination groups (A vs B)	*Scolopsis taeniopterus*	B			
	Secutor insidiator	B			
	Selar boops	A			
	Selaroides leptolepis	B			
	Sillago burrus	B			
	Sillago ingenuua	B			
	Synodus sageneus	B			
	Terapon jarbua	B			
	Torquigener tuberculiferus	B			
	Torquigener whitleyi	B			
	Trachinocephalus myops	B			
	Trixiphichthys weberi	B			
	Upeneus asymmetricus	B			
	Upeneus sundaicus	B			
	Upeneus tragula	B			

Summary of the univariate analyses.

The proportion of species for which the covariates, depth, effort and percent mud, were significant varied among the regions and times (Table 8.3.18). In 'South Groote' 1997 day, 'South Groote' 1998 day and night depth was significant for the highest proportion of species, more than 30% (Table 8.3.18). In 'South Groote' 1997 night and 'North Groote' 1998 day and night the percentage of mud was significant for over 30% of the species (Table 8.3.18).

In both regions and in both years a higher percentage of species showed significant contrasts between the areas (far versus combined closed and near areas and closed versus near) at night than during the day (Table 8.3.19). 'South Groote' 1998 at night had the highest proportion of species with differences among the regions (Table 8.3.19). In 1998, the proportion of species with a significant difference in the contrast between far and combined closed and near varied from 16-24% (Table 8.3.19). In 'South Groote' this proportion was similar day and night, while in 'North Groote' it was higher during the day (Table 8.3.19). In 1997 'South Groote' no species showed significant differences during the day (Table 8.3.19).

The contrast between the closed and near areas had a lower percentage of species (1-16%) with a significant difference than the previous contrast (Table 8.3.19). The effect of the block of days/nights sampled was clearly seen in 'South Groote' in 1998 where about 20% of the species showed an effect (Table 8.3.19). The catch rate of many of these species showed a significant decrease in the sample days/nights around the full moon.

Table 8.3.16 The species at 'North Groote' 1998, during the night, that showed significant results for the contrasts and effects from the ANCOVA. The area or block of days with the highest catch rate is shown. f = far, cn = closed and near, c = closed, n = near, the numbers refer to blocks of days (Table 8.3.1.), A and B refer to the groups from the ordination (Figure 8.3.12.).

Significant contrasts and effects	Species	Highest catch rate	Time 1	Time 2	Time 3
Far vs closed/near	*Anodontostoma chacunda*	cn			
	Caranx bucculentus	cn			
	Gerres macrosoma	cn			
	Grammatobothus polyophthalmus	f			
	Leiognathus decorus	cn			
	Leiognathus splendens	cn			
	Paramonacanthus filicauda	f			
	Pentaprion longimanus	f			
	Pomadasys trifasciatus	cn			
	Sirembo imberbis	cn			
	Terapon theraps	cn			
	Thryssa setirostris	cn			
	Trixiphichthys weberi	cn			
	Upeneus sulphureus	f			
	Upeneus sundaicus	cn			
(Far vs closed/near)* Time	*Carangoides talamparoides*		cn	f	f
	Leiognathus splendens		cn	cn	cn
	Nemipterus peronii		cn	cn	cn
	Pomadasys maculatus		cn	cn	cn
	Rhizoprionodon acutus		cn=f	cn	cn
	Tetrabrachium ocellatum		f	f	f
Closed vs near	*Carangoides hedlandensis*	c			
	Centriscus scutatus	n			
	Gerres macracanthus	n			
	Lagocephalus sceleratus	c			
	Lagocephalus spadiceus	c			
	Leiognathus moretoniensis	n			
	Leiognathus splendens	n			
	Nemipterus peronii	n			
	Pelates quadrilineatus	n			
	Pentaprion longimanus	c			
	Pomadasys kaakan	c			
	Terapon theraps	n			
	Torquigener whitleyi	c			
	Upeneus sundaicus	n			
(Closed vs near)* Time	*Callionymus grossi*		n	c	c
	Gazza minuta				
	Gerres macrosoma		n	c	n
	Lagocephalus spadiceus		c	c	n
	Leiognathus decorus		c	c	n
	Leiognathus splendens		c	n	n
	Pelates quadrilineatus		n	n	n
	Pomadasys trifasciatus		c	c	n
	Pseudorhombus arsius		c	c	c
	Rhizoprionodon acutus		c=n	n	c
	Scolopsis taeniopterus		c	n	c=n
(Closed vs near)* Time	*Leiognathus ruconius*		c	n	n
	Selaroides leptolepis		n	n	c

Table 8.3.16 The species at 'North Groote' 1998, during the night, that showed significant results for the contrasts and effects from the ANCOVA. The area or block of days with the highest catch rate is shown. f = far, cn = closed and near, c = closed, n = near, the numbers refer to blocks of days (Table 8.3.1.), A and B refer to the groups from the ordination (Figure 8.3.12.).

Significant contrasts and effects	Species	Highest catch rate			
			Time		
			1	2	3
Block of days	*Sardinella gibbosa*	1			
Ordination groups (A vs B)	*Alepes sp.*	B			
	Atule mate	B			
	Carangoides hedlandensis	B			
	Gnathanodon speciosus	B			
	Lagocephalus sceleratus	B			
	Leiognathus leuciscus	B			
	Scomberomorus queenslandicus	B			
	Selaroides leptolepis	B			
	Ulua aurochs	B			
	Anodontostoma chacunda	A			
	Apogon ellioti	A			
	Apogon fasciatus	A			
	Apogon poecilopterus	A			
	Bregmacerotidae	A			
	Carangoides humerosus	A			
	Caranx bucculentus	A			
	Centriscus scutatus	A			
	Elates ransonnetii	A			
	Engraulididae	A			
	Gerres macracanthus	A			
	Gerres macrosoma	A			
	Apistus carinatus	A			
	Leiognathus decorus	A			
	Leiognathus splendens	A			
	Nemipterus hexodon	A			
	Nemipterus peronii	A			
	Pelates quadrilineatus	A			
	Polydactylus multiradiatus	A			
	Pomadasys maculatus	A			
	Pomadasys trifasciatus	A			
	Priacanthus tayenus	A			
	Sardinella gibbosa	A			
	Saurida micropectoralis	A			
	Saurida sp. 2	A			
	Scolopsis taeniopterus	A			
	Secutor insidiator	A			
	Sirembo imberbis	A			
	Terapon puta	A			
	Terapon theraps	A			
	Thryssa setirostris	A			
	Trixiphichthys weberi	A			
	Upeneus sulphureus	A			
	Upeneus sundaicus	A			

Table 8.3.17 The species at 'North Groote' 1998, during the day, that showed significant results for the contrasts and effects from the ANCOVAs, the area or block of days of highest catch rate is shown. f = far, cn = closed and near, c = closed, n = near, the numbers refer to blocks of days (Table 8.3.1.), A and B refer to the groups from the ordination (Figure 8.3.14.).

		Highest catch rate			
Significant contrasts and			**Time**		
effects	**Species**		**1**	**2**	**3**
Far vs closed/near	*Carangoides caeruleopinnatus*	f			
	Carangoides talamparoides	f			
	Caranx bucculentus	cn			
	Carcharhinus dussumieri	cn			
	Herklotsichthys lippa	f			
	Selar boops	f			
	Upeneus sulphureus	f			
	Upeneus sundaicus	cn			
Far vs closed/near	*Caranx kleinii*		cn	f	f
	Carangoides malabaricus		f	f	f
	Carangoides talamparoides		f	f	f
	Caranx bucculentus		cn	f	cn
	Saurida sp. 2		f	f	f
Closed vs near	*Apogon poecilopterus*	c			
	Gerres macracanthus	n			
	Gnathanodon speciosus	n			
	Leiognathus leuciscus	n			
	Nemipterus hexodon	n			
	Pelates quadrilineatus	n			
	Psenopsis humerosa	n			
	Sillago burrus	c			
	Upeneus sundaicus	n			
Closed vs near	*Apogon ellioti*		c	c	n
	Caranx bucculentus		c	c=n	n
	Carcharhinus dussumieri		c	n	c
	Elates ransonnetii		n	c	c=n
	Pegasus volitans		c	c	c=n
	Pomadasys maculatus		c=n	c	n
	Scolopsis taeniopterus		n	n	c
	Sillago burrus		c	c	c=n
Block of days	*Carangoides talamparoides*	2			
	Caranx bucculentus	2			
Ordination groups (A vs B)	*Anodontostoma chacunda*	A			
	Carangoides caeruleopinnatus	A			
	Carangoides humerosus	A			
	Caranx bucculentus	A			
	Carcharhinus dussumieri	A			
	Chirocentrus dorab	A			
	Engraulididae	A			
	Gazza minuta	A			
	Gerres macracanthus	A			
	Herklotsichthys koningsbergeri	A			
	Herklotsichthys lippa	A			
	Leiognathus decorus	A			
	Leiognathus equulus	A			

Table 8.3.17 The species at 'North Groote' 1998, during the day, that showed significant results for the contrasts and effects from the ANCOVAs, the area or block of days of highest catch rate is shown. f = far, cn = closed and near, c = closed, n = near, the numbers refer to blocks of days (Table 8.3.1.), A and B refer to the groups from the ordination (Figure 8.3.14.).

Significant contrasts and effects	Species	Highest catch rate	Time 1	2	3
	Leiognathus splendens	A			
	Parastromateus niger	A			
	Pelates quadrilineatus	A			
Ordination groups (A vs B)	*Pellona ditchela*	A			
	Pomadasys maculatus	A			
	Pomadasys trifasciatus	A			
	Psenopsis humerosa	A			
	Rhizoprionodon acutus	A			
	Sardinella gibbosa	A			
	Scomberoides tol	A			
	Secutor insidiator	A			
	Leiognathus ruconius	A			
	Selar boops	B			
	Terapon theraps	A			
	Thryssa setirostris	A			
	Trichiurus lepturus	A			
	Ulua aurochs	B			
	Upeneus sundaicus	B			

Table 8.3.18 The number and percent of species which had a significant coefficient for the covariates from the ANCOVAs, in each region and time.

Region	Time	Direction	Depth species (n)	%	Effort species (n)	%	% Mud species (n)	%
'South Groote' 1998	**Day**	+	25	*21*	4	*3*	10	*9*
		-	15	*13*	4	*3*	16	*14*
	Night	+	32	*26*	9	*7*	17	*14*
		-	23	*19*	22	*18*	20	*16*
'South Groote' 1997	**Day**	+	12	*24*	8	*16*	5	*10*
		-	12	*24*	5	*10*	3	*6*
	Night	+	18	*23*	9	*11*	17	*22*
		-	6	*8*	2	*3*	18	*23*
'North Groote' 1998	**Day**	+	4	*6*	2	*3*	19	*26*
		-	4	*6*	8	*11*	3	*4*
	Night	+	3	*3*	7	*8*	25	*28*
		-	16	*18*	18	*20*	11	*12*

When the mean size of a species could be compared among all three areas in a region, in 'South Groote' 1997 day and night, 'South Groote' 1998 night and 'North Groote' 1998 day most species had their longest size in the far area (Table 8.3.21). In 'South Groote' 1998 day most species were longest in the near and in 'North Groote' night most species showed no significant difference (Table 8.3.21). In the latter, of the species that showed a significant difference they were longest in far.

Table 8.3.19 The number and percentage of species that showed significant contrasts for the ANCOVAs in each region and time. f vs cn = contrast beteween far and combined closed and near areas, c vs n = contrast between closed and near areas, (f vs cn)*time = the interaction between time and the first contrast, (c vs n)* time = the interaction between time and the second contrast, PC1 groups = the contrast between the groups of near and closed sites on the first principal component, (PC1)*cn = the interaction between time and the contrast between the groups on the first principal component.

'South Groote' 1997 Night

	f vs cn		c vs n		block of days		time		(f vs cn)*time		(c vs n)*time	
	species (n)	%	species (n)	%	species (n)	%	species (n)	%	species (n)	%	Species (n)	%
ANCOVA	14	*13*	5	*5*	5	*5*	8	*7*	5	*5*	6	*5*
Total species	111											

'South Groote' 1997 Day

	f vs cn		c vs n		block of days		time		(f vs cn)*time		(c vs n)*time	
	species (n)	%	species (n)	%	species (n)	%	species (n)	%	species (n)	%	Species (n)	%
ANCOVA	0	*0*	1	*1*	0	*0*	0	*0*	1	*1*	1	*1*
Total species	75											

South Groote' 1998 Night

	f vs cn		c vs n		block of days		time		(f vs cn)*time		(c vs n)*time		grid		PC1 groups		(PC1)*cn	
	species (n)	%	species (n)	%	species (n)	%	species (n)	%	species (n)	%	Species (n)	%	species (n)	%	species (n)	%	species (n)	%
ANCOVA	21	*17*	15	*12*	23	*19*	13	*11*	8	*7*	8	*7*	20	*16*	76	*62*	31	*25*
Total species	123																	

'South Groote' 1998 Day

	f vs cn		c vs n		block of days		time		(f vs cn)*time		(c vs n)*time		grid		PC1 groups		(PC1)*cn	
	species (n)	%	species (n)	%	species (n)	%	species (n)	%	species (n)	%	Species (n)	%	species (n)	%	species (n)	%	species (n)	%
ANCOVA	19	*16*	5	*4*	19	*16*	15	*13*	13	*11*	10	*9*	28	*24*	45	*38*	24	*21*
Total species	117																	

Table 8.3.19 The number and percentage of species that showed significant contrasts for the ANCOVAs in each region and time. f vs cn = contrast beteween far and combined closed and near areas, c vs n = contrast between closed and near areas, (f vs cn)*time = the interaction between time and the first contrast, (c vs n)* time = the interaction between time and the second contrast, PC1 groups = the contrast between the groups of near and closed sites on the first principal component, (PC1)*cn = the interaction between time and the contrast between the groups on the first principal component.

'North Groote' 1998 Night

	f vs cn		c vs n		block of days		time		(f vs cn)*time		(c vs n)*time		grid		PC1 groups		(PC1)*cn	
	species (n)	%	species (n)	%	species (n)	%	species (n)	%	species (n)	%	species (n)	%	species (n)	%	species (n)	%	species (n)	%
ANCOVA	15	*17*	14	*16*	1	*1*	12	*13*	6	*7*	13	*15*	32	*36*	51	*57*	23	*26*
Total species	89																	

'North Groote' 1998 Day

	f vs cn		c vs n		block of days		time		(f vs cn)*time		(c vs n)*time		grid		PC1 groups		(PC1)*cn	
	species (n)	%	species (n)	%	species (n)	%	species (n)	%	species (n)	%	species (n)	%	species (n)	%	species (n)	%	species (n)	%
ANCOVA	17	*24*	4	*6*	1	*1*	1	*1*	1	*1*	5	*7*	8	*11*	5	*7*	8	*11*
Total species	72																	

For the species where only two areas could be compared, in the comparisons involving the far area, most species were longest in far (Table 8.3.21). In the comparisons between near and closed, most species were longest in near (Table 8.3.21).

Some species appear to show some consistency in the differences among areas, between day and night comparisons and between regions. *Apogon fasciatus, A. poecilopterus, Pentaprion longimanus* and most leiognathid species were larger in the far area and this was consistent between night and day and among regions (Table 8.3.22).

Table 8.3.20. The number of species for which comparisons of their mean size were made among areas.

	Species (n)					
	'South Groote' 1997		'South Groote' 1998		'North Groote' 1998	
Comparison	**Day**	**Night**	**Day**	**Night**	**Day**	**Night**
Among all 3 areas in a region	14	24	36	41	18	28
Between 2 areas in a region	13	15	6	17	15	22
Total for a region	27	39	40	58	33	50

Table 8.3.21 The summarised results for the comparison of the size of species among the areas in the regions, during day and night. The table shows the percentage of species with significant results.

		Species (%)					
		'South Groote' 1997		'South Groote' 1998		'North Groote' 1998	
	Area of maximum size	**Day**	**Night**	**Day**	**Night**	**Day**	**Night**
Closed vs Near vs Far		(14)	(24)	(34)	(41)	(18)	(28)
	C>N, F=C, F=N	0	8	0	0	0	0
	C=N>F	0	0	0	2	0	0
	C>N>F or C>F>N	0	0	3	0	6	4
	F=C>N	14	4	3	2	0	0
	F=N>C	21	4	18	10	0	11
	F>C, N=F, N=C	0	4	12	2	6	0
	F>C>N or F>N>C	50	46	18	39	44	29
	F>N=C	0	8	0	2	0	4
	N>F=C	7	4	3	2	6	7
	N>F>C OR N>C>F	0	0	44	0	6	11
	No significant difference	7	21	0	39	33	36
Far vs Near		(5)	(0)	(0)	(3)	(0)	(2)
	F>N	40	-	-	67	-	0
	N>F	0	-	-	33	-	50
	No significant difference	60	-	-	0	-	50
Far vs Closed		(1)	(5)	(2)	(4)	(1)	(5)
	F>C	0	60	100	50	0	0
	C>F	0	0	0	0	0	20
	No significant difference	100	40	0	50	100	80
Closed vs Near		(7)	(10)	(4)	(10)	(14)	(15)
	C>N	0	20	0	0	7	0
	N>C	43	20	75	10	29	20
	No significant difference	57	60	25	90	64	80

Table 8.3.22 The results from the comparison of mean size of species among the areas (closed = C, near = N and far = F) in each region and at the two times. The areas in the analysis are listed in the results or where the result was not significant they are in brackets, i.e. (3) means all 3 areas (closed, near and far) were in the analysis, — represents where replicates were not sufficient for an analysis. The levels of significance are * = 0.01 < P < 0.05; ** = 0.001 < P < 0.01, *** = P<0.001.

	South Groote 1997		South Groote 1998		North Groote 1998	
Species	**Day**	**Night**	**Day**	**Night**	**Day**	**Night**
Apogonidae						
Apogon ellioti	—	F>N C=F C=N*	—	F=N>C**	—	F>N>C***
Apogon fasciatus	—	F>N=C***	F>N=C***	F>N>C***	—	C>F=N***
Apogon poecilopterus	F>N**	F>N=C***	F>N=C***	F>N>C***	F>C N=F N=C***	F=N>C***
Ariidae						
Netuma thalassinus	—	—	—	F>C*	—	—
Bathysauridae						
Saurida micropectoralis	—	F>N=C***	F>C N=F N=C***	F>N=C***	—	ns (3)
Saurida sp. 2	—	ns (3)	N>F C=N C=F***	N>F C=N C=F***	—	F>N C=F C=N**
Bothidae						
Pseudorhombus elevatus	—	—	—	N>F*	—	—
Pseudorhombus spinosus	—	—	—	ns (3)	—	—
Callionymidae						
Callionymus goodladi	—	—	—	ns (3)	—	ns (C F)
Callionymus grossi	—	—	—	ns (C N)	—	—
Carangidae						
Alepes sp.	F=C>N***	ns (C N)	ns (3)	—	—	ns (C N)
Atule mate	—	—	—	—	ns (3)	ns (C N)
Carangoides caeruleopinnatus	ns (C F)	ns (C F)	ns (3)	ns (3)	ns (3)	ns (3)
Carangoides hedlandensis	ns (3)	ns (C N)	ns (3)	ns (C N)	ns (C N)	ns (C N)
Carangoides humerosus	ns (N F)	F>N C=F C=N*	ns (3)	ns (3)	ns (3)	N>F C=N C=F*
Carangoides malabaricus	—	—	—	—	—	ns (C F)
Carangoides talamparoides	ns (N F)	F>C*	—	ns (3)	ns (3)	F>N=C***
Caranx bucculentus	F=C>N***	C>N F=C F=N*	F=N>C***	ns (3)	N>C=F***	N>F C=N C=F*
Caranx kleinii	—	—	—	—	ns (C F)	—
Parastromateus niger	—	—	—	—	C>N>F***	—
Selar boops	N>F*	—	—	—	—	—
Selaroides leptolepis	F>N>C***	F=N>C***	F>N>C***	F>N>C***	F>C>N***	ns (3)
Ulua aurochs	—	—	ns (3)	—	ns (3)	ns (C N)
Carcharhinidae						
Carcharhinus dussumieri	N>C*	—	ns (3)	ns (C N)	ns(C N)	ns (C N)
Rhizoprionodon acutus	—	—	ns (C N)	—	—	—
Centriscidae						
Centriscus scutatus	—	—	—	—	—	ns (C N)
Clupeidae						
Anodontostoma chacunda	—	—	—	—	ns (C N)	ns (3)
Dussumieria elopsoides	ns (C N)	—	C>F=N*	ns (3)	F>N>C***	N>F*
Herklotsichthys koningsbergeri	—	—	—	ns (C N)	—	—
Herklotsichthys lippa	N>C**	ns (C N)	F=N>C***	ns (C N)	ns (3)	ns (C F)
Pellona ditchela	ns (C N)	C>N F=C F=N***	ns (3)	ns (3)	F>N>C***	F>N>C***
Cynoglossidae						
Cynoglossus maculipinnis	—	—	—	F>N***	—	—
Engraulididae						
Thryssa setirostris	—	ns (C N)	F>C**	ns (3)	ns (C N)	ns (3)
Gerreidae						
Pentaprion longimanus	ns (N F)	F>N>C***	F=N>C***	F>N=C***	—	F>N=C***
Gobiidae						
Yongeichthys nebulosus	—	F>C***	—	F>N>C***	—	—
Haemulidae						
Diagramma pictum	—	—	—	ns (C F)	—	—
Pomadasys maculatus	—	ns (C N)	N>C**	ns (C N)	—	ns (C N)
Pomadasys trifasciatus	—	—	—	—	N>C**	N>C***
Labridae						
Choerodon cephalotes	—	—	—	ns (C N)	—	—
Leiognathidae						
Gazza minuta	F>N>C***	ns (3)	F>N=C***	F>N=C***	F>N=C***	F>N=C***

Table 8.3.22 The results from the comparison of mean size of species among the areas (closed = C, near = N and far = F) in each region and at the two times. The areas in the analysis are listed in the results or where the result was not significant they are in brackets, i.e. (3) means all 3 areas (closed, near and far) were in the analysis, — represents where replicates were not sufficient for an analysis. The levels of significance are * = 0.01 < P < 0.05; ** = 0.001 < P < 0.01, *** = P<0.001.

	South Groote 1997		**South Groote 1998**		**North Groote 1998**	
Species	**Day**	**Night**	**Day**	**Night**	**Day**	**Night**
Leiognathus bindus	F>N>C***	F>C>N***	F=N>C***	F=N>C***	F>N>C***	N>F>C***
Leiognathus decorus	—	—	—	ns (C N)	N>C*	N>C***
Leiognathus leuciscus	F>N=C***	F>N=C*	F=N>C***	F>N>C***	ns (C N)	F=N>C**
Leiognathus moretoniensis	F>N>C***	F>C>N***	F>C N=F N=C**	F>N>C***	N>C***	N>F>C***
Leiognathus ruconius	—	—	—	—	N>C*	ns (C N)
Leiognathus sp.	F=N>C***	F>N=C***	ns (3)	ns (3)	—	—
Leiognathus splendens	N>C***	N>C*	N>C***	ns (C N)	F>N=C***	F>N>C*
Secutor insidiator	F=N>C**	ns (C N)	F>C N=F N=C*	F>N C=F C=N*	F>N=C***	F>N=C***
Lethrinidae						
Lethrinus laticaudis	—	—	F>C***	F>C*	—	—
Mullidae						
Upeneus asymmetricus	—	—	F>C N=F N=C***	F=N>C**	—	—
Upeneus sulphureus	—	—	—	—	—	ns (N F)
Upeneus sundaicus	F=N>C***	F>N>C***	ns (3)	F>N=C***	N>F C=F C=N*	ns (3)
Nemipteridae						
Nemipterus furcosus	—	—	ns (3)	ns (3)	—	—
Nemipterus hexodon	—	F>N>C***	ns (3)	ns (3)	ns (C N)	N>C=F***
Nemipterus peronii	—	F>N=C***	F=C>N***	F=N>C**	—	—
Scolopsis taeniopterus	—	F>C N=F N=C*	F>N=C*	F>C>N***	—	ns (C N)
Pegasidae						
Pegasus volitans	—	—	—	N>C*	—	—
Platycephalidae						
Elates ransonnetii	—	ns (3)	ns (3)	ns (3)	ns (C N)	F=N>C**
Inegocia japonica	—	ns (3)	—	C=N>F***	—	ns (3)
Polynemidae						
Polydactylus multiradiatus	—	—	—	—	—	ns (C N)
Priacanthidae						
Priacanthus tayenus	—	—	—	—	—	ns (3)
Psettodidae						
Psettodes erumei	—	—	ns (3)	ns (3)	—	—
Sciaenidae						
Johnius borneensis	—	C>N**	—	F>C N=F N=C*	—	—
Scombridae						
Scomberomorus queenslandicus	ns (C N)	—	ns (3)	—	ns (C N)	N>C***
Scorpaenidae						
Apistus carinatus	—	N>F C=N C=F***	—	ns (3)	—	ns (3)
Serranidae						
Epinephelus sexfasciatus	—	—	—	F>N**	—	—
Sillaginidae						
Sillago burrus	F>N***	ns (C F)	N>C***	F>N=C***	—	—
Sillago ingenuua	—	F>C**	F>N>C***	F>N>C***	—	—
Terapontidae						
Pelates quadrilineatus	—	C>N*	—	ns (C F)	—	—
Terapon puta	—	—	—	—	—	ns (C N)
Terapon theraps	F>N=C***	F=C>N***	ns (3)	F=C>N***	C>N**	ns (3)
Tetraodontidae						
Lagocephalus sceleratus	—	—	—	F>N=C**	—	F>C>N***
Lagocephalus spadiceus	—	—	—	—	—	C>F*
Torquigener tuberculiferus	—	—	—	ns (3)	—	—
Torquigener whitleyi	—	N>C***	—	F>N>C**	—	—
Triacanthidae						
Trixiphichthys weberi	F>N=C**	ns (3)	F=N>C***	F>N>C***	ns (C N)	ns (C N)
Trichiuridae						
Trichiurus lepturus	ns (C N)	—	—	—	F>N=C*	ns (C F)

Table 8.3.23 The mean length and standard error (se) for species in each area in each region for the 2 times (day and night). n = sample size

	South Groote 1997												South Groote 1998												North Groote 1998											
	Day						Night						Day						Night						Day						Night					
	Closed		Near		Far		Closed		Near		Far		Closed		Near		Far		Closed		Near		Far		Closed		Near		Far		Closed		Near		Far	
Species	Length (mm)		Length (mm)		Length (mm)		Length (mm)		Length (mm)		Length (mm)		Length (mm)		Length (mm)		Length (mm)		Length (mm)		Length (mm)		Length (mm)		Length (mm)		Length (mm)		Length (mm)		Length (mm)		Length (mm)		Length (mm)	
	mean	se	mean	se	mean	se	mean	se	mean	se	mean	se	mean	se	mean	se	mean	se	mean	se	mean	se	mean	se	mean	se	mean	se	mean	se	mean	se	mean	se	mean	se
Apogonidae																																				
Apogon ellioti	—		—		—		66	2.0	57	2.3	69	2.0	—		—		—		47	1.5	54	1.3	57	1.3	—		—		—		54	0.6	57	0.6	68	1.3
Apogon fasciatus	—		—		—		59	1.8	57	1.0	69	1.6	51	1.2	49	1.8	63	2.0	48	1.4	55	0.9	60	0.8	—		—		—		58	0.9	52	1.0	49	0.7
Apogon poecilopterus	—		56	3.8	75	3.4	54	1.3	50	0.7	69	1.4	53	3.1	55	3.2	78	3.4	48	1.1	54	0.9	64	1.2	52	0.9	59	2.1	64	2.2	53	0.5	57	0.5	56	0.5
Ariidae																																				
Netuma thalassinus	—		—		—		—		—		—		—		—		—		164	9.7	—		224	28.2	—		—		—		—		—		—	
Bathysauridae																																				
Saurida micropectoralis	—		—		—		173	5.9	174	2.9	235	5.8	176	4.1	192	5.6	217	9.4	187	4.0	188	3.2	213	4.0	—		—		—		195	6.0	180	3.2	193	3.0
Saurida sp. 2	—		—		—		152	5.0	145	2.6	149	2.0	158	5.5	163	3.1	141	2.9	151	4.5	165	1.6	145	1.5	—		—		—		142	2.1	154	2.7	135	1.3
Bothidae																																				
Pseudorhombus elevatus	—		—		—		—		—		—		—		—		—		—		105	4.8	91	2.1	—		—		—		—		—		—	
Pseudorhombus spinosus	—		—		—		—		—		—		—		—		—		133	4.0	125	5.4	141	4.5	—		—		—		—		—		—	
Callionymidae																																				
Callionymus goodladi	—		—		—		—		—		—		—		—		—		91	4.8	97	1.1	98	1.3	—		—		—		95	6.0	—		89	4.4
Callionymus grossi	—		—		—		—		—		—		—		—		—		138	1.2	135	2.7	—		—		—		—		—		—		—	
Carangidae																																				
Alepes sp.	180	3.0	162	2.8	176	4.3	152	4.1	153	6.7	—		178	2.0	172	2.5	181	2.5	—		—		—		—		—		—		176	4.3	164	7.8	—	
Atule mate	—		—		—		—		—		—		—		—		—		—		—		—		105	7.0	127	4.7	122	6.5	136	13.1	133	6.4	—	
Carangoides aeruleopinnatus	129	10.6	—		154	5.6	109	15.2	—		136	4.5	144	11.6	159	8.9	136	5.9	152	15.6	92	14.7	88	4.5	107	13.3	125	7.9	131	2.2	61	7.5	74	7.3	87	12.4
Carangoides hedlandensis	124	2.8	128	2.8	130	4.8	131	4.6	109	9.7	—		142	3.9	144	2.8	139	3.4	122	6.4	124	10.8	—		134	1.6	139	2.3	—		133	2.0	134	3.8	—	
Carangoides humerosus	—		145	10.2	154	2.2	143	5.8	133	4.7	148	2.3	150	4.7	161	4.4	151	2.3	134	5.2	141	2.8	140	2.4	117	8.8	134	7.0	127	7.0	119	2.3	125	3.0	109	4.6
Carangoides malabaricus	—		—		—		—		—		—		—		—		—		—		—		—		—		—		—		58	2.4	—		83	3.0
Carangoides talamparoides	—		119	6.8	133	1.6	94	6.2	—		125	2.7	—		—		—		99	8.3	99	11.1	103	3.7	108	7.4	108	7.8	117	1.6	58	2.1	65	3.9	85	2.3
Caranx bucculentus	146	3.1	127	2.3	149	4.3	135	1.8	127	2.3	144	3.8	139	2.8	159	4.5	152	3.4	134	2.6	131	2.3	136	2.0	134	5.6	161	5.5	112	3.1	144	1.9	149	2.2	115	3.3
Caranx kleinii	—		—		—		—		—		—		—		—		—		—		—		—		120	5.8	—		127	5.4	—		—		—	
Parastromateus niger	—		—		—		—		—		—		—		—		—		—		—		—		186	5.2	166	5.1	133	1.9	—		—		—	
Selar boops	—		188	4.6	173	2.8	—		—		—		—		—		—		—		—		—		—		—		—		—		—		—	
Selaroides leptolepis	120	1.4	129	1.0	136	1.1	122	0.8	125	1.1	129	1.1	125	1.0	128	0.7	132	0.7	117	1.9	127	1.1	132	1.1	109	0.9	114	0.9	125	0.8	113	1.1	112	1.0	116	1.5
Ulua aurochs	—		—		—		—		—		—		140	3.3	135	2.6	129	1.7	—		—		—		134	2.4	136	2.6	125	4.6	132	3.0	132	2.1	—	
Carcharhinidae																																				
Carcharhinus dussumieri	715	7.0	738	5.6	—		—		—		—		730	6.4	733	4.7	756	6.5	724	5.2	739	6.5	—		717	5.7	718	8.3	—		700	10.5	706	15.0	—	
Rhizoprionodon acutus	—		—		—		—		—		—		586	33.0	590	41.0	—		—		—		—		—		—		—		—		—		—	
Centriscidae																																				
Centriscus scutatus	—		—		—		—		—		—		—		—		—		—		—		—		—		—		—		92	4.5	100	2.8	—	
Clupeidae																																				
Anodontostoma chacunda	—		—		—		—		—		—		—		—		—		—		—		—		118	0.5	118	0.9	—		118	0.5	119	0.8	—	
Dussumieria elopsoides	119	0.9	116	1.8	—		—		—		—		128	2.2	116	1.5	123	1.1	115	5.9	115	1.7	121	1.5	120	0.9	124	0.9	131	1.5	—		123	2.0	116	1.6
Herklotsichthys koningsbergeri	—		—		—		—		—		—		—		—		—		102	1.0	103	1.1	—		—		—		—		—		—		—	
Herklotsichthys lippa	116	1.2	121	1.0	—		115	1.6	115	1.4	119	2.0	115	1.2	123	1.3	123	0.9	119	2.3	124	1.7	—		118	3.1	117	2.6	121	0.6	122	2.3	—		122	2.3
Pellona ditchela	111	2.9	111	1.4	—		107	1.2	96	0.8	102	1.6	103	1.3	109	2.2	109	1.3	108	1.6	111	1.0	109	0.7	98	1.0	107	0.9	111	1.0	102	0.8	108	0.7	113	0.8

Table 8.3.23 The mean length and standard error (se) for species in each area in each region for the 2 times (day and night). n = sample size

South Groote 1997

Species	Day Closed Length (mm)		Day Near Length (mm)		Day Far Length (mm)		Night Closed Length (mm)		Night Near Length (mm)		Night Far Length (mm)	
Cynoglossidae												
Cynoglossus maculipinnis	—		—		—		—		—		—	
Engraulididae												
Thryssa setirostris	—		—		—		133	1.5	129	2.8	—	
Gerreidae												
Pentaprion longimanus	—		79	1.6	90	0.5	55	2.0	69	1.2	86	0.5
Gobiidae												
Yongeichthys nebulosus	—		—		—		89	1.3	—		104	1.1
Haemulidae												
Diagramma pictum	—		—		—		—		—		—	
Pomadasys maculatus	—		—		—		114	1.2	109	1.6	—	
Pomadasys trifasciatus	—		—		—		—		—		—	
Labridae												
Choerodon cephalotes	—		—		—		—		—		—	
Leiognathidae												
Gazza minuta	83	0.6	85	0.5	94	1.0	83	0.5	84	0.5	86	1.2
Leiognathus bindus	58	0.8	62	1.0	74	0.6	60	0.8	53	0.6	71	1.2
Leiognathus decorus	—		—		—		—		—		—	
Leiognathus leuciscus	85	0.4	85	0.4	93	1.0	84	0.3	84	0.5	87	0.7
Leiognathus moretoniensis	69	0.8	73	1.2	77	0.7	64	0.5	57	0.6	75	0.5
Leiognathus ruconius	—		—		—		—		—		—	
Leiognathus sp.	88	1.3	98	0.7	98	0.8	82	1.8	87	2.3	95	0.8
Leiognathus splendens	86	1.1	92	0.7	—		86	1.2	90	1.0	—	
Secutor insidiator	80	0.9	84	0.5	83	0.9	81	3.3	83	1.9	—	
Lethrinidae												
Lethrinus laticaudis	—		—		—		—		—		—	
Mullidae												
Upeneus asymmetricus	—		—		—		—		—		—	
Upeneus sulphureus	—		—		—		—		—		—	
Upeneus sundaicus	109	2.0	126	3.2	129	2.7	113	0.8	116	0.7	121	1.2
Nemipteridae												
Nemipterus furcosus	—		—		—		—		—		—	
Nemipterus hexodon	—		—		—		91	2.2	104	1.9	136	2.1
Nemipterus peronii	—		—		—		112	1.1	115	2.3	126	2.2
Scolopsis taeniopterus	—		—		—		115	1.7	127	4.4	122	2.7
Pegasidae												
Pegasus volitans	—		—		—		—		—		—	
Platycephalidae												
Elates ransonnetii	—		—		—		151	1.4	149	1.3	153	0.8
Inegocia japonica	—		—		—		135	1.0	133	1.5	136	1.8

South Groote 1998

Species	Day Closed Length (mm)		Day Near Length (mm)		Day Far Length (mm)		Night Closed Length (mm)		Night Near Length (mm)		Night Far Length (mm)	
Cynoglossidae												
Cynoglossus maculipinnis	—		—		—		—		98	1.3	109	1.4
Engraulididae												
Thryssa setirostris	142	2.8	—		153	2.2	134	1.7	136	2.8	148	6.0
Gerreidae												
Pentaprion longimanus	51	4.0	78	3.5	73	2.0	42	1.8	45	2.3	66	2.0
Gobiidae												
Yongeichthys nebulosus	—		—		—		95	1.4	100	1.0	105	1.2
Haemulidae												
Diagramma pictum	—		—		—		273	36.1	—		344	45.5
Pomadasys maculatus	107	1.4	119	2.2	—		108	1.3	104	1.7	—	
Pomadasys trifasciatus	—		—		—		—		—		—	
Labridae												
Choerodon cephalotes	—		—		—		125	2.7	137	5.4	—	
Leiognathidae												
Gazza minuta	85	0.5	87	0.5	94	0.6	84	1.3	84	0.7	93	0.5
Leiognathus bindus	59	1.1	72	1.1	72	0.9	54	1.9	68	1.6	69	1.2
Leiognathus decorus	—		—		—		93	2.8	97	1.3	—	
Leiognathus leuciscus	86	0.4	91	0.4	91	0.7	86	0.3	88	0.4	94	0.9
Leiognathus moretoniensis	67	0.8	71	1.2	73	1.4	59	0.7	64	1.0	68	0.9
Leiognathus ruconius	—		—		—		—		—		—	
Leiognathus sp.	95	1.0	100	1.1	99	0.8	91	3.1	93	1.8	97	1.0
Leiognathus splendens	81	1.1	91	1.2	—		82	1.0	82	0.9	—	
Secutor insidiator	80	0.6	83	0.6	84	0.4	79	1.8	77	1.0	84	0.7
Lethrinidae												
Lethrinus laticaudis	153	11.6	—		275	11.5	175	6.8	—		212	4.9
Mullidae												
Upeneus asymmetricus	109	1.3	112	2.5	117	1.0	105	2.0	122	6.1	120	1.3
Upeneus sulphureus	—		—		—		—		—		—	
Upeneus sundaicus	118	0.9	120	0.9	121	2.2	117	0.6	117	0.5	125	0.8
Nemipteridae												
Nemipterus furcosus	153	3.8	153	5.9	147	3.0	144	3.6	148	2.1	150	1.8
Nemipterus hexodon	120	4.6	124	3.6	130	2.4	121	5.0	117	2.7	123	1.7
Nemipterus peronii	117	1.0	122	0.8	124	1.2	116	1.0	120	0.7	121	1.9
Scolopsis taeniopterus	120	2.3	114	3.8	133	3.6	121	1.5	115	1.8	130	2.0
Pegasidae												
Pegasus volitans	—		—		—		106	1.2	110	1.1	—	
Platycephalidae												
Elates ransonnetii	148	0.6	146	0.5	147	0.9	147	0.8	147	0.5	147	0.7
Inegocia japonica	—		—		—		127	1.0	126	0.9	120	1.3

North Groote 1998

Species	Day Closed Length (mm)		Day Near Length (mm)		Day Far Length (mm)		Night Closed Length (mm)		Night Near Length (mm)		Night Far Length (mm)	
Cynoglossidae												
Cynoglossus maculipinnis	—		—		—		—		—		—	
Engraulididae												
Thryssa setirostris	132	3.1	131	2.0	—		119	0.9	121	0.9	150	2.9
Gerreidae												
Pentaprion longimanus	—		—		—		66	0.7	63	1.8	77	0.5
Gobiidae												
Yongeichthys nebulosus	—		—		—		—		—		—	
Haemulidae												
Diagramma pictum	—		—		—		—		—		—	
Pomadasys maculatus	—		—		—		108	2.5	110	1.4	—	
Pomadasys trifasciatus	69	0.7	74	1.0	—		69	0.3	74	0.4	—	
Labridae												
Choerodon cephalotes	—		—		—		—		—		—	
Leiognathidae												
Gazza minuta	82	0.8	80	0.5	98	1.4	79	0.8	79	1.4	95	1.8
Leiognathus bindus	47	1.0	55	0.9	81	0.8	43	0.4	52	0.5	49	1.2
Leiognathus decorus	87	0.7	94	1.8	—		86	0.4	91	0.6	—	
Leiognathus leuciscus	91	1.3	89	0.5	—		81	1.2	84	0.7	90	1.9
Leiognathus moretoniensis	47	1.4	68	1.8	—		44	0.4	61	0.4	56	0.5
Leiognathus ruconius	59	1.3	64	1.3	—		56	1.6	60	1.0	—	
Leiognathus sp.	—		—		—		—		—		—	
Leiognathus splendens	79	0.8	77	0.6	85	1.2	77	0.4	78	0.4	88	2.0
Secutor insidiator	75	0.7	75	0.5	79	0.4	71	0.9	72	0.6	75	0.5
Lethrinidae												
Lethrinus laticaudis	—		—		—		—		—		—	
Mullidae												
Upeneus asymmetricus	—		—		—		—		—		—	
Upeneus sulphureus	—		—		—		—		112	2.6	96	0.4
Upeneus sundaicus	119	3.4	116	1.0	104	1.9	110	0.7	110	0.5	116	2.2
Nemipteridae												
Nemipterus furcosus	—		—		—		—		—		—	
Nemipterus hexodon	122	9.8	133	2.3	—		96	1.7	102	1.8	93	1.6
Nemipterus peronii	—		—		—		—		—		—	
Scolopsis taeniopterus	—		—		—		99	2.0	105	2.0	—	
Pegasidae												
Pegasus volitans	—		—		—		—		—		—	
Platycephalidae												
Elates ransonnetii	146	1.4	141	3.4	—		136	0.6	140	0.5	139	0.9
Inegocia japonica	—		—		—		127	2.1	130	1.7	139	5.8

Table 8.3.23 The mean length and standard error (se) for species in each area in each region for the 2 times (day and night). n = sample size

South Groote 1997

	Day						Night					
	Closed		Near		Far		Closed		Near		Far	
Species	Length (mm)		Length (mm)		Length (mm)		Length (mm)		Length (mm)		Length (mm)	
Polynemidae												
Polydactylus multiradiatus	—		—		—		—		—		—	
Priacanthidae												
Priacanthus tayenus	—		—		—		—		—		—	
Psettodidae												
Psettodes erumei	—		—		—		—		—		—	
Sciaenidae												
Johnius borneensis	—		—		—		143	4.0	129	1.8	—	
Scombridae												
Scomberomorus queenslandicus	315	5.8	307	8.2	—		—		—		—	
Scorpaenidae												
Apistus carinatus	—		—		—		83	2.1	89	1.4	79	1.7
Serranidae												
Epinephelus sexfasciatus	—		—		—		—		—		—	
Sillaginidae												
Sillago burrus	—		164	2.9	187	4.8	153	1.4	—		153	1.8
Sillago ingenuua	—		—		—		120	2.1	—		138	1.6
Terapontidae												
Pelates quadrilineatus	—		—		—		113	2.7	102	1.3	—	
Terapon puta	—		—		—		—		—		—	
Terapon theraps	117	1.7	112	2.7	137	1.4	125	0.8	113	1.5	128	1.4
Tetraodontidae												
Lagocephalus sceleratus	—		—		—		—		—		—	
Lagocephalus spadiceus	—		—		—		—		—		—	
Torquigener tuberculiferus	—		—		—		—		—		—	
Torquigener whitleyi	—		—		—		74	1.5	88	2.7	—	
Triacanthidae												
Trixiphichthys weberi	126	3.1	126	3.3	140	2.1	121	1.0	125	1.2	130	2.2
Trichiuridae												
Trichiurus lepturus	350	17.7	395	3.5	—		—		—		—	

South Groote 1998

	Day						Night					
	Closed		Near		Far		Closed		Near		Far	
Species	Length (mm)		Length (mm)		Length (mm)		Length (mm)		Length (mm)		Length (mm)	
Polynemidae												
Polydactylus multiradiatus	—		—		—		—		—		—	
Priacanthidae												
Priacanthus tayenus	—		—		—		—		—		—	
Psettodidae												
Psettodes erumei	199	13.3	215	13.6	207	7.7	201	24.9	214	15.3	207	18.1
Sciaenidae												
Johnius borneensis	—		—		—		130	1.8	134	3.8	141	3.0
Scombridae												
Scomberomorus queenslandicus	356	5.6	378	8.7	375	7.8	—		—		—	
Scorpaenidae												
Apistus carinatus	—		—		—		72	1.7	70	1.4	68	1.4
Serranidae												
Epinephelus sexfasciatus	—		—		—		—		102	7.9	137	5.2
Sillaginidae												
Sillago burrus	145	1.1	156	2.0	—		155	2.4	147	2.3	170	2.7
Sillago ingenuua	128	1.4	138	1.0	144	1.3	120	1.6	136	0.8	147	1.5
Terapontidae												
Pelates quadrilineatus	—		—		—		107	0.9	—		107	1.8
Terapon puta	—		—		—		—		—		—	
Terapon theraps	123	1.4	119	1.9	127	2.9	124	0.8	118	1.1	137	2.2
Tetraodontidae												
Lagocephalus sceleratus	—		—		—		49	2.9	41	2.0	68	10.3
Lagocephalus spadiceus	—		—		—		—		—		—	
Torquigener tuberculiferus	—		—		—		109	2.2	104	1.8	110	2.1
Torquigener whitleyi	—		—		—		73	1.5	78	2.0	100	3.5
Triacanthidae												
Trixiphichthys weberi	113	1.3	121	1.2	133	3.8	115	1.1	118	0.9	134	3.0
Trichiuridae												
Trichiurus lepturus	—		—		—		—		—		—	

North Groote 1998

	Day						Night					
	Closed		Near		Far		Closed		Near		Far	
Species	Length (mm)		Length (mm)		Length (mm)		Length (mm)		Length (mm)		Length (mm)	
Polynemidae												
Polydactylus multiradiatus	—		—		—		141	1.8	138	1.8	—	
Priacanthidae												
Priacanthus tayenus	—		—		—		109	0.8	104	0.9	109	1.1
Psettodidae												
Psettodes erumei	—		—		—		—		—		—	
Sciaenidae												
Johnius borneensis	—		—		—		—		—		—	
Scombridae												
Scomberomorus queenslandicus	358	4.3	370	10.0	—		380	12.6	436	8.5	—	
Scorpaenidae												
Apistus carinatus	—		—		—		71	1.8	79	4.5	75	2.8
Serranidae												
Epinephelus sexfasciatus	—		—		—		—		—		—	
Sillaginidae												
Sillago burrus	—		—		—		—		—		—	
Sillago ingenuua	—		—		—		—		—		—	
Terapontidae												
Pelates quadrilineatus	—		—		—		—		—		—	
Terapon puta	—		—		—		103	2.0	101	1.2	—	
Terapon theraps	124	3.6	112	2.7	—		128	2.3	124	1.2	130	2.5
Tetraodontidae												
Lagocephalus sceleratus	—		—		—		43	1.3	29	1.5	80	12.7
Lagocephalus spadiceus	—		—		—		117	4.6	—		105	2.1
Torquigener tuberculiferus	—		—		—		—		—		—	
Torquigener whitleyi	—		—		—		—		—		—	
Triacanthidae												
Trixiphichthys weberi	110	10.5	115	7.9	—		102	2.5	99	2.1	—	
Trichiuridae												
Trichiurus lepturus	313	6.8	297	14.1	336	7.9	321	29.0	—		259	12.5

8.3.3 Discussion

The comparison of areas open and closed to fishing is an obvious way to examine the impacts of fishing on communities and ecosystems. This type of comparison has been undertaken in many areas where marine reserves have been implemented to protect species or areas from fishing impacts (Alcala and Russ, 1990; Polunin and Roberts, 1993; Roberts, 1995; Rakitin and Kramer, 1996). This study used a comparison of open and closed areas to determine whether an impact of trawling on the vertebrate biodiversity could be detected. In two regions, a closed area was compared against two open areas, near and far. The near area was adjacent to the closure and therefore similar in seabed characteristics and depth (Table 8.3.2) but the commercial fishing effort in this area was lower (Figures 8.3.1 and 8.3.2). The far area was higher in commercial fishing effort (Figures 8.3.1 and 8.3.2), but the seabed characteristics differed and the area was deeper (Table 8.3.2).

The results of the present study suggest that there were differences between the areas open and closed to trawling, but the results are equivocal. The patterns of total catch rates (Table 8.3.4) and number of species detected (Table 8.3.5) do not show a strong or consistent difference between the closed and open areas. In 'North Groote' the average total catch in the closed area was higher at night than during the day, while the near and far areas were higher during the day. This might be the pattern expected if the commercial night-time trawling reduced the total catch of bycatch species at night in the open areas. However, the pattern was not the same in 'South Groote' 1997 and 1998. In 1998 'South Groote' all three areas had higher catch rates during the day, while in 1997 'South Groote' the closed and far areas had higher catch rates during the day, and the near during the night.

In terms of the number of species detected (Table 8.3.5), there was no consistent pattern across the areas between the regions. In 'South Groote' 1998 at night, the highest number of species was detected in the closed area, while during the day the three areas had a similar number of species detected. However, in 'North Groote' at both times, the number of species were similar across the areas. These two gross measures of biodiversity show no consistent pattern of difference between the open and closed areas.

The results of the multivariate and univariate analyses showed that in both regions, 'North Groote' and 'South Groote', the far area was clearly different to the near and closed areas. However, there was little difference between the latter areas. The multivariate analyses, that compared the overall bycatch composition among the areas, showed a clear separation of the far area from the near and closed combined in 'North Groote' 1998 and 'South Groote' 1998 at both times (Figures 8.3.7, 8.3.9, 8.3.12 and 8.3.14). The results from 'South Groote' 1997 were not as clear (Figures 8.3.5 and 8.3.6), but the 1997 survey was not originally designed to answer this question and the number of trawls was much lower (Section 8.2.2).

In 'South Groote' 1998 night and day and 'North Groote' day the separation of the far area from the near and closed, was on the second principal component of the ordination (Figures 8.3.7, 8.3.9 and 8.3.14). However, in 'North Groote' at night (Figure 8.3.12) the separation was on a combination of the first and second principal components. The correlations between the abiotic variables and the principal components from the ordinations suggest that this difference in overall bycatch composition was related to differences in depth, seafloor roughness and hardness, the percentage mud in the sediment and the level of commercial effort (Table 8.3.7). These abiotic variables showed their strongest correlation with the second principal component for 'South Groote' 1998 night and day and 'North Groote' day where the separation between the areas occurred. In 'North Groote' night the correlations were with both the first and second principal components.

The sites sampled in the near and closed areas did not separate on the basis of the area but separated into two groups of mixed sites (Figures 8.3.7, 8.3.9, 8.3.12 and 8.3.14). In 'South Groote' 1998 these groups clearly reflected the block of day/night when the sampling took place, many species showed a significant decrease in abundance around the full moon. The variation due to this factor was stronger than variation due to any difference caused by trawling in the near area.

The results of the univariate ANCOVAs, examining the difference in the abundance of individual species among the areas, showed a similar pattern to the multivariate analyses. Between 16% and 24% of species in a region at one time showed a significant contrast between the far area and the combined near and closed. The proportion of species that showed a significant contrast between the closed and near areas was less, 1% to 16%. Of the species with a significant contrast between the far and combined near and closed areas 45% were more abundant in the far, 38% in the combined near and closed and for 21% the area of highest abundance varied with the time of night/day. For most of the species (43%) that had a significant contrast between near and closed areas, the area of highest abundance varied with the time of night/day. There were few species that showed the same significant contrasts in both regions (Tables 8.3.14 – 8.3.17). There was no consistent tendency for a decrease in the abundance of individuals in the areas open to trawling.

There is no apparent consistency in the type of species that had significant differences in their abundance among the areas. It might be expected that the differences between open and closed areas were seen primarily in benthic or demersal species, as prawn trawls have a potentially greater impact on these species and their movement patterns may be less. However, many of the species that showed a significant difference were pelagic (Tables 8.3.14 - 8.3.17). The saurids are a group that are suggested may increase in abundance in trawled areas (Sainsbury *et al.,* 1992; Poiner *et al.*, 1998). In the present study, two species (*Saurida* sp. 2 and *S. micropectoralis*) did show a higher abundance in the open areas in at least one region at one time, while one species (*Synodus sagenus*) was higher in the combined closed and near(Tables 8.3.14 - 8.3.17). However, the pattern was not strong.

The results of the comparison of the mean size of species among the areas were also ambiguous. Most of the species with significant results had larger individuals in the far area (Table 8.3.21). Some species showed a consistent difference in both night and day and between regions, e.g. the apogonids and leiognathids (Table 8.3.22), with larger individuals in the far area. The pattern displayed by the leiognathids was similar to that found for these species in the eastern Gulf of Carpentaria, where most species show an increase in size with depth (Staunton-Smith *et al.*, 1999). However, the pattern observed here is different from that observed in comparisons between marine reserves and fished areas (Roberts, 1995; Rakitin and Kramer, 1996). There is generally an increase in the size of individuals within the marine reserves in comparison to fished areas. This is thought to be due to fishing reducing the average size of individuals in open areas.In the present comparison there was no indication of this for most species, although the comparison between open and closed areas is confounded by the response of species to changes in depth and seafloor characteristics.

The interpretation of the results of the present study is not straightforward. If the comparison had been made between the closed and far areas only, the results show a clear difference in teleost bycatch composition and the individual abundance of many species. These differences, however, are contributed to by differences in the depth and seafloor characteristics, which influence the abundance of individual species. However these abiotic variables do not explain all the differences observed. In comparison, if the contrast had been made between the closed and near areas only, the results show very little difference in the bycatch composition and abundance of species. These areas are similar in depth and seafloor characteristics.

The equivocal results are similar those from a comparison of open and closed areas in the northern Great Barrier Reef (GBR) (Poiner *et al.*, 1998). The comparison on the GBR found that more species showed significant latitudinal differences in abundance than differences between the open and closed area. The absence of a clear difference between open and closed areas in the present study cannot be interpreted as indicating that trawling has had no effect on the community in the area. Several studies have demonstrated the impact of trawling on epibethos (e.g. Van Dolah *et al.*, 1987; Collie *et al.*, 1997). The reason why the contrast between open and closed did not show a strong signal could be due to several reasons. The contrast between the open and closed areas may not be large. The open areas examined had relatively low commercial effort in the near area (Figures 8.3.1 and 8.3.2). The commercial effort in the NPF (approximately 2,000 days per year, NPF Annual Catch Statistics) is much less than that in other trawl fisheries such as the Queensland East Coast Otter Trawl Fishery (approximately 92,000 days per year, excluding Moreton Bay, QFMA Draft Management Plan). Most of the grids in the near areas had less than 30 days commercial effort recorded in 1997. A days effort is the equivalent of about 14 h trawling and so 30 days equates to 420 h. Trawling of 1000 h is the equivalent of covering an entire 6 n mile grid once, if the trawl paths are laid out uniformly on the seabed. Such low effort may reduce the contrast between open and closed.

The impact of trawling is also likely to be aggregated within grids. Trawling patterns in the NPF are highly aggregated within the 6 n mile grid scale used to report effort (FRDC 95/014). The trawls are not evenly spread within grids, as trawlers repeatedly trawl the same track. This means that randomly distributed survey trawls within a grid may cover both impacted and non impacted areas. This will increase the variation observed and make the detection of impacts more difficult.

There may also have been some trawling within the closed area, which means the communities in the closure have not been completely unimpacted for the 15 years of the closure. There has been effort recorded in the grids inside the closure since its protection, this could be due to errors in the recording of effort or be a reflection of trawling that has occurred in the closure. This effort within the closure may confound the results of the study, reducing the contrast between the open and closed areas. Since the introduction of compulsory Vessel Monitoring Systems (VMS) the closure should now be completely protected.

The mobility of vertebrate bycatch species may also reduce the contrast between the areas. These species can readily move across the boundary and so will not necessarily always remain in the open or closed area. This is an important aspect of a closure as species can use it as a temporary refuge from trawling, but it will reduce any contrasts. A greater contrast may be seen in the sessile or less mobile communities.

In addition to the factors that may reduce the contrast between the open and closed areas, the high natural variation in these communities and the spatial variation potentially obscure any effect of fishing. Section 6.2 clearly illustrates the variation in bycatch communities in the different fishing regions of the NPF. If the contrast between the open and closed is comparatively small and the natural variation high it would be difficult to detect an impact.

The results, therefore, do not demonstrate a clear difference in the biodiversity of vertebrate bycatch between the open and closed areas that can be attributed to impacts of trawling. However, this does not imply that there is no impact of trawling on the vertebrate communities. The results highlight the comparative difficulty of detecting an impact when the contrast may be small and the natural variation high.

8.3.4 Conclusions

- The number of species detected and the total catch rate of vertebrate bycatch did not show a consistent difference between areas open and closed to trawling in the two regions.
- The multivariate analysis of the vertebrate bycatch showed that in general the open area far from the closure was different to the near and closed areas.There was little difference between the latter areas.The separation of the far area was related to differences in depth and sea floor characteristics.
- The univariate analysis of the abundance of individual species, showed significant differences for up to 24% of species in a region at one time (day or night) between the far and combined near and closed areas.Fewer species showed a significant difference between the near and closed areas.The depth and sea floor characteristics were significant covariates in the analysis, but there were still significant differences between the far and combined near and closed areas.
- There was no consistent tendency for a decrease in the abundance of individuals in the areas open to trawling.Overall, the proportion of species showing an increase was larger than the number showing a decrease.
- In the comparisons of the mean size of species among the areas, there was no general trend towards larger individuals in the closure.Most species with significant results had larger individuals in the far open area.This comparison is confounded by the differences in depth and seafloor characteristics between the areas.
- Overall the results were equivocal with respect to the impact of trawling on the biodiversity of the vertebrate bycatch.This, however, does not mean that there is no impact from trawling on these fauna.The contrast

between open and closed areas may be reduced by the low commercial effort in the open areas, the aggregated nature of trawling, potential trawling in the closure, and the mobile nature of the species.This combined with the high natural variation may obscure any impacts of trawling.

References

Alcala, A.C., Russ, G.R., 1990.A direct test of the effects of protective management on abundance and yield of tropical marine resources.J. Cons. Int. Explor. Mer. 46, 40-47.

Collie, J.S., Excanero, G.A., Valentine, P.C., 1997.Effects of bottom fishing on the benthic megafauna of Georges Bank.Mar. Ecol. Prog. Ser. 155, 159-172.

Poiner, I., Glaister, J., Pitcher, R., Burridege, C., Wassenberg, T., Gribble, N., Hill, B., Blaber, S., Milton, D., Brewer, D., Ellis, N., 1998.Final report on effects of trawling in the far northern section of the Great Barrier Reef.CSIRO Division of Marine Research, Cleveland, Australia.

Polunin, N.V.C., Roberts C.M., 1993.Greater biomass and value of target coral-reef fishes in two small Caribbean marine reserves.Mar. Ecol. Prog. Ser.100: 167-175.

Sokal, R.R., Rohlf, F.J., 1996.Introduction to biostatistics, 2nd edition.Freeman and Company, New York.

Staunton-Smith, J., Blaber, S.J.M., Greenwood, J.G., 1999.Interspecific differences in the distribution of adult and juvenile ponyfish (Leiognathidae) in the Gulf of Carpentaria, Australia.Mar. Freshwat. Res.50, -.

Rakitin, A., Kramer, D.L., 1996.Effect of a marine reserve on the distribution of coral reef fishes in Barbados.Mar. Ecol. Prog. Ser. 131: 97-113.

Roberts, C.M., 1994.Rapid build-up of fish biomass in a Caribbean marine reserve.Cons. Biol. 9, 815-826.

Van Dolah, R.F., Wendt, P.H., Levisen, M.V., 1991.A study of the effects of shrimp trawling on benthic communities in two South Carolina sounds.Fish. Res. 12, 139-156.

Williams, W.T., 1976.Pattern analysis in agricultural science.CSIRO Publishing, Melbourne, and Elsevier Scientific, Amsterdam.

9. METHODS FOR MONITORING AND DESCRIBING BYCATCH

To develop cost-effective, accurate and feasible methods of describing and monitoring prawn trawl bycatch that would be acceptable to all stakeholders

9.1 General introduction

Section 9 of this report describes issues associated with sampling and monitoring prawn trawl bycatch in Australia's remote NPF. The primary objective is to assess methods for monitoring bycatch. In achieving this broad objective, we have divided the section into six subsections. The first five address important issues that improve our knowledge of sampling procedures and factors that affect the design of a monitoring program. The last section uses these studies and other information gained during the project to compare the most suitable methods for monitoring prawn trawl bycatch in the NPF.

9.2 The effect of subsampling position

9.2.1 Introduction

It is important to ensure that samples of bycatch are representative. However, because of the large variety of animals in the bycatch of the Northern Prawn Fishery (NPF), some species might be distributed unevenly in the codend during trawling and winching operations. This may come about because of different body shapes, weights, behaviour and swimming abilities. Sampling of the catch could therefore be biased for these species. Main and Sangster (1981) noted that flatfish in the North Sea were mostly pressed against the codend meshes in a fish trawl towed at similar speeds to that of Northern Prawn Fishery (NPF) trawlers. This may have led to the flatfish being unevenly distributed on the deck after the codend had been spilled. Tamsett *et al.* (1999) showed that fish trawl catches from the NE Scottish coast, UK, were well mixed. They found that taking samples of both marketable fish and catch discards at different times from either the sorting conveyor belt or from the pound to be a reliable method of sampling catches. But there are few other reports of distribution patterns of animals within the spilled catch of trawls.

We have assumed that, if a bycatch species aggregates in a particular position in the spilled catch on the sorting tray of NPF trawlers, that uneven distribution pattern should be consistently repeated. The two codends are usually winched simultaneously from the sea until they are suspended just above the sorting tray. The tray is divided in the middle to separate the two catches, and one codend is usually spilled first. During the spilling of the catch, the codends are usually oriented in the same direction relative to the sorting tray (because the crew pull the codend release drawstrings from the same position on the deck almost every time). This ensures that if a species consistently aggregates in one section of the codend, it should consistently show a higher abundance in one position in the spilled catch. A sampling technique that collected subsamples from only the same position on the sorting trays may not accurately represent the abundance of that species. We tested whether the position where the samples are collected on trawler sorting trays affected their representativeness. The specific objective was to:

- assess whether taking subsamples of bycatch from different positions on the sorting tray affects the accuracy of estimating catch composition

9.2.2 Materials and Methods

Study Site

Trawl samples were collected during research cruises of the R.V. *Southern Surveyor* from eight of the major tiger prawn regions of the NPF ('Weipa', 'East Mornington', 'North Mornington', 'West Mornington', 'North Vanderlins', 'South Groote', 'North Groote' and 'Melville') and one from TSPF (See Section 6.2 for regions). All trawls were made in either February-March 1997 (at the end of the wet season) or in September-October 1997 (dry season). The duration of trawls ranged from 1 to 3 h (Table 9.2.1), and depths ranged from 23 to 42.3m.

Table 9.2.1 Summary of catch data from 14 entirely sorted trawls from the Northern Prawn Fishery and Torres Strait Prawn Fishery. (n) is the total number.

Region	Duration (h)	Start time	Catch weight (kg)	Subsamples (n)	Animals (n)	Fish taxa (n)	Invert. taxa (n)	All taxa (n)
'Melville'	3.0	0130	170	14	4635	60	30	90
'North Groote'	3.0	0215	85	9	2792	60	34	94
'North Groote'	2.5	2230	147	12	5558	68	28	96
'South Groote'	2.7	0250	165	17	3856	64	25	89
'South Groote'	2.0	0345	315	27	23751	105	25	130
'Vanderlins'	2.7	0310	156	15	7182	71	19	90
'WestMornington'	1.7	0400	269	26	6967	87	24	111
'WestMornington'	1.6	0415	174	16	5976	100	21	121
'North Mornington'	2.2	0330	100	10	5067	77	34	111
'North Mornington'	2.0	0350	71	7	1771	60	30	90
'EastMornington'	2.9	0250	87	8	2019	77	45	122
'EastMornington'	1.0	0415	274	24	7313	90	18	108
'Weipa'	2.7	0220	166	16	4911	92	36	128
'Torres Straits'	1.2	0400	94	9	4151	74	21	95
TOTALS	31.2		2273	210	85949			

Subsampling technique

In order to find out whether the same species were consistently found in the same position in the spilled catch, we processed entire catches by taking samples from predetermined positions. Catches were spilled from the codend on to the flat deck of the research vessel (equivalent to the sorting tray on commercial vessels). The codend drawstrings were pulled from the same direction every time to control the way codends were oriented during trawling and winching. The entire catch of each trawl was progressively partitioned by shovelling the catch into consecutively numbered boxes, each of approximately 10 kg. Partitioning of the catch started with the collection of subsample No. 1 from the outer edges of the mound of bycatch species at a position that coincided with the direction of the ship's bow, and called 'North'. The codend drawstrings were pulled from the 'South West' direction relative to the ship's bow in each catch. Subsample No. 2 was taken from the outer edge at position called 'East', subsample No. 3 from 'South', subsample No. 4 from 'West' and subsample No. 5 back at 'North' again. This process of working clockwise around the edges continued until the entire catch had been collected in numbered boxes (subsample replicates) (Figure 9.2.1 a, b). All subsamples were processed separately using the methods described in Section 6.2.2.

Data Analysis

Design of distribution patterns

Two designs were used to test the effect of position of the sample in the catch: one a three-position design and the other a five-position design. We used the three-position design to describe the distribution patterns of species that might accumulate either at the outer rim, the middle rim, or in the centre of a catch on the sorting tray. The five-position design was chosen to describe the distribution patterns of species that may accumulate in a particular quadrant or semicircle of a catch on the sorting tray.

The null hypothesis for the three-position design states that animals were distributed evenly by numbers, weight and total number of species (species richness) throughout the outer rim, middle rim and the centre of the spilled catch. To test this, we first divided each catch as evenly as possible into these three positions. For example, in a catch consisting of 12 subsamples (approx 120 kg), subsamples 1- 4 were allocated to the outer rim, 5- 8 to the middle rim and 9-12 to the centre (Figure 9.2.1a). Then we compared the numbers of animals, total weight and total number of species (species richness) amongst the three positions.

The null hypothesis for the five-position design states that taxa were distributed evenly by numbers, weight and total number of species (species richness) throughout the four compass directions ('North', 'East', 'South' and 'West'), and the centre of the spilled catch. To test this, we first divided each catch as evenly as possible into these five positions. For example, in a catch consisting of 12 subsamples (approx 120 kg), subsamples 1 and 5 were allocated to position 'North', 2 and 6 to 'East', 3 and 7 to 'South', 4 and 8 to 'West', and subsamples 9 - 12 to the centre, (Figure 9.2.1 b). Then we compared the numbers of animals, total weight and total number of species (species richness) amongst the five positions.

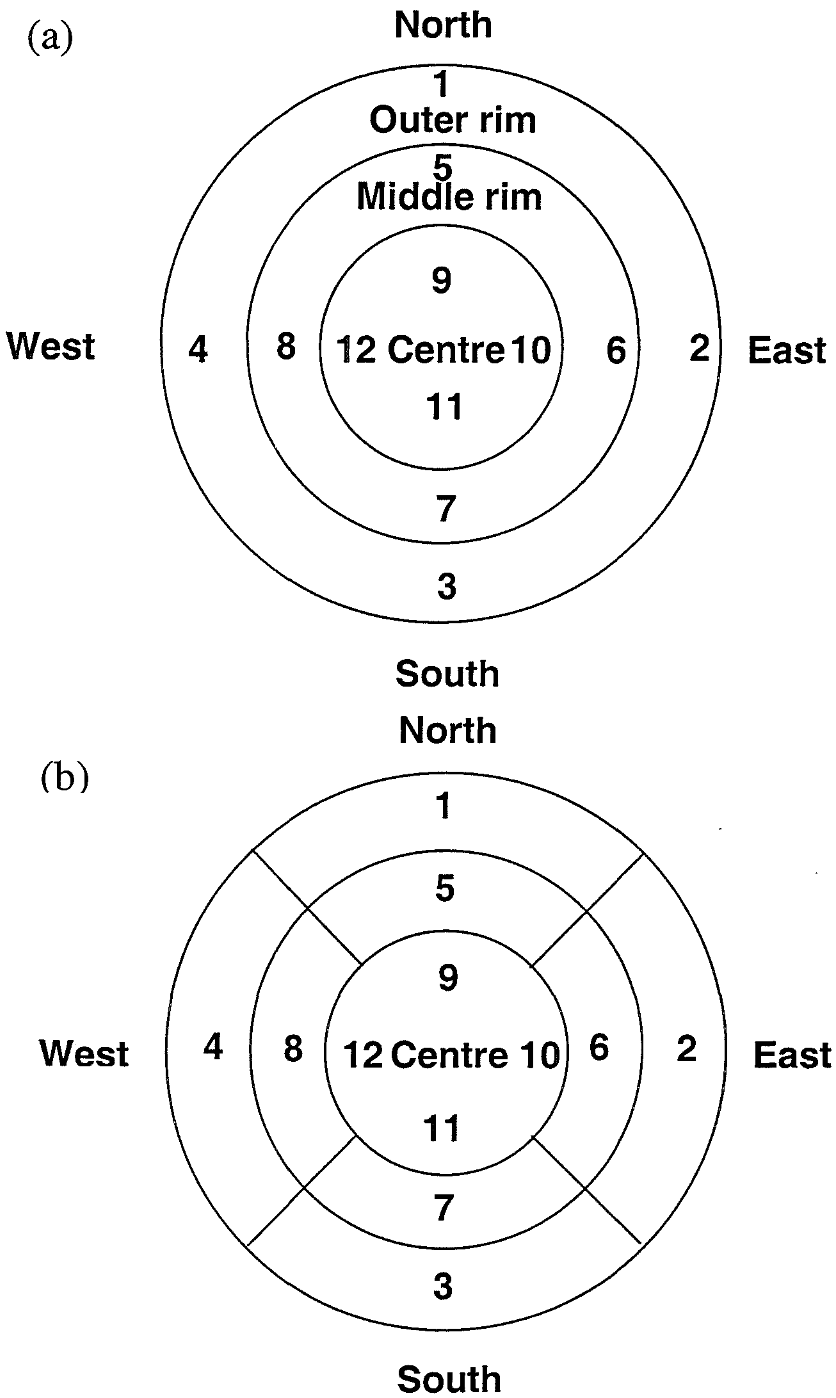


Figure 9.2.1 Schematic diagrams showing how a 12 kg catch was divided into 12 subsamples for analyses in (a) the three-position design, showing Outer, Middle and Centre positions and (b) the five-position design showing North, East, South, West and Centre positions.The numbers refer to the numbers of sequentially collected subsamples.

Both designs accounted only for the two-dimensional distribution of the catch and we made no attempt to account for differences in the vertical distribution of a spilled catch. The designs are, in general, unbalanced in their allocation of subsamples to a given position, because the number of subsamples in a catch cannot always be evenly divided by three, and/or five. In the cases above, the twelve subsamples (120 kg) were equally distributed in the three-position design with four subsamples or replicates in each position (Figure 9.2.1a). However, subsamples were unequally distributed in the five-position design with two subsamples in four of the positions but four subsamples in the centre position (Figure 9.2.1b). In the smaller catches (less than 12 subsamples), subsamples were allocated to positions in each design in an 'ad hoc' manner to ensure that there was at least one subsample in each position. Also subsamples differed slightly in weight, especially the last subsample taken in most catches.

Abundance groupings

The bycatch species recorded in this study vary greatly in body shape, size, weight, and swimming abilities. In order to obtain an overview of this diverse group of species, we reduced every occurrence of a species throughout the 14 catches, to an index of abundance. These indices were based on the average number of individuals of a given species that were recorded in a standardised 10 kg subsample taken from that catch. To generate this index, we used the following equation:

$$\mathbf{N = 10 * (T / W)} \qquad \text{(Model 9.2.1)}$$

where **N** was the mean number of individuals of a given species per 10 kg subsample, **T** was the total number of individuals of that species in the whole catch, and **W** was the total weight of the catch in kg.

We grouped all the indices of abundance into three categories – 'rare' (less than one individual per 10 kg subsample averaged over all subsamples in that catch), 'common' (from one to less than five individuals per 10 kg subsample), and 'abundant' (five or more individuals per 10 kg subsample). Each species had its abundance index calculated separately for every catch where it was recorded. So species 'X' may have been classed as 'rare' in one catch, but 'abundant' in a different catch.

Two levels of analyses were undertaken for each design in order to test for differences in the distribution patterns of species between positions: total catch analyses using all species grouped together, and a separate series of analyses looking at the distribution patterns of individual species. We also tested for the effect of the region where trawls were made.

Total catch analysis

All fourteen trawl catches were used in the overall analyses. A generalised linear model was fitted to the three dependent variables, the total numbers of individuals, total weight of individuals, and the total number of species (species richness), and differences in their distribution patterns examined. These analyses were made separately for fish and invertebrates. We expected that the best chance of detecting the effects of position on the sorting tray would occur in the 'abundant' group of species, rather than with species recorded only occasionally in a catch.

For example, if only one individual of a 'rare' species occurred in a particular catch, then it was impossible for that species to be recorded in all positions in either the three- or the five position designs, and this could bias the analysis. Consequently, we used the groupings of 'rare', 'common' or 'abundant' in order to reduce the effects of 'rare' species on the analyses.

The program PROC GENMOD (SAS 1993) was used in all analyses. In the analyses describing the differences in species numbers for both designs, the data were fitted to a Poisson distribution with an over-dispersion parameter. The log of subsample weight was used as an offset variable to allow for the effects of differences in weight. Observations from different trawls are assumed to be independent. For individual trawls, observations are assumed to be equally correlated (i.e. an exchangeable correlation structure).

For the analysis of species weight, the data were normalised by log-transformation and fitted to a normal distribution. The log of subsample weight was used as an offset variable to allow for the effects of differences in weight. The link function was set to 'log' in these two analyses to reduce the effect of extreme data points.

Data for the total number of species were fitted to a binomial distribution and the link function set to 'logit' to reduce effects of extreme data points.

The model used is described as follows:

$$\mathbf{Y} = \mathbf{C} + \mathbf{R} + \mathbf{A} + \mathbf{P} + (\mathbf{P} * \mathbf{A}) \qquad \text{(Model 9.2.2)}$$

where **Y** was the response variable — either total numbers of fish, total weight of fish or total numbers of species; **C** was a constant, **R** was the region where the catch was taken; **A** represented the abundance categories of 'abundant', 'common' or 'rare'; **P** was the position variable — either outer rim, middle rim or centre for the three-position design, or 'North', 'East', 'South', 'West' and centre in the five-position design;
(P * A) was the interaction between position and the abundance categories.

Individual species analysis

As a way of detecting differences in effects of position on the sorting tray, we also examined whether the total numbers of individual species varied in the different positions throughout the catch. Data analysed for both the three and five-position designs were restricted to the 10 catches where the total number of subsamples was 10 or greater. Catches with less than 10 subsamples had disproportionate allocations of subsamples between positions in the two designs and were omitted from the analyses. After preliminary inspection of the data, we also restricted these analyses to the 'abundant' group of species that had five or more individuals per subsample (for these analyses, 50 or more animals in a catch).

Firstly, we used PROC GENMOD (SAS 1993) to examine whether an individual species showed a significant difference in distribution patterns over all the catches where it was classed as 'abundant'. We used the following equation:

$$\mathbf{Y} = \mathbf{C} + \mathbf{R} + \mathbf{P} \qquad \text{(Model 9.2.3)}$$

where **Y** was the response variable—total numbers of a species (either fish or invertebrates), and **C, R** and **P** were defined as forModel 9.2.1.

Secondly, for those 'abundant' species where we detected an overall significant difference in distribution patterns (model 9.2.3), we used PROC GENMOD (SAS 1993) in order to detect whether an individual species had a significantly different pattern of distribution in each separate catch. We used the following equation:

$$\mathbf{Y} = \mathbf{C} + \mathbf{P} \qquad \text{(Model 9.2.4)}$$

where **Y** was the response variable — total numbers of a species (either fish or invertebrates), and **C, P** were defined as for Model 9.2.1.

We described the differences in individual catches by plotting the mean numbers of animals in subsamples from each position in the two designs. These data were standardised by the weight of each subsample. We only examined the distribution patterns for those taxa with significant differences in more than one catch (a significant difference in only one catch could be caused by chance alone). We have presented histograms only for two species (one from each design) that showed the strongest trends in distribution patterns.

9.2.3 Results

General Results

A total of 85,949 fish and invertebrates were sorted from 14 prawn trawl catches. We identified 237 fish and 130 invertebrate taxa. Catches ranged in size from 71 to 315 kg (Table 9.2.1) with an average of 105 taxa in each (ranging from 89 to 130). Of these, 60 to 105 were fish taxa and 18 to 45 were invertebrate taxa.

Total catch analysis

There were no significant differences (model 9.2.1) between subsamples from different positions for the total numbers of individuals, total weights of individuals, or the total number of fish or invertebrate taxa in either of the two positional designs (Table 9.2.2). Region and abundance were significantly different for the same response variables, indicating that the numbers, weights and the total numbers of total fish and total invertebrate taxa were different in the nine regions trawled, with different proportions in each of the three abundance categories in each region. However, there were no significant differences for the interaction between the three abundance categories ('rare', 'common' and 'abundant'), and position for the same variables in either design.

Individual species analysis

Three-position design

For the three-position design, there were 121 cases (made up of 52 taxa from 10 catches) where taxa were classed as 'abundant'. As an example *Leiognathus moretoniensis* occurred in 10 catches altogether, but was classed as 'abundant' in only eight of them.

In the analyses using only those taxa classed as 'abundant' (model 9.2.2), a total of six taxa showed a significant difference in distribution patterns. These represented 11.5% of the taxa and accounted for 16 cases (out of the total 121 cases) where taxa were 'abundant'. Further analysis (model 9.2.3) showed that only one of these six taxa – *L. moretoniensis* – had significantly different distribution patterns in more than one catch. This species had significantly different distribution patterns in four out of the eight catches where it was 'abundant'. In three of these four catches, the mean number of fish per subsample was higher in the outer rim (Figure 9.2.2a, b, c). In the other catch, the mean number of fish was highest in both the outer rim and in the centre (Figure 9.2.2d).

The remaining 46 taxa (88.5%) showed no significant differences between distribution patterns over all trawl catches (105 of the possible 121 cases where taxa were 'abundant'). Of these 46 taxa, 18 taxa were 'abundant' in only one catch; and 28 taxa were 'abundant' in more than one catch each, eight of which were 'abundant' in four or more catches. However, all 46 taxa showed no differences in numbers between the three different positions in the trawl catch.

Table 9.2.2 Summary of results of total catch analyses from model 9.2.1, showing the class variables, the degrees of freedom (DF) and the probability values (*P*) for both fish and invertebrates, for each of the response variables tested.

Response variables	Class variables	DF	Fish *P*	Invertebrates *P*
Total numbers of animals	Region	13	*0.0001*	*0.0001*
	Abundance	2	*0.0001*	*0.0001*
	3 Position	2	*0.99*	*0.99*
	3 Position * Abundance	4	*0.99*	*0.78*
	5 Position	4	*0.95*	*0.99*
	5 Position * Abundance	8	*0.99*	*0.99*
Total weight of animals	Region	13	*0.0001*	*0.0001*
	Abundance	2	*0.0001*	*0.0001*
	3 Position	2	*0.91*	*0.97*
	3 Position * Abundance	4	*0.72*	*0.1*
	5 Position	4	*0.99*	*0.96*
	5 Position * Abundance	8	*0.79*	*0.57*
Total numbers of species	Region	13	*0.0001*	*0.0001*
	3 Position	2	*0.38*	
	5 Position	4	*0.75*	

Five-position design

For the five-position model, in the analyses using only those taxa classed as 'abundant' (model 9.2.2), a total of 13 taxa showed a significant difference in distribution patterns. These represented 25% and accounted for 34 cases (out of a total of 121 cases) where taxa were 'abundant'. Further analysis (model 9.2.3) showed that only four of these 13 taxa had significantly different distribution patterns in two or more catches. They included one fish *Saurida* sp. 2 (with four cases), and three invertebrate taxa, the saucer scallop *Amusium pleuronectes*, the roughback prawn *Metapenaeopsis* spp.and the heart urchin *Lovenia* spp. (with two cases each). Examination of the mean number of individuals per subsample in each of the five positions for each catch showed *Amusium pleuronectes* had the strongest trend with the 'West' position, and in one catch, the adjacent 'South' position, having consistently higher numbers than the other positions (Figure 9.2.3a, b). For the other three taxa, *Saurida* sp. 2, *Metapenaeopsis* spp. and *Lovenia* spp, the trends were not consistent in direction.

The remaining 39 taxa (75%) showed no significant overall differences between distribution patterns over all trawl catches (87 of the possible 121 instances of 'abundant' taxa). Of these 39 taxa, 17 taxa were 'abundant' in only one catch, and 22 taxa were 'abundant' in more than one catch each, 11 of which were 'abundant' in four or more catches each. However, all 39 taxa showed no differences in numbers between the five positions in the trawl catch.

9.2.4 Discussion

Most taxa seen in the diverse catches of the NPF show no difference in their spatial distribution on the catch-sorting tray. Because most taxa are well mixed throughout the catch, subsamples can be taken from any position without introducing bias. Both the three- and the five-position designs identified differences in distribution patterns in some taxa. However, relatively few of the 'abundant' taxa (11.5% in three-position, 25% in five-position design) were distributed unevenly throughout the catch, which would require making changes in monitoring methods. This is an important result for monitoring the bycatch from tropical prawn trawl fisheries.

Our results agree with the findings of Tamsett *et al.* 1999, who sampled both marketable fish and discards from either the sorting conveyor or the pound on a Scottish fish trawler. They also found catches to be well mixed and that taking subsamples from either position during the sorting process gave reasonable estimates of the catch composition.

It is not clear why some species are distributed unevenly throughout the spilled trawl catch but it may be related to the way in which species enter the net and are oriented in the codend during trawling. For example, flatfishes were always pressed against the meshes of the codend in North Sea trawls (Main and Sangster 1981). In our three-position design, there were more *Leiognathus moretoniensis* on the outer edges of the catch. Possibly schools of this species were captured late in three of the trawls; or this pattern could be due to these trawls being made just before dawn, when species of Leiognathidae increase greatly in catches (pers. obs.). If a school of fish enters the net just before it is winched in, it would probably end up on top of the catch in the codend, and above animals caught earlier in the trawl. When the catch is spilled, these livelier animals on the top of the catch would gravitate down the slope to the outer rim in larger numbers.

In the five-position design, the saucer scallop *Amusium pleuronectes* was deposited in higher numbers in the 'West' and 'South' quadrants in two catches. Due to their body shape and weight, they may have dropped and accumulated at the bottom of the codend during trawling and winching, and were consequently spilled consistently to one side of the catch on the sorting tray.

Although some taxa in the catch are aggregated (and could cause subsampling problems), most taxa are well mixed. This mixing may be due to their behaviour in the trawl (as a result of body shape or weight) or to water turbulence in the codend during trawling and winching; both of these are likely to occur during a single trawl. However, many less-common events may also influence the way taxa are mixed in the codend and distributed on the tray. These include differences in water turbulence caused by a change in winching-up speed (e.g. to avoid seabed obstructions), effects of heavy weather, increased steaming speed in order to avoid sharks or to flush large animals into the codend. When large, live animals (e.g. sharks, rays, turtles) are spilled from the codend onto the sorting tray, they can redistribute the remaining bycatch across the tray. However, although the effects of these events are difficult to measure, they are more likely to mix taxa through the catch than to clump them. In any future monitoring, collecting samples from different positions on sorting trays would further reduce the chance of bias in representing individual species in catches.

9.2.5 Conclusions

- Between 11.5% and 25% of the 52 bycatch taxa tested, were unevenly distributed on the NPF trawler sorting trays.
- Only the saucer scallop *Amusium pleuronectes* and the ponyfish *Leiognathus moretoniensis* showed an uneven distribution pattern that was consistent in two or more catches.
- Taking subsamples from any position on sorting trays should not bias representativeness for most taxa.

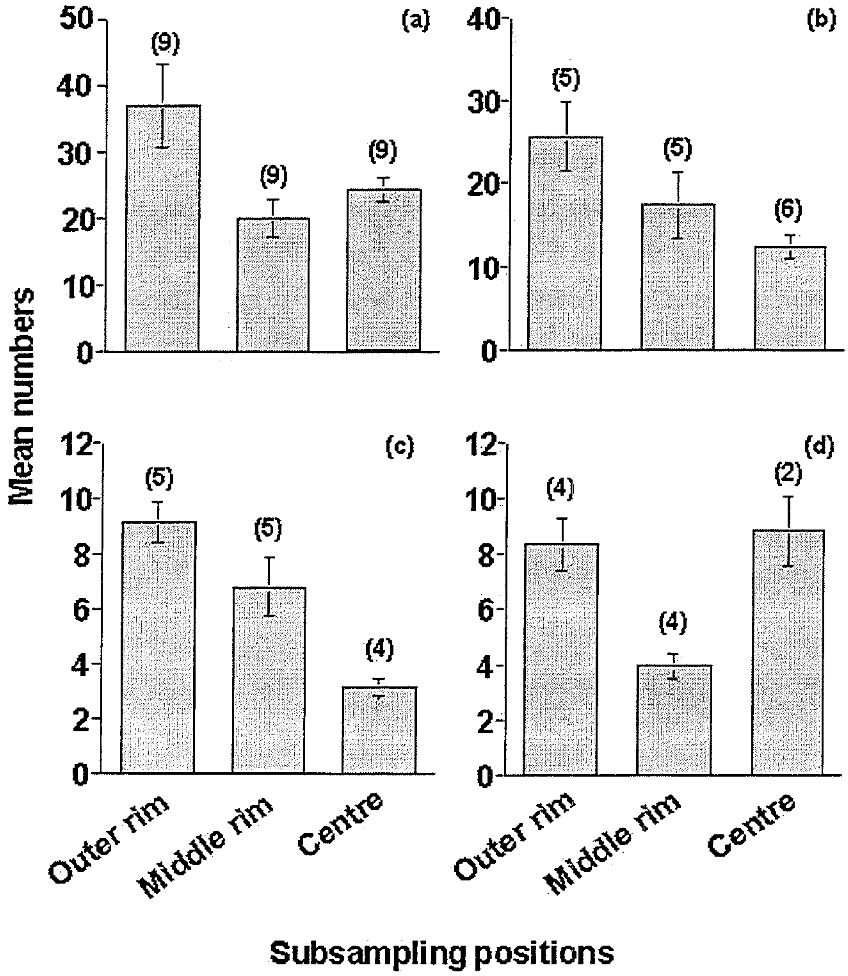


Figure 9.2.2. Means (± se) of the numbers of *Leiognathus moretoniensis* in subsamples from four catches (a-d) that showed significant differences in their distribution patterns in the three-position design. The number of subsamples in each position on the sorting tray is shown in bold.

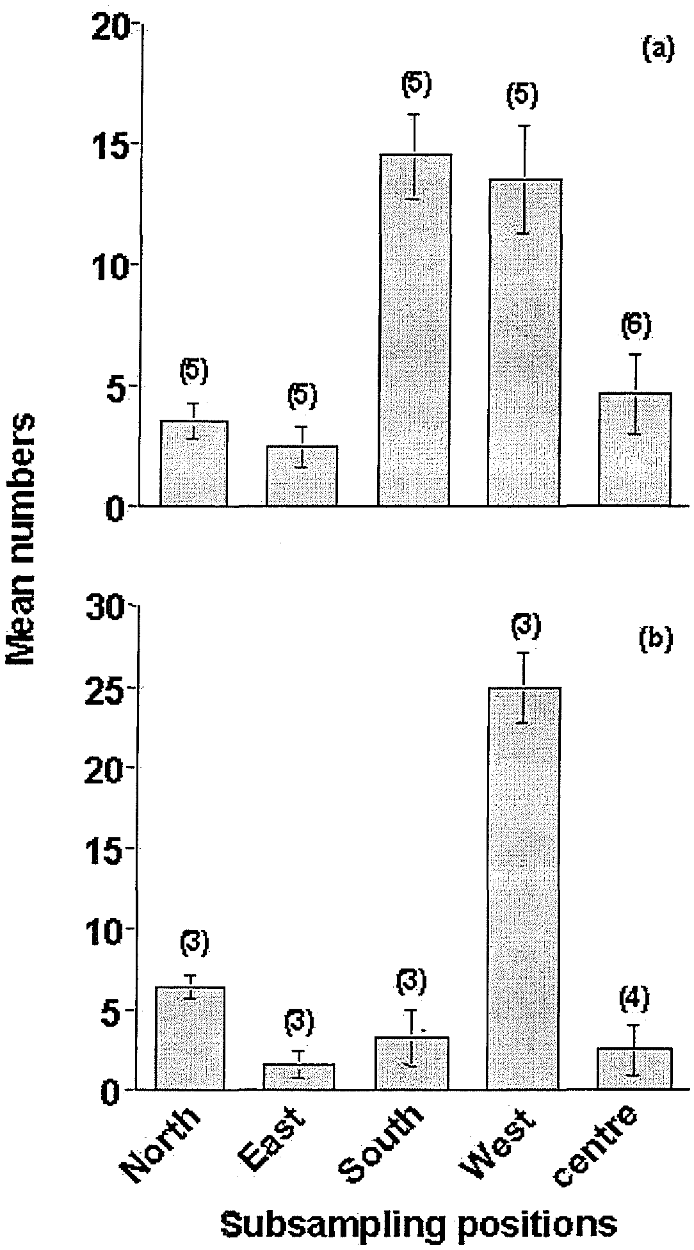


Figure 9.2.3. Means (± se) of the numbers of *Amusium pleuronectes* in subsamples from two catches that showed significant differences in their distribution patterns in the five-position design. The number of subsamples in each position on the sorting tray is shown in bold.

References

Main, J., and Sangster, G.I., 1981. A study of the fish capture process in a bottom trawl by direct observations from a towed underwater vehicle. Scott. Fish. Res. Report No 23.

Tamsett, D., Janacek, G. and Emberton, M. 1999. A comparison of methods for onboard sampling of discards in commercial fishing. Fish. Res. 42: 127-135.

SAS Institute Inc., 1993. SAS Technical Report P-243 SAS/STAT Software: The Genmod Procedure, Release 6.09, Cary, NC: SAS Institute Inc., 88pp.

9.3 Hopper sampling

9.3.1 Introduction

An increasing percentage of the trawlers (currently around 22%) in the Northern Prawn Fishery (NPF) use seawater hoppers for holding catches prior to sorting. If a fishery-dependent method is used to monitor NPF bycatch, then samples will be collected from trawlers and some of these will use seawater hoppers.

Hoppers are seawater tanks on the trawler deck, into which the codends are spilled at the completion of each trawl. The catch is extracted from the bottom of the hopper by a conveyor belt with a ribbed surface. The unsorted catch on the conveyor then travels horizontally at waist height along the deck and the crew sort prawns and byproduct from the stream (Figure 9.3.1). Unwanted bycatch is fed straight back to sea. This system offers improved quality and reduced sorting times for the prawns and may also allow higher survival rates for some bycatch species.

Taking samples of both marketable fish and catch discards at different times from a sorting conveyor belt on a fish trawler (off the NE Scottish coast, UK) has been shown to be a reliable method of sampling catches (Tamsett *et al.* 1999). We have examined the effects, on sampling accuracy, of taking subsamples from different positions on the sorting trays of NPF trawlers (Section 9.2). These results show that catches are fairly well mixed and that subsamples of the small bycatch species can be taken from any position. However, in the case of hoppers, catches are immersed in seawater and this may affect the distribution of species because of differences in buoyancy, changing seawater levels and the physical size of the catch in the hopper. We need to know whether taking subsamples from different sections of the catch (as it comes out of the hopper on the conveyor belt), will bias the accuracy of the sampling procedure. The specific objective was to:

- To assess whether taking subsamples from the hopper conveyor belt causes bias in estimates of catch composition

9.3.2 Methods

We sorted the entire bycatch of three trawls taken by a twin rigged commercial trawler from west of Mornington Island in the Northern Prawn Fishery (NPF) in June 1998. The trawler used a seawater hopper to hold catches prior to sorting. After winching in both nets, the codends were spilled onto a grid (approx 300 mm wide spacing) above the hopper. This separated the large unwanted animals in the catch such as sharks and rays that could then be easily thrown overboard. The smaller bycatch and target species fell through the grid into a tapered water-bath into which ambient temperature seawater was continually pumped (Figure 9.3.1). The catch was extracted from the bottom of the hopper by a conveyor belt that moved the unsorted species in a constant stream past the crew. The invertebrate target species (prawns) and byproduct (squid, scallops, bugs etc) tended to sink to the bottom of the hopper and were removed first. Floating or swimming fish tended to be removed last. The unwanted bycatch was washed back to sea, usually within one minute of being extracted from the hopper.

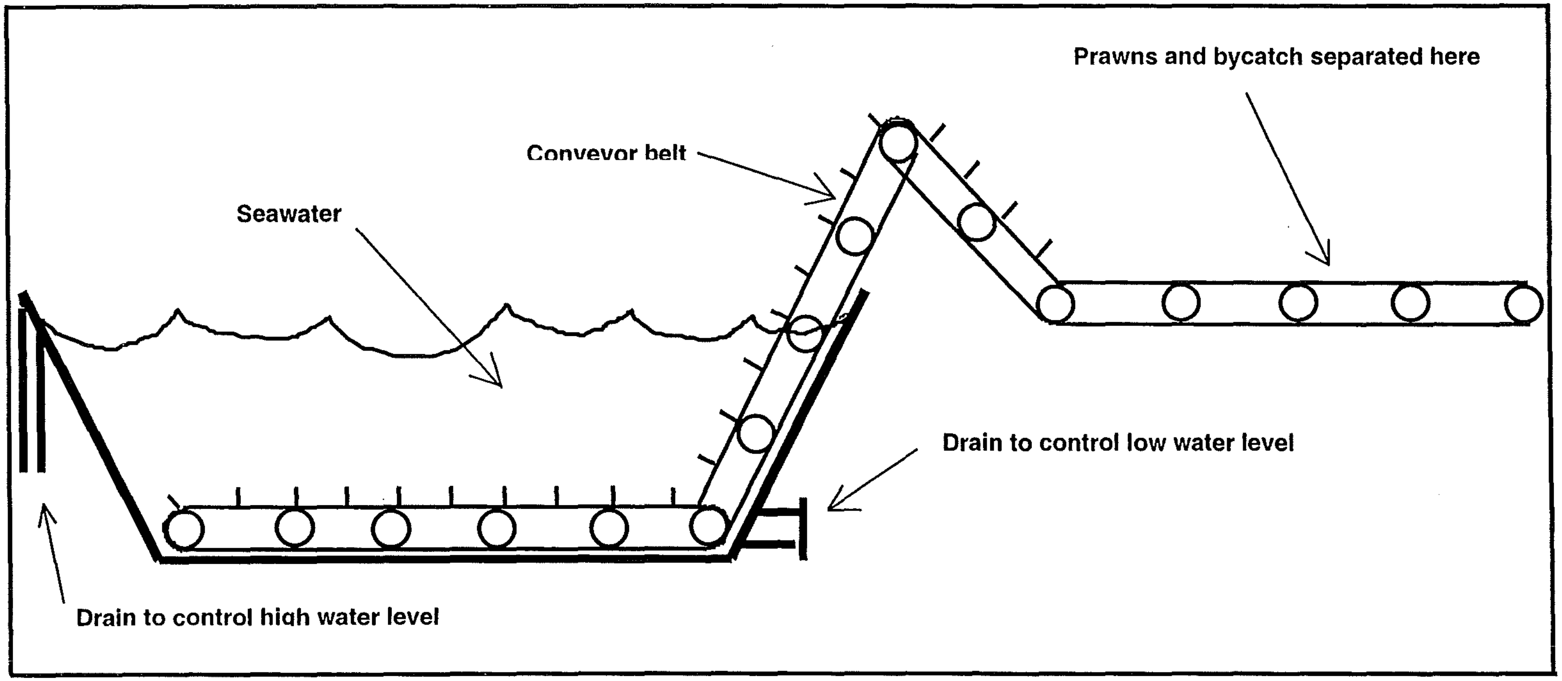


Figure 9.3.1 Schematic diagram of seawater hopper system for holding catch prior to sorting. Note that the conveyor belt is positioned to extract catch from the bottom of the hopper.

If small bycatch species were not evenly distributed within the hopper, taking samples from the sorting conveyor belt at different times (or positions) throughout the sorting process may bias the estimates of catch composition. In order to test whether bycatch species were evenly distributed, we collected the entire bycatch from a trawl in a series of subsamples (approx 10 kg each). The subsamples were collected after the target species had been removed and each subsample was collected in the order that the bycatch exited the hopper on the conveyor belt. We repeated this process for three entire catches.

The subsamples were frozen on board and transferred back to the CSIRO laboratory in Cleveland. During processing in the laboratory, subsamples were thawed and all bycatch items were identified to the lowest possible taxonomic level, counted and weighed. After checking, the data were entered directly into Oracle database tables.

Although most bycatch items were identified to species level, some could only be identified to genus or family. In order to be consistent in terminology throughout this Section, we use the term species (plural form) even when referring to groupings at the higher taxonomic level.

Abundance groups

In order to gain an overview of major differences in species distribution throughout the catch sorting process, we separated the species in each catch into three groups based on their abundance per 10 kg subsample (averaged over the whole catch). We used the same categories of 'rare', 'common' and 'abundant' and calculated the average abundance for each species in a catch using the same equation as described in Section 9.2.2, (model 9.2.1).

Design model

In order to determine whether taking subsamples from the conveyor belt biased estimates of species composition or abundance, we divided each catch into three approximately equal groups of subsamples based on the time that they were collected: the first group, middle group and last group. In order to demonstrate how a catch might be divided into the design model, for a catch containing 39 consecutively numbered subsamples, subsamples 1-13 were allocated to the first group, 14 - 26 to the middle group, and 27-39 in the last group.

Data analysis

Species composition

If the total number of species in a catch was evenly distributed throughout the sorting process, we would expect that the number of species in each catch group (first, middle and last) would be approximately equal. In order to determine whether the numbers of species were significantly different, we used a one-way ANOVA (SAS 1998) to compare the average number of species (per standardised 10 kg subsample) from the three catch groups. We did this for each of the three abundance categories, 'rare', 'common' and 'abundant'.

Species abundance
If the total number of a given species in a catch was evenly distributed throughout the sorting process, we would expect the average number of individuals recorded per standardised 10 kg subsample from each of the three catch groupings, would be approximately equal. In order to test whether subsampling from different positions on the conveyor belt biased estimates of the abundance of individual species, we used a one-way ANOVA (SAS 1998) to compare the average number (per 10 kg subsample) of individuals of each species recorded in the three positions in the catch. We grouped species into the three abundance categories, 'rare', 'common' and 'abundant'.

When a significant difference was detected, the means from each of the three catch groupings were compared. In order to determine whether particular species were extracted from the hopper early or late in the sorting process, we grouped species within each abundance category, into three groups. Groups were based on the distribution of abundance means, either skewed towards the first catch group, the middle group or the last group of subsamples. In order to demonstrate the two most common distribution patterns, we have plotted the percentage of the total numbers of *Amusium pleuronectes* and *Leiognathus moretoniensis* that were recorded in each 10kg subsample as increasing percentages of the three catches were sorted.

9.3.3. Results

Total weights of the catches used in this study were 207 kg (catch 1), 334 kg (catch 2) and 509 kg (catch 3); the number of 10 kg subsamples were 18, 26 and 39 respectively; and the numbers of species recorded (both fish and invertebrates) in the catches were 93, 116 and 108, respectively. The percentage of 'rare' species in catches ranged from 68 to 78%, 'common' species from 9 to 19%, and 'abundant' species from 13 to 16% (Table 9.3.1).

Species composition
The number of 'rare' species recorded was significantly different between catch groups in one of the three catches (Table 9.3.2). The number of 'common' and 'abundant' species were significantly different between catch groups in two catches.

Species abundance
Between 29 and 36% of the 'rare' species had significantly different mean numbers per subsample between catch groups over the three catches (Table 9.3.3). Of these 'rare' species that were unevenly distributed, 56% had abundance distributions skewed towards the first catch group of subsamples, 13% were the highest in the 'middle catch group' and the remaining 31% had distributions skewed towards the last catch group of subsamples (Table 9.3.4).

Between 60 and 86% of 'common' species had significantly different mean numbers per subsample between catch groups over the three catches (Table 9.3.3). Of these 'common' species that were unevenly distributed, 52% had abundance distributions skewed towards the first catch group of subsamples; 10% were hiughest in the 'middle catch group' and 37.5% had distributions skewed towards the last catch group (Table 9.3.4)

Between 75 and 100% of the 'abundant' species had significantly different mean numbers per subsample over the three catches (Table 9.3.3). Of these, 45% had abundance distributions skewed towards the first group; 16% were highest in the 'middle catch group'; and 39% had distributions skewed towards the last group (Table 9.3.4).

The 'abundant' species, *Amusium pleuronectes*, is used to depict those species that had abundance distributions skewed towards the first catch group in all three catches (Figure 9.3.2a). The 'abundant' species, *Leiognathus moretoniensis* is used to depict those species that had abundance distributions skewed towards the last catch group in all three catches (Figure 9.3.2b).

9.3.4 Discussion

Over 20% of the trawlers in the Northern Prawn Fishery (NPF) use seawater hoppers to hold catches prior to sorting. Our work shows that subsampling from hoppers for the small bycatch species is strongly biased when samples are taken from the sorting conveyor belt. Most individual species have abundance distributions that are strongly skewed towards either the first or the last catch groups.

These results differ from those recorded by Tamsett *et al.* 1999, who also sampled fish discards from a sorting conveyor on a Scottish fish trawler. They found that taking subsamples at three different times during the sorting process gave reasonable estimates of the catch composition of the discards. Similarly, we also found (Section 9.2) that the position where subsamples are taken in the spilled catch does not bias the accuracy of subsampling for most bycatch species on NPF trawlers using conventional sorting trays. Catches in the Tamsett *et al.* study were not spilled into a seawater hopper, but into a pound, presenting a similar situation to that of subsampling bycatch spilled on to the sorting trays of NPF trawlers.

Buoyancy, changes in water level in the hopper and the size of the catch all affect the distribution of a given species throughout the sorting process. After the catch is dumped into the hopper, many species, such as the target species of penaeid prawns as well as most invertebrates, sink to the bottom and are extracted in the first catch group. This tendency to sink streamlines the sorting process, thus making the hoppers more attractive to fishers. Many fish, including the abundant ponyfish, *Leiognathus splendens,* have been shown to float (99% of those caught in shallow depths) after being taken as bycatch in prawn trawls (Harris and Poiner, 1990). These floating species are recorded in higher numbers towards the end of the sorting process in the last catch group.

Although the order in which species in these catches are sorted appears to depend largely on buoyancy, there are other factors of lesser importance that can influence the distribution of species throughout the catch. These include changes to the level of water in the hopper by the crew in order to control the volume of catch moving past the sorters at the conveyor belt. Similarly, large catches can also change the consistency of bias because they fill the hopper above the grid and the drain holes. The system becomes choked and the buoyancy effect of floating species is negated until the ratio of catch to water changes. As a result, the bias in species distribution throughout the sorting process is inconsistent.

Table 9.3.1 Summary of catch data for three catches that were removed from a hopper by a conveyor belt sorter on a Northern Prawn Fishery trawler. (n) is the total number.

Catch number	Start time (h)	Duration (h)	Catch weight (kg)	No of bycatch items (n)	No of subsamples (10kg) (n)	No of species (n)	Percentage of 'rare' species	Percentage of 'common' species	Percentage of 'abundant' species
1	2200	2	207	7453	18	93	68	19	13
2	1840	2.5	334	13611	26	116	72	12	16
3	1830	1.8	509	23563	39	108	78	9	13

Table 9.3.2 Summary of GLM results (from three separate catches) comparing the number of bycatch species between the first, middle and last groups of subsamples removed from a hopper by a conveyor belt sorter.'Rare', 'common' and 'abundant' species were analysed separately. * denotes significant at $P = 0.05$.

DF	Abundance categories	Catch 1 *P*	Catch 2 *P*	Catch 3 *P*
2	'rare'	*0.326*	*0.156**	*0.000**
2	'common'	*0.442*	*0.000**	*0.000**
2	'abundant'	*0.084*	*0.000**	*0.000**

Table 9.3.3 The number and percentage of species (from three separate catches) that had significantly different (uneven) distributions between the first, middle and last groups of subsamples removed from a hopper by a conveyor belt sorter.'Rare', 'common' and 'abundant' species were treated separately.

Catch	Number of 'rare' species in each catch	Percentage with uneven distributions	Number of 'common' species in each catch	Percentage with uneven distributions	Number of 'abundant' species in each catch	Percentage with uneven distributions
1	63	29	18	61.1	12	75
2	83	36	14	85.7	19	78.9
3	84	36	10	60	14	100

Table 9.3.4 The percentages of species that were most abundant in either the first, middle or last groups of subsamples removed from a hopper by a conveyor belt sorter. 'Rare', 'common' and 'abundant' species were treated separately. Percentages are based on those cases where a species had a significantly different distribution in any of the three catches.

Abundance category	Percentage of species most abundant in first catch group	Percentage of species most abundant in middle catch group	Percentage of species most abundant in last catch group
'rare'	56	13	31
'common'	52	10	38
'abundant'	45	16	39

The skewed distribution of many species has important implications for future monitoring of selected species in the bycatch. Observers on trawlers with hoppers may need to scan whole catches as they are being sorted in order to collect individuals from a selected list of species. Prior knowledge of the direction and degree of skewness in the distribution of selected species may lead to more efficient scanning procedures.

Subsamples of the small bycatch from trawlers using seawater hoppers should be collected before the catch falls into the hopper. For example, a small sheet of plywood (approx 1m square) could be placed on top of the hopper grid before the catch is spilled from the codend. Subsamples can be collected from the portion of the catch spilled on to the plywood, and the remainder returned to the hopper. Previous studies on NPF trawlers with conventional sorting trays have shown that the position where subsamples are taken in the spilled catch does not bias the accuracy of subsampling for most species (Section 9.2). We consider that the catch collected on the plywood tray would be equivalent to any section of a catch spilled on the conventional sorting tray of an NPF trawler. Consequently, this method of subsample collection should have the same sampling error as taking subsamples from a conventional sorting tray.

9.3.5 Conclusions

- Taking samples of the small bycatch species from the sorting conveyor belts that extract catch from hoppers is not representative of catch composition because –
  - (a) the species compositions from groups of subsamples taken at different times during the sorting process, are significantly different
  - (b) between 60 and 85.7% of 'common' species, and between 75 and 100% of 'abundant' species are unevenly distributed between groups of subsamples taken at different times during the sorting process

- Poor mixing of species in hoppers is probably due to a combination of factors including differences in buoyancy of species, changing water levels in the hoppers, and differences in the sizes of catches. Consequently, alternative sampling methods need to be employed to sample from hoppers.

- Recommendation - that subsamples of the small bycatch species be collected before catches fall through the grid above the hopper – this is equivalent to taking subsamples from any position on a conventional sorting tray and should cause no subsampling bias for most species

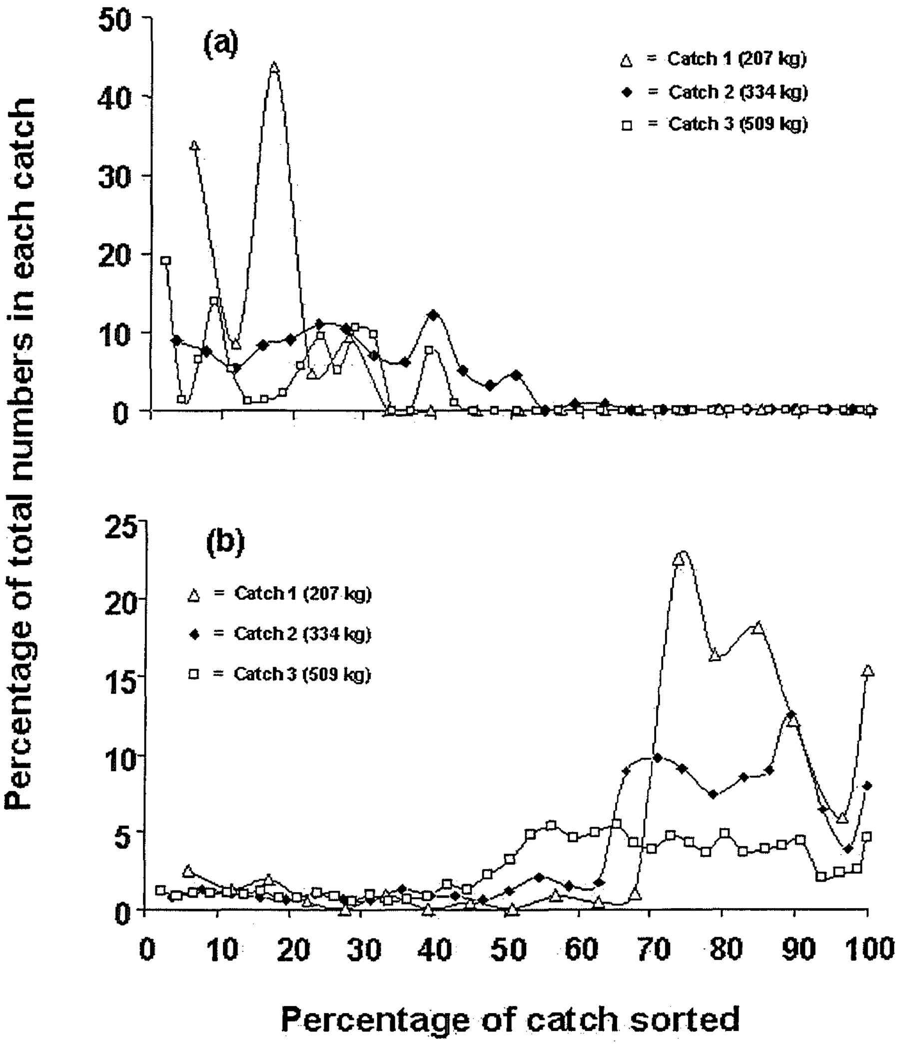


Figure 9.3.2 For (a) the saucer scallop, *Amusium pleuronectes* and (b) the pony fish, *Leiognathus moretoniensis;* the percentage of the total numbers (in each of three catches) that were recorded with increasing percentage of the catch sorted.

References

Harris, A. N., and Poiner, I. R. 1990. By-catch of the prawn fishery of Torres Strait: composition and partitioning of the discards into components that float or sink.Aus. J. Mar. Freshw. Res. 41: No 1. pp37.

SAS 1998. SAS Language, Version 7.SAS Institute Inc. Cary.

Tamsett, D., Janacek, G. and Emberton, M. 1999. A comparison of methods for onboard sampling of discards in commercial fishing. Fish. Res. 42: 127-135.

9.4 The effect of subsample size

9.4.1 Introduction

The bycatch of the Northern Prawn Fishery (NPF) is large and very diverse and descriptions of its composition rely on sampling of the catch. How well samples represent the catch depends on how diverse the catch is, how well the catch is mixed before the samples are taken and what proportion of the catch is taken as a sample.

There is a large literature on sampling theory for terrestial insect studies (e.g. Van Ark & Meiswinkel 1992), aquatic macro-invertebrate studies (e.g. Vinson 1996, Walsh 1997), and marine ecological studies (e.g. Andrew & Mapstone 1987). However, most of these studies apply to situations where samples of very small animals collected in the field can be resuspended in fluid and mixed evenly in the laboratory before the subsamples are taken. Very few studies have documented the ability of subsamples to describe the total catches in fisheries. This is especially true where large catch sizes ensure that limited opportunities exist to manipulate and redistribute the catch evenly before subsamples are taken. In spite of this, there has been a little research in some fisheries on the impact of subsampling on estimates of the abundance and different size ranges of one or a few dominant species. For example, in the *Crangon* trawl fisheries in Belgian waters, the effect of sampling strategy had only a minor effect on the reliability of estimates of size selectivity for shrimp (Polet and Redant 1999). In UK waters, taking subsamples of trawled fish (both marketable and discards) from either the sorting conveyor or the pound was found to cause no bias to catch composition estimates (Tamsett *et al.* 1999).

However, in tropical fisheries where catches are very diverse, there has been little research on subsampling techniques. In the course of the present project, we have examined the effect on sampling accuracy of taking subsamples of the small bycatch species from different positions on the trawler sorting trays (Section 9.2). No other studies have examined the accuracy of subsampling techniques in representing multi-species trawl catches.The specific objective of this section was:

- To assess the effect of taking different size samples on the accuracy of sampling

9.4.2 Methods

Data were collected from a series of 14 trawl samples taken during two research cruises of the RV *Southern Surveyor*; from one region of the Torres Straits Prawn Fishery (TSPF), and from eight of the major tiger prawn fishing regions of the NPF, (namely Weipa, 'East Mornington' , 'North Mornington' , 'West Mornington', 'North Vanderlins', South Groote', 'North Groote' and 'Melville') (see Section 6.2 for geographical descriptions of regions). All trawls were done in either late summer 1997 (Feb.-March at the end of the wet season) or in mid-spring 1997 (Sept.-October, the dry season). We used a single 14-fathom Florida-Flyer prawn trawl net to be comparable with one of the two nets used by the twin rigged commercial NPF vessels in the tiger prawn fishery. All trawls were done at night, again to be comparable with the fishery. Duration of trawls ranged from 1 to 3 h (Table 9.4.1), and depths ranged from 23 to 42.3 m.

Table 9.4.1 Summary of catch data for 20 entirely sorted trawls from the Northern Prawn Fishery and Torres Strait Prawn Fishery. (n) is the total number.

Region	Duration of trawl (h)	Start time of trawls	Catch weight (kg)	Subsamples (n)	Animals (n)	Fish species (n)	Invertebrate species (n)	All species (n)
Torres Straits	1.2	0400	94	9	4151	74	21	95
Weipa	2.7	0220	166	16	4911	92	36	128
'EastMornington'	1.0	0415	274	24	7313	90	18	108
'EastMornington'	2.9	0250	87	8	2019	77	45	122
'NorthMornington'	3.3	1845	182	16	9762	101	36	137
'NorthMornington'	3.0	2215	194	17	11015	94	42	136
'NorthMornington'	3.2	1840	445	36	13826	114	52	166
'NorthMornington'	2.0	0350	71	7	1771	60	30	90
'NorthMornington'	2.2	0330	100	10	5067	77	34	111
'WestMornington'	1.6	0415	174	16	5976	100	21	121
'West Mornington'	1.7	0400	269	26	6967	87	24	111
'NorthVanderlin'	2.7	0310	156	15	7182	71	19	90
'SouthGroote'	2.0	0345	315	27	23751	105	25	130
'SouthGroote'	2.7	0250	165	17	3856	64	25	89
'NorthGroote'	2.5	2230	147	12	5558	68	28	96
'NorthGroote'	3.0	0215	85	9	2792	60	34	94
'NorthGroote'	3.5	1830	158	13	5664	89	43	132
'NorthGroote'	3.5	2215	169	15	8289	96	63	159
'NorthGroote'	3.5	2215	189	16	5748	96	43	139
'Melville Is	3.0	0130	170	14	4635	60	30	90
TOTALS			3610	323	140253			

A further six trawl catches were sampled by an observer on board commercial NPF vessels fishing the tiger prawn regions 'North Mornington' in late May 1997, and 'North Groote' in late September 1997. Each trawl sample consisted of the entire catch from one of the two 14-fathom Florida-Flyer prawn trawl nets used by these vessels. All trawls were done at night. Duration of trawls ranged from 3 to 3.5 h (Table 9.4.1) and depths ranged from 29 to 41 m.

Sample collection

On the research vessel, catches were spilled from the codend on to the flat deck (equivalent to the sorting tray on commercial vessels). The entire catch of each trawl was progressively partitioned by shovelling the catch into consecutively numbered boxes (subsample replicates), each of approximately 10 kg (methods described in Section 9.2.2). Samples on the research vessel were sorted and identified using the methods described in Section 6.2.2.

On the commercial vessels, the catches were spilled on to the sorting tray and the commercial-sized prawns removed. The bycatch would then normally move down a trash chute and go overboard. However, to sample a catch, the trash chute was diverted so that all the bycatch was collected in consecutively numbered boxes (subsample replicates) each of approximately 10 kg. All samples collected from commercial vessels were frozen on board and transported to the laboratory for subsequent sorting, identification, and data entry using the same methods as described in Section 9.3.2.

Although most bycatch species were identified to species level, some could only be identified to genus or family. In order to be consistent in terminology throughout this Section, we use the term species (plural form) even when referring to groupings at the higher taxonomic level.

The methods used to collect subsamples on both the research and commercial vessels differed only in the position from which subsamples were taken. Studies in Section 9.2.2 showed that the majority of bycatch species were evenly distributed throughout the catch. Consequently, we combined the data from the 14 catches collected from the research vessel with the data from the six catches from commercial vessels for all analyses.

Data analysis

Abundance groupings

There was an extremely large range of species (both fish and invertebrates) that appeared on the sorting tray. These species also occurred at many different levels of relative abundance throughout the 20 catches. In order to obtain an overview of such a diverse group of bycatch species, we reduced each occurrence of a species in a catch to an index of relative abundance. We concentrated solely on determining the accuracy of different size subsamples in representing the large range of abundances (from very low to very high) that were observed in these catches.

These indices were based on the average number of individuals of a given species recorded from each standardised (std) 10 kg subsample from the catch and were calculated using the same methods as described in Section 9.2.2. Thus, for each species, we derived an index of abundance calculated separately for every catch where it was recorded. For example, a species that occurred in all 20 catches would have 20 different abundance indices in the analysis.

In order to better understand the differences in distribution between the 'rare' and the 'abundant' species when estimating catch composition, we grouped the indices of abundance into 11 categories, ranging from less than one individual per subsample, up to 10 or more individuals per subsample. Those species having abundance indices of less than one individual per std 10 kg subsample were classed as 'rare'. Species having five or more individuals per std 10 kg subsample were classed as 'abundant'. The remainder were classed as 'common'. To illustrate this point, the fish species *Leiognathus moretoniensis* was classed as 'abundant' in 11 of the 20 catches, as 'common' in eight catches and 'rare' in one catch. We examined the relative frequency of all the (species by trawl) cases in each abundance category (throughout the combined 20 catches).

In order to calculate the average number of bycatch items recorded in each 10 kg subsample, we divided the total number of bycatch items recorded in all subsamples (over all 20 catches), by the total number of subsamples (over all 20 catches). We then examined the average occurrence ratios within 10 kg subsamples for both the 'rare' and 'abundant' species (i.e. < one per 10kg subsample and five or more per 10 kg subsample).

Catch composition

In order to examine the relationship between the number of species recorded and the weight of catch sorted, the subsamples were firstly analysed in the numbered order that they were collected. The cumulative number of species (both fish and invertebrates) was plotted against the cumulative weight of catch sorted, for each of the 20 catches. Each catch was also summarised in matrix form in terms of the percentage of species recorded for each 10% increment of weight of catch sorted.

The order (position on the sorting tray) in which the subsamples were collected on both the research and commercial vessels, was just one of the many possible ways that any given catch could be divided into 10 kg subsamples. In order to determine the level of accuracy in recording the species in a catch, we examined 200 combinations of subsample selection (with no replacement), by randomly reordering the subsamples using Monte Carlo simulations for each catch. We also calculated the cumulative number and percentage of species recorded, as well as the cumulative weight and percentage of the catch sorted, for each catch. The proportion of species recorded was fitted as a power function of the proportion of the weight of catch sorted, as described by the following asymptotic equation (Snedecor and Cochran 1980):

$$\mathbf{Y = p^k} + \varepsilon$$

where **y** was the proportion of species recorded, **p** was the proportion of the weight of catch sorted, **k** was the mean exponential parameter, and ε was the random error term. The variance of ε was assumed to be $\mathbf{p\ (1\text{-}p)}\ \sigma^2$

to ensure that the variance of **y** was fixed at zero when **p** = 0 and 1. This formulation has the property such that, when none of the catch has been sorted, then no species will have been recorded. It also ensures that **y** = 1 when **p** =1, i.e. when all the catch has been sorted, all of the species have been recorded. The estimate of σ^2 was obtained from fitting the following model:

$$\mathbf{y} / \sqrt{((1-\mathbf{p})\mathbf{p})} = \mathbf{p}^{\mathbf{k}} / \sqrt{(\mathbf{p}(1-\mathbf{p}))} + \varepsilon^*$$

where $\varepsilon^* = \varepsilon / \sqrt{(\mathbf{p}(1-\mathbf{p}))}$ and ε^* has homogeneous variance structure.

Different **k** values were estimated for each catch to reflect the variation in the relationship. The mean $\mathbf{k_i}$ value for a given catch (**i** = 1-20) was obtained from 200 analyses for that catch. The predicted **y** values i.e. $\bar{\mathbf{y}}_{\mathbf{p}}$ (at **p** = 0.1, 0.2 etc to 1.0) were obtained by averaging $\mathbf{p}^{\mathbf{k_i}}$ values across the 20 catches (note that this is different to $\mathbf{p}^{\bar{\mathbf{k}}}$ where $\bar{\mathbf{k}}$ is the mean **k** value for the 20 catches). We defined the $\bar{\mathbf{y}}_{\mathbf{p}}$ values as the predicted expected proportion of species recorded after **p** proportion of catches had been sorted.

The corresponding 95% confidence interval for the predicted mean values ($\bar{\mathbf{y}}_{\mathbf{p}}$) was evaluated using the width 1.96 $\sigma_{\mathbf{m}}$ where $\sigma^2_{\mathbf{m}}$ is the variance of $\bar{\mathbf{y}}_{\mathbf{p}}$ given by:

$$\sigma^2_{\mathbf{m}} = (\mathbf{p}(1-\mathbf{p})\,\sigma^2) + (\log(\mathbf{p})\,\bar{\mathbf{y}}_{\mathbf{p}}\sigma_{\mathbf{k}})^2$$

where $\bar{\mathbf{y}}_{\mathbf{p}}$ was the predicted mean proportion, σ^2 was obtained from the mean squared residuals across 20 catches by 200 analyses, and $\sigma^2_{\mathbf{k}}$ was the estimated variance of **k** across 20 catches by 200 analyses. All **p** and y values are presented as percentages in results.

Abundance estimates

The sampling error of different subsample sizes, in estimating the total number of a given species in a catch was determined by using a running mean (of the estimate of abundance) following the equation:

$$\mathbf{s} = \left|\mathbf{100\,(n/p-N)\,/\,N}\right| \qquad \textbf{(Equation 1)}$$

where **s** was the absolute percentage of sampling error, **n** was the observed number of that species after **p** proportion of the catch had been sorted, **N** was the total number of individuals of that species in the whole catch. The values for **s** were truncated at 100 for ease of presenting results.

We used the following statistical model in which **s** is subtracted from **1** in order to correspond to the equation used for species composition:

$$\mathbf{1 - s = p^k} + \varepsilon$$

where $\mathbf{1 - s}$ is fixed at $\mathbf{1}$ when $\mathbf{p = 1}$, and the var(ε) = $\mathbf{(1-p)}\ \sigma_i^2$ to ensure that there is no sampling error when the entire catch has been sorted.

In order to obtain estimates of σ_i^2, we fitted the following model

$$\mathbf{(1 - s) / \sqrt{(1 - p)} = p^k / \sqrt{(1 - p)}} + \varepsilon / \mathbf{\sqrt{(1 - p)}}$$

The variance of a predicted $\mathbf{(1 - s)}$ was given by an equation similar to equation (1) (for species composition) being:

$$\sigma^2_{\mathbf{m}} = \mathbf{(1 - p)}\ \sigma^2 + \mathbf{(log(p)\ (1 - s)}\ \sigma^2_{\mathbf{k}})$$

so that the error term ε has a homogeneous variance structure.

In order to examine the accuracy in recording the abundance of all the species in a catch, we modelled the order (200 times) in which subsamples were taken (as described above for catch composition estimates). For each (species by trawl) case, i.e. where a species was recorded at a given level of abundance, we calculated the sampling error **s** for ranges of **p** from 0.1 to 0.9. We grouped all the (species by trawl) cases of different levels of abundance into eight categories for these analyses.

The SAS procedure NLIN was used to fit the power curve for catch composition, as well as the separate power curves for sampling error for the different abundance classes (SAS 1998)

9.4.3 Results

General Results

Catches ranged in size from 71 to 445 kg and had an average of 117 species per trawl, comprising 84 fish species and 33 invertebrate species. A total of 140,253 fish and invertebrates were recorded from 323 subsamples taken from the 20 prawn trawl catches that were sorted entirely (Table 9.4.1). On average, each subsample weighed 11.2 kg and contained 434 individuals (or 389 individual items of bycatch per standardised (std) 10 kg subsample). We identified a total of 276 fish and 141 invertebrate species.

A total of 69.3% (1617 out of 2333), of the (species by trawl) cases of abundance occurred at less than one individual per std 10 kg subsample and were classed as 'rare' (Figure 9.4.1). Only 11.7% of species (274 cases out of 2333) had an average of five or more individuals per std 10 kg subsample and were classed as 'abundant' (Figure 9.4.1). The remaining 442 (species by trawl) cases of abundance were classed as 'common'.

Catch composition.
The number of species recorded increased as the weight of sorted catch increased for 19 of the 20 catches. This relationship appeared to approach an asymptote in the remaining large catch of 445 kg (Figure 9.4.2a, b).

After 10% of all 20 catches were sorted, the cumulative percentage of the species recorded ranged from 31% (in the 315 kg catch) to 78% (in the182 kg catch) (Table 9.4.2). In order to detect 80% of the species present in a single catch, the proportion of the catch that needed to be sorted, varied from 20% to 70%.

Simulation modelling showed that sorting 10% of catch weight detects (on average) 50% of the species present, with the confidence interval ranging from 44 to 57% (Figure 9.4.3). Sorting 50% of the catch was necessary to detect 80% of the species present.

Abundance estimates
The simulation modelling showed that the mean sampling error curves (for the eight abundance categories) decreased as increasing percentages of the catch were sorted (Figure 9.4.4). After 10% of the weight of catches were sorted, only two abundance categories ($10 \leq$ number per subsample < 50, and ≥ 50 per subsample), had mean sampling error rates below 25%.

For the 'rare' species (less than 1 per subsample), the gradient of the mean sampling error curve is close to constant (Figure 9.4.5). The 95% upper confidence interval is over 100% until more than 40% of the catches were sorted. Even when 90% of the catches had been sorted, the mean sampling error was just below 10%, and the 95% upper confidence interval remained above 25%.

For the 'abundant' species (five or more per subsample), the mean sampling error curve started just below 25% after 10% of catches were sorted, and fell below 10% soon after 40% of the catches had been sorted (Figure 9.4.6). The 95% confidence interval did not fall below 25% until 50% of catches had been sorted.

9.4.4 Discussion

This study has shown that a large subsample is required to accurately represent the species composition of a large multi-species catch. As more of the catch is sorted, more new species are encountered. On average, 50% of the catch weight needs to be sorted to record 80% of the species in a single catch. Our data suggest that taking subsamples between 10 and 30% of catch weight can result in highly variable percentages (from 31 to 88%) of the total species in the catch. When estimating abundance of individual species within a catch, subsampling small percentages of catch weight (around 10%) causes sampling error around 25% for the 'abundant' species.

It is important to note, when estimating the abundance of a species within a catch, that the sampling error is a function of the total number of individuals of all the species caught in that trawl. It is not related to the number of that species caught in the trawl, or even the number caught per hectare swept by the trawl. For example, 10 individuals of species 'X' may occur in one trawl, at a ratio of 1 in every 100 items of bycatch.

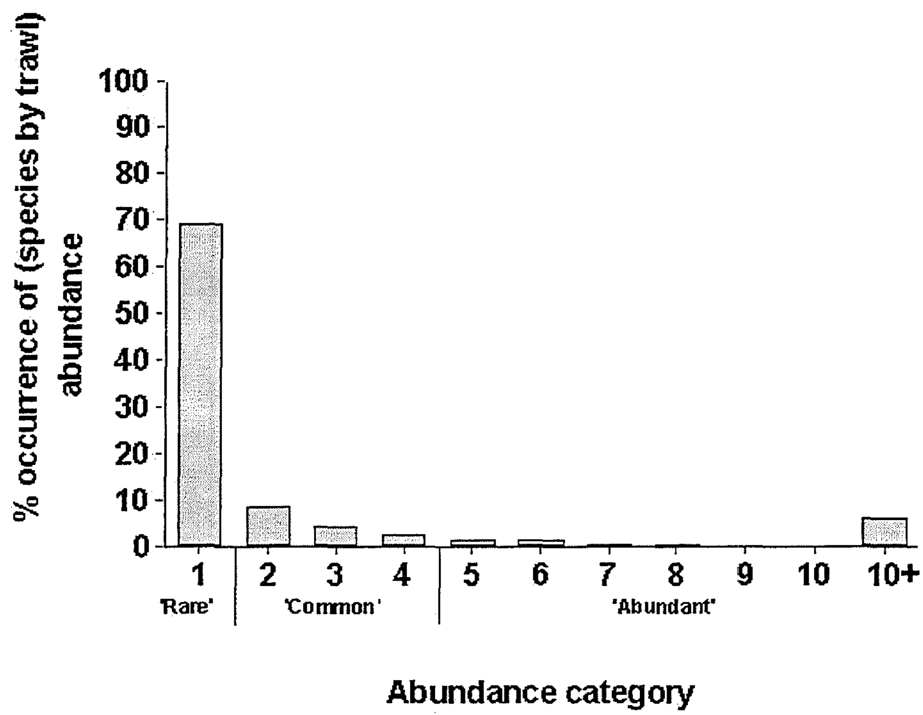


Figure 9.4.1 The percentage of occurrence of 2333 cases of (species by trawl) abundance for bycatch species recorded from 20 trawl catches. The cases are grouped into 11 categories of abundance indices based on the average number of a species recorded per 10 kg subsample of catch.

In the very next trawl, the 10 individuals of species 'X' may only occur at a ratio of 1 in every 1000 items of bycatch because other 'abundant' species have swamped its occurrence ratio. And the sampling error for the same number of individuals of species 'X' varies greatly between trawls.

There are two sources of within-trawl variation when calculating catch rates for individual species. The first is due to changes in catchability at the trawl-species interface (either on sea floor or in water column). The second is due to on-deck subsampling techniques. This study is important because it allocates percentages of sampling error based on the occurrence rate of a species of interest within individual catches.

In order to do this, we have calculated the average occurrence ratios for the different categories of abundance used in this study. 'Rare' species occurred at a rate of less than one individual in every 389 bycatch items. 'Abundant' species occurred at a rate of one or more individuals in every 89 bycatch items. We are now in a position to use these ratios for species recorded in other trawl catches and apply an average sampling error for individual trawls for the species of interest.

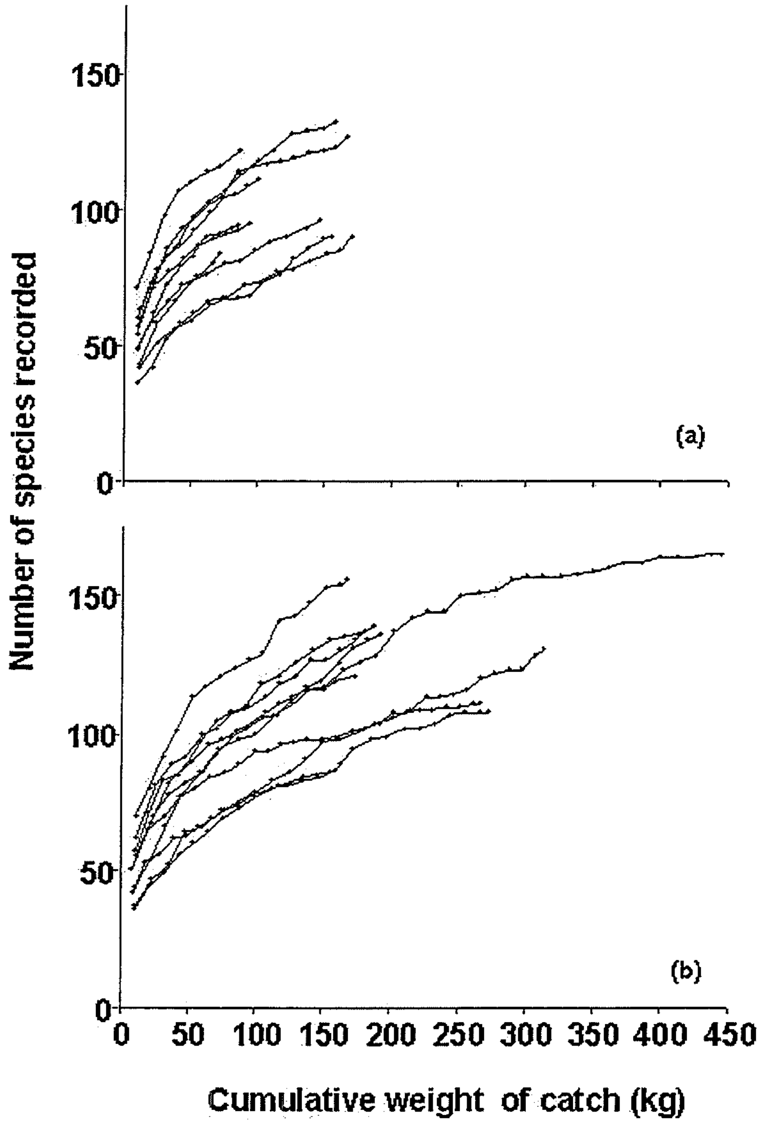


Figure 9.4.2 The cumulative numbers of bycatch species recorded with increasing weight of catch analysed for (a) the 10 smallest and (b) the 10 largest catches that were entirely sorted

Table 9.4.2 The cumulative percentage of species recorded as increasing catch weight is sorted (10% increments). Percentages are calculated separately for 20 trawl catches that were entirely sorted. The demarcation line denotes where 80% or more of the species in catches have been recorded.

Region	Catch weight (kg)	Number of species	Percentage of species recorded (10% weight increments)								
			10%	20%	30%	40%	50%	60%	70%	80%	90%
'North Mornington'	71	90	51	62	70	76	81	86	90	94	97
'North Groote'	85	94	49	60	69	75	81	85	89	93	97
'East Mornington'	87	122	56	66	74	79	84	88	91	95	97
'Torres Straits'	94	95	60	70	76	81	86	89	92	95	98
'North Mornington'	100	111	56	66	74	79	84	88	91	95	97
'North Groote'	147	96	50	61	69	76	81	86	90	93	97
'East Vanderlin'	156	90	39	52	61	69	75	81	86	91	96
'North Groote'	158	132	65	74	80	84	88	91	94	96	98
'South Groote'	165	89	51	63	71	77	82	86	90	94	97
'Weipa'	166	128	54	65	73	78	83	87	91	94	97
'North Groote'	169	159	57	68	75	80	85	88	92	95	98
'Melville'	170	90	46	58	67	73	79	84	89	93	97
'West Mornington'	174	121	52	63	71	77	82	86	90	94	97
'North Mornington'	182	137	78	84	88	91	93	95	96	98	99
'North Groote'	189	139	61	71	77	82	86	90	93	95	98
'North Mornington'	194	136	67	76	81	85	89	92	94	96	98
'West Mornington'	269	111	52	63	70	77	82	86	90	94	97
'East Mornington'	274	108	40	53	62	69	76	82	87	92	96
'SouthGroote'	315	130	31	44	54	63	70	77	84	89	95
'NorthMornington'	445	166	61	71	77	82	86	90	93	95	98

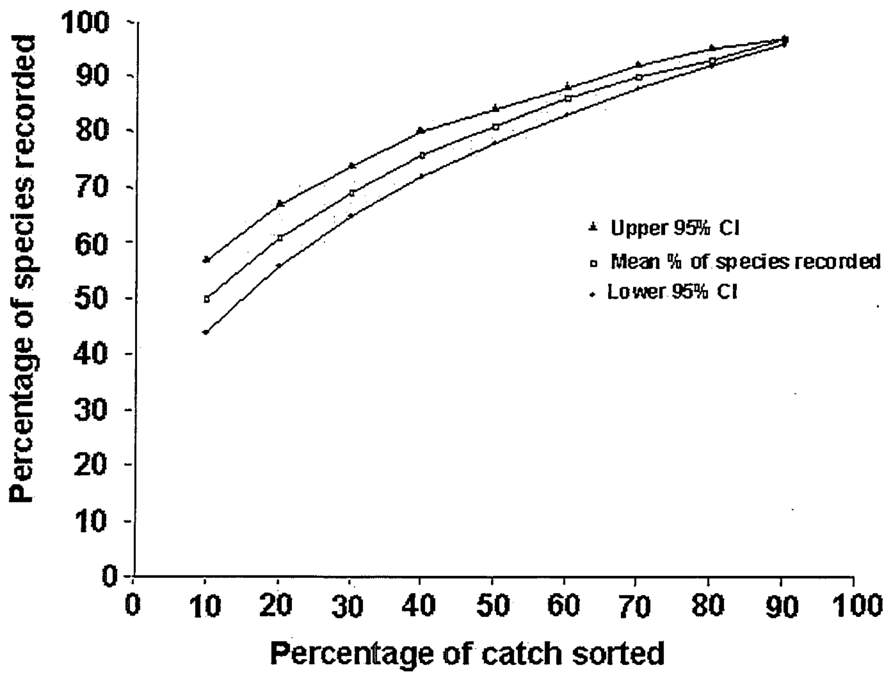


Figure 9.4.3 The mean percentage (and 95% CI) of species recorded as increasing percentages of catch weight were sorted. Curves were generated from 200 random selections of the numbered order in which subsamples were collected within each catch.

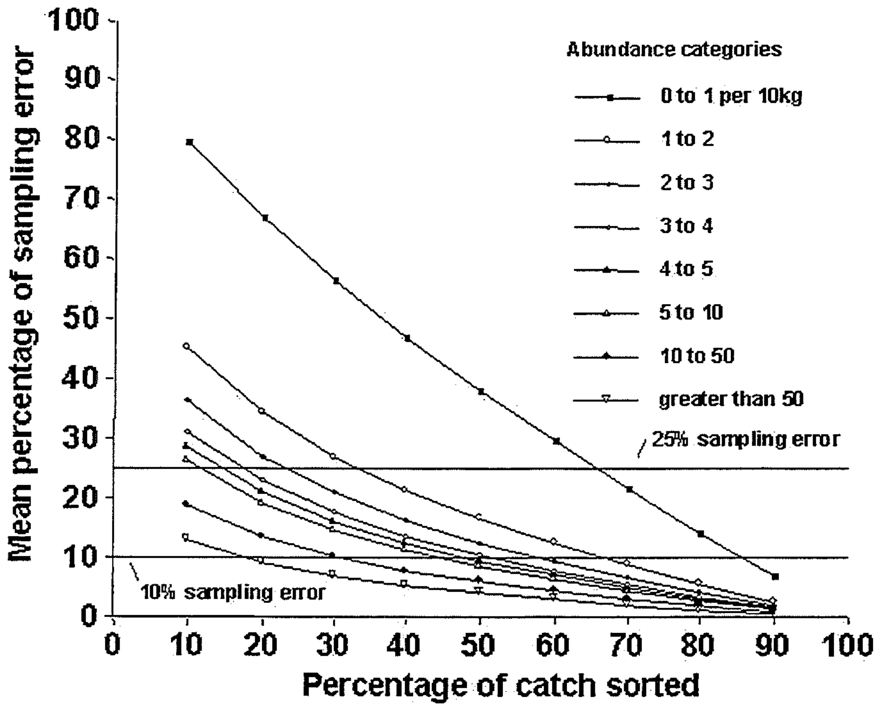


Figure 9.4.4 The mean percentage of sampling error calculated when estimating the abundance of bycatch species grouped into eight categories of abundance indices. Curves were generated from 200 random selections of the numbered order in which subsamples were collected within each catch.

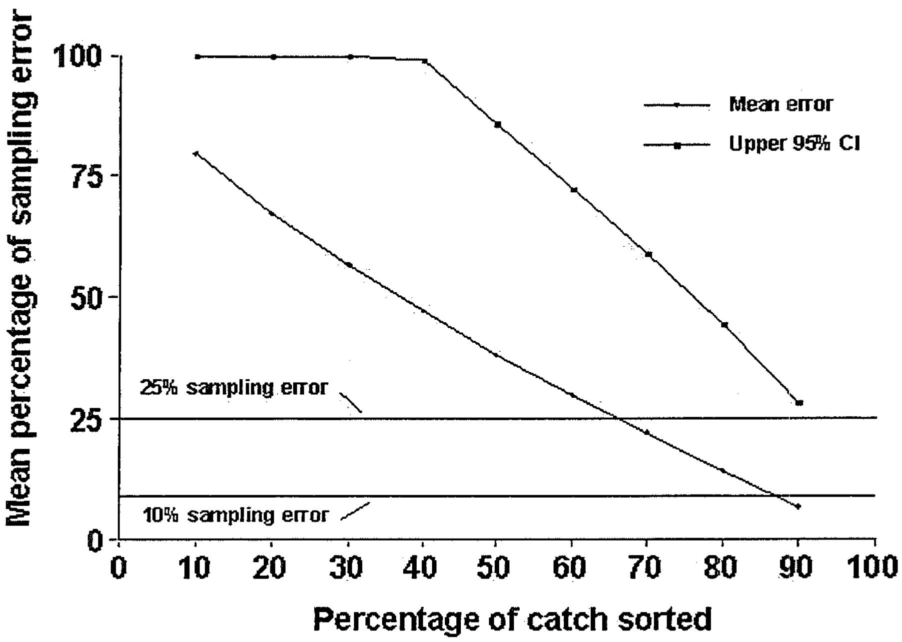


Figure 9.4.5 The mean percentage of sampling error calculated when estimating the abundance of 'rare' bycatch species (< 1 individual per10 kg subsample). Curves were generated from 200 random selections of the numbered order in which subsamples were collected within each catch.

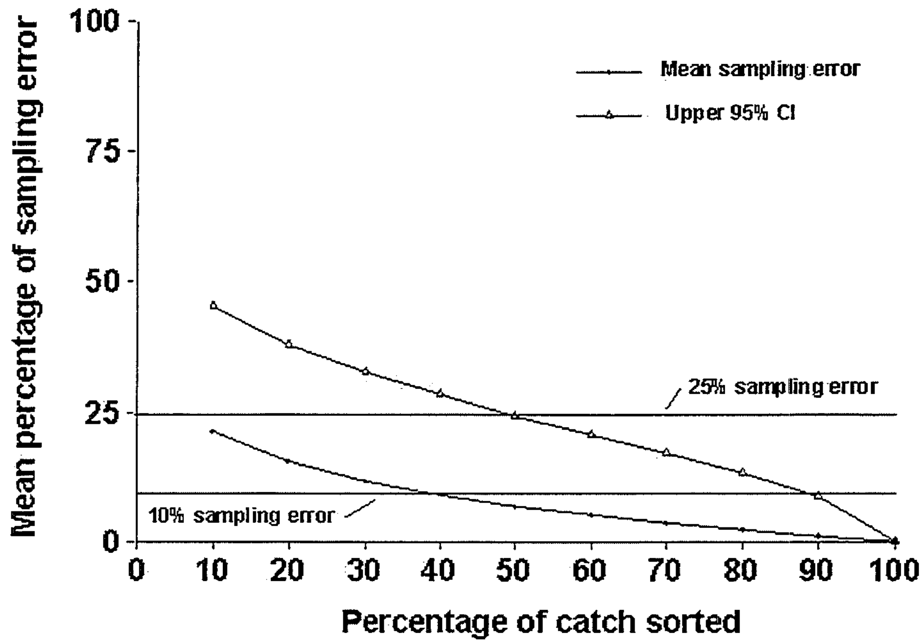


Figure 9.4.6. The mean percentage of sampling error calculated when estimating the abundance of 'abundant' bycatch species (> 5 individuals per 10 kg subsample).Curves were generated from 200 random selections of the numbered order in which subsamples were collected within each catch.

The range of data in this study include many of the sources of variation likely to be encountered if setting up a wide ranging bycatch monitoring program, and the results we present are a valuable guide to the accuracy of subsampling. In particular, this study emphasises the value of collecting large subsamples when you are restricted to representing the bycatch of an area by only one or a few trawls. This situation commonly arises on research cruises when many regions need to be sampled in a short time frame (e.g. Blaber *et al.* 1994), and similarly for observers on commercial fishing vessels that are restricted by the nature of commercial practice. Because there is a high level of sampling error when estimating the abundances for 'rare' species, reliable estimates will require either taking large subsamples, or sorting entire catches.

The size of the catches in this study may be larger than many other tropical prawn trawl fisheries in Australia and overseas. However, the range of cumulative species (per proportion of catch sorted) data in the matrix (Table 9.4.2) will allow managers of other trawl fisheries as well as the NPF to better understand the implications and likely accuracy of bycatch subsampling programs.

9.4.5 Conclusions

- About 70% of NPF bycatch species are 'rare', occurring in catches at less than one individual per 10 kg subsample, or less than one individual in every 389 items of bycatch.
- About 12% of NPF bycatch species are 'abundant', occurring in catches at five or more individuals per 10 kg subsample, or one or more individuals in every 89 items of bycatch.
- When sampling around 10% (by weight) of a single catch, only 50% of the species in the catch will be recorded, on average.
- When sampling around 10% (by weight) of a single catch, the sampling error in estimating abundance will be about 80% for the 'rare' species, on average.
- When sampling around 10% (by weight) of a single catch, the sampling error in estimating abundance will be around 25% for the 'abundant' species, on average.
- When taking subsamples of the small NPF bycatch species, a minimum of 10% of catch weight should be taken as a sample.

References

Andrew, N.L., Mapstone, B.D. 1987. Sampling and the description of spatial pattern in marine ecology. Oceanog. Mar. Biol. Ann. Rev., 25, 39-90.

Blaber, S.J.M., Brewer, D.T., Harris, A.N. 1994. Distribution, biomass and community structure of demersal fishes of the Gulf of Carpentaria, Australia. Aust. J. Mar. Freshwat. Res. 45, 375-396.

Polet, H., Redant, F. 1999. Effect of population structure, sampling strategy and sample size on the estimates of selection parameters for shrimp (*Crangon crangon*) trawls. Fish. Res. 40, 213-225.

SAS 1998. SAS Language, Version 7.SAS Institute Inc. Cary.

Snedecor, G. W., Cochran, W. G. 1980. Statistical Methods (7th ed.). The Iowa State University Press, Ames, Iowa.

Tamsett, D., Janacek, G. and Emberton, M. 1999. A comparison of methods for onboard sampling of discards in commercial fishing. Fish. Res. 42: 127-135.

Van Ark, H., Meiswinkel, R. 1992. Subsampling of large light trap catches of *Culcoides* (Diptera: Ceratopogonidae). Onderstepoort J. Vet. Res. 59, 183-189.

Vinson, M.R. 1996. Effects of sampling area and subsampling procedure on comparisons of taxa richness among streams. J. N. Am. Benthol. Soc.15(3), 392-399.

Walsh, C.J. 1997. A multivariate method for determining optimal subsample size in the analysis of macroinvertebrate samples. Mar. Freshw. Res. 48, 241-248.

9.5 The effect of sampling scale

9.5.1 Introduction

The Northern Prawn Fishery Bycatch Action Plan states that an effective monitoring program should be in place by the year 2001. However, planning and establishing such a program requires detailed information about monitoring methodology such as the level of sampling effort needed to detect changes in bycatch populations. A fisheries-dependent method may be used to monitor bycatch of the Northern Prawn Fishery (NPF) (Section 9.7), either independently or with scientific observers on board. The following section describes how we calculated the future level of (fisheries-dependent) sampling effort required to detect changes in populations of the small bycatch taxa (i.e. those small enough to be sampled using the standard 10 kg waxed fish carton).

Trawl surveys are conducted annually in many countries to provide abundance estimates for target species. For example, in Canada and the United States, fisheries-independent surveys, mostly using stratified random designs, provide information on groundfish abundance for use in stock assessments of target species (see Azarovitz 1981; Halliday and Koeller 1981; Pitt *et al.*1981). However, there are few studies that examine the statistical power and precision of fisheries-dependent trawl surveys when estimating catch rates for non-targeted bycatch taxa, and in particular, studies relevant to the bycatch taxa of a large and diverse tropical fishery.

Before designing a monitoring program, a pilot study that examines the precision in estimating catch rates was carried out to ensure that the sampling design (particularly the level of effort) has sufficient statistical power to detect biologically significant inter-annual changes (Section 9.7).

The level of effort required for precise monitoring will depend on the effect size to be detected, as well as between-trawl variability of sampling for individual taxa.The effect size will depend on inter-annual variation in the population size of individual taxa. However, little is known about population dynamics of most NPF bycatch taxa, and the inter-annual range in population sizes (of taxa of interest) are potentially large. Consequently, effect sizes also need to be equally wide ranging. What may be a significant biological effect size in one taxon may be well within the range of inter-annual variation in population size for another. For example, it may be a waste of scarce economic resources to try to detect a 25% decline in catch rates from a baseline survey level, for taxa that typically exhibit 'boom or bust' dynamics such as some Clupeidea taxa.

Catchability of a taxon by the trawl *(q)*, may also vary between annual surveys due to changes in abiotic variables (temperature, salinity and current), or biotic variables such as density-dependent effects (see Godo *et al.* 1999), causing further error in detecting certain effect sizes.

In order to calculate the effect size detectable by each of the two regional surveys, we have assumed each survey to be the 'baseline' trawl survey for that region. From a future monitoring perspective, a baseline survey followed by similar size (both spatially and temporally) yearly surveys will have to be conducted in selected regions in order to detect biologically significant changes in catch rates of individual taxon. Our calculations of the level of sampling effort required, are based on the variability of sampling individual taxon from each region.

Before deciding on a method and sampling design for monitoring the small NPF bycatch species, the fishery manager needs to know what level of effort is required in order to detect specific levels of change in bycatch populations in subsequent annual surveys. In order to examine what size trawl survey is needed to detect changes in catch rates for the small NPF bycatch taxa, we examined two trawl survey data sets collected by an observer on commercial trawlers.The specific objective of this section was:

- To estimate the fishery-dependent sampling effort required to detect changes in populations of bycatch species and implications for monitoring

9.5.2 Methods

Field sampling

A CSIRO observer collected two subsamples (approx 10kg each) of bycatch from each of 52 trawls from a twin-rigged commercial trawler working in the Northern Prawn Fishery (NPF) in the 'North Mornington' region between the 25th May and 14th June 1997 (see Section 9.4.2 for detailed methods). A further 43 trawls were subsampled (in the same manner) from a second commercial trawler working 'North Groote' between the 22nd September and the 7th October 1997 (see Section 9.3.2 for processing of subsamples procedure).

Both trawlers mostly completed four trawls each night during both sampling periods, with trawl duration ranging from 2 to 3.75 h. The first trawl of the night usually included ½ h of twilight and the last trawl of the night included up to 2h of dawn or full daylight. Little is known about diel changes in catchability for almost all of the many bycatch species across the night-day transition. However, from a monitoring perspective, the commercial fleet does trawl during the transition period when significant quantities of bycatch are taken so we have included all trawls in the analysis.

The approximate areas of the region trawled were 2096 km^2 at 'North Mornington' and 1948 km^2 at 'North Groote' (Figure 9.5.1a, b). The distribution of trawl sites at 'North Mornington' was fairly random given the commercial nature of the survey. The distribution of trawl sites at 'North Groote' was heavily biased towards the north-east corner of the grid trawled where 30 (69.8%) out of the 43 trawls were contained in one small square of approx 99.5 km^2 (Figure 9.5.1b).

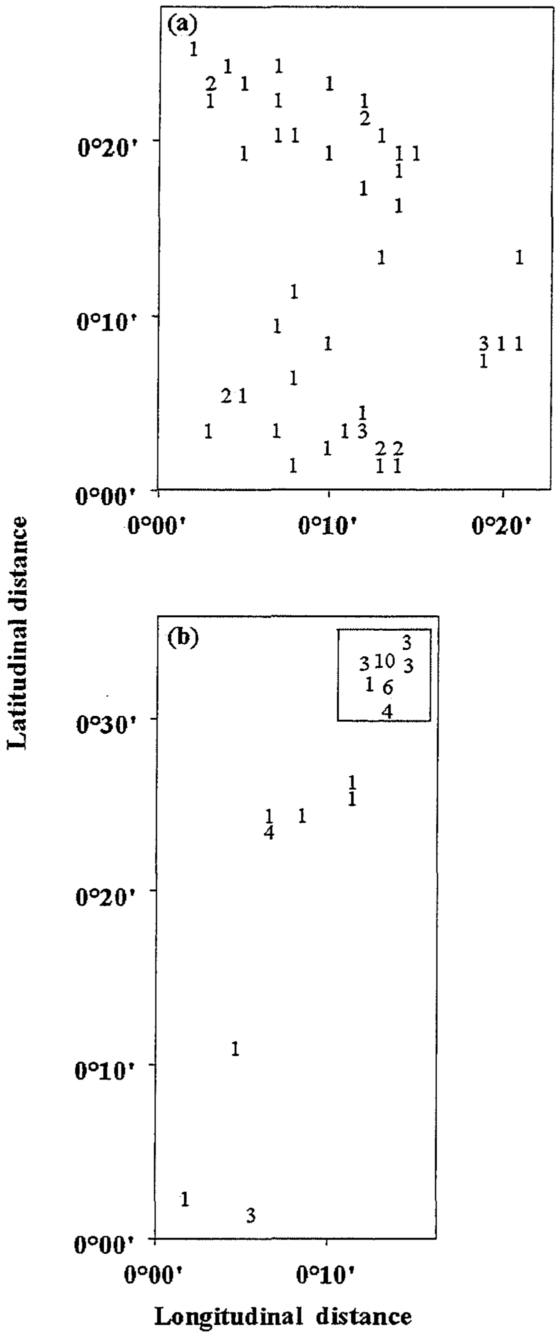


Figure 9.5.1 Distribution of the trawl survey sites for two NPF regions (a) 'North Mornington', (b) 'North Groote' used in analyses to estimate the effort required to detect declines in catch rates for bycatch taxa. The number of trawls sampled at each site is indicated on the map.

Estimating sampling effort

In order to examine how well different numbers of observer survey trawls represented the taxa of the respective regions, we plotted the species-area curves as the cumulative number of species recorded as increasing numbers of trawls were subsampled in the order in which they were collected.

Using catch rates (CPUE) of bycatch taxa to monitor inter-annual changes in bycatch populations assumes that they are indices proportional to the true abundance of individual taxa in the environment. This implies that the catchability of individual taxa by the trawl net (q) does not vary both within (between-trawl variability) or among annual surveys (among survey variability). However, catchability probably will vary at both levels of analysis.

The two sources of between-trawl variability in catch rates are differences in species-catchability between trawls, and differences due to the subsampling techniques on-deck. Catchability may vary greatly between trawls due to changes in both biotic (e.g. diel and lunar cycles, feeding, reproductive, schooling and avoidance of predator behaviour), and abiotic factors (trawl speed, net sizes, weather conditions etc).On-deck subsampling techniques will introduce sampling errors mostly caused by taking too small a subsample from a catch (see Sections 9.2, 9.3, 9.4). Both catchability changes and differences in on-deck subsampling techniques will be reflected in the variability of sampling individual taxa within a region.

We use three levels of effect size (in mean catch rates) to be detected, namely declines of 50%, 75% and 99.9% in the mean catch rate for individual taxa in the baseline survey. The range of these effect sizes would indicate that catch rates have declined to around 3% of the baseline level after five years (for a 50% decline); to around 2% of the baseline level after three years (75% decline); or to 0.1% of the baseline level after one year (99.9% decline), provided the same rate of decline (from the baseline level) continued each year. Using a constant rate of decline may be an overly conservative model of how stocks of individual bycatch species react to declines of these magnitudes (50, 75 or 99.9%). However, little is known about year to year variation in bycatch populations from the NPF and only future monitoring surveys will provide this information.

Net catch data and particularly bottom trawl catch data are commonly skewed, usually dominated by many catches with zeroes and a few catches with low occurrences of a given taxon. Such skewed data are better described by the application of the negative binomial or the Poisson distributions rather than the normal distribution (Cyr *et al.* 1992, Power and Moser 1999). After preliminary examination of the counts of individuals per trawl data, we assumed that catch rate estimates for each taxon fell into either of two distributions. Those taxa recorded with variance less than their mean catch rate were analysed using a Poisson distribution and taxa with variance greater than their mean catch rate were analysed using the negative binomial distribution. We estimated the parameters of either the Poisson or negative binomial distributions in order to calculate sample size necessary to allow us to detect changes at the three levels (50, 75 and 99.9%).

Both the Poisson and the negative binomial distributions have properties such that the mean and variance are related. This has implications for *a priori* and *a posteriori* estimates of effort required to detect given effect sizes. One consequence is that fewer trawls are needed to *a priori* detect only a downward change, than for an upward change. For the purpose of these analyses, we have only calculated the number of trawls required to *a priori* detect the changes in a downward direction (i.e. declines).

In order to determine the sample size required to detect the given levels of decline for each taxon in each region, we used the following equation (Snedecor & Cochran 1989):

$$N = ((Z_1 + Z_2)^2 * (S_1^2 + S_2^2)) / \delta^2 \qquad \textbf{(Model 9.5.1)}$$

where **N** was the number of trawls required to detect a given level of decline, Z_1 was the normal deviate for the significance level of decline to be detected, Z_2 was the normal deviate for the power of detecting a decline, $S_1^2 = \bar{X}$ for the Poisson distribution, or $S_1^2 = \bar{X} + h\bar{X}^2$ for the negative binomial distribution; $S_2^2 = p\bar{X}$ for the Poisson distribution, or $S_2^2 = p\bar{X} + hp^2\bar{X}^2$ for the negative binomial distribution, where **p** was the proportion of the baseline mean catch rate that gives the mean for the subsequent year (e.g. 0.5, 0.25 or 0.001, corresponding to declines of 50, 75 and 99.9% of the mean, the latter being as close to a decline of 100% as we could estimate). The term δ was the decline in mean to be detected, with $\delta = (1-p) * \bar{X}$, where $\bar{X}$ was the mean baseline survey catch rate for a taxa. We estimated **h**, a dispersion parameter, using the equations for the mean and variance, and these calculations were programmed in the SAS language (1993).

We have chosen the significance level to be 0.05 and the power to be 0.9 which gives $(Z_1 + Z_2)^2$ a value of 10.5. Cyr *et al.* (1992) have considered estimating sample sizes for negative binomial populations in a similar manner to the above, but used *t*-statistics instead of the normal deviates used in the Model 9.5.1, but this was not used because it required an iterative procedure.

Species catch rates

In order to calculate the total number of each taxa occurring in the whole catch on a per hectare basis, we used the following equation:

$$\bar{A} = \bar{M} * \bar{F}$$

where $\bar{A}$ was the estimated mean catch rate (no.ha^{-1}) for a taxa over all catches in the region, $\bar{M}$ is the mean number per trawl, and $\bar{F}$ is the factor that converts this number per trawl to number per hectare. The details of $\bar{M}$ and $\bar{F}$ are as follows: $\bar{M} = \Sigma M_i / n$ and $\bar{F} = \Sigma F_i / n$, ie average catch and scaling factors on a per trawl basis. The scaling factor for the $_i$ th trawl, F_i, are given by:

$$F_i = Q_i / (W_i * D_i * 10.135)$$

$\mathbf{M_i}$ was the catch rate (per two subsamples) for a taxa in the **i** th individual catch; $\mathbf{F_i}$ was the scaling factor for the $_i$ th individual catch; $\mathbf{Q_i}$ was total weight (kg) of subsamples sorted in the $_i$ th individual catch, $\mathbf{W_i}$ was the total weight (kg) of the $_i$ th individual catch, $\mathbf{D_i}$ was the duration (h) of the $_i$ th individual catch, and **10.135** was the area scaling factor. The area scaling factor was based on the area swept by one 14 fathom headrope length trawl in one hour of trawling (based on a spread ratio of 0.6 of headrope length and an average trawl speed of 3.2 knots).

Thus $\overline{\mathbf{A}}$, the estimated mean catch rate (no.ha^{-1}) for a taxon over all catches in the region was computed as the product of $\overline{\mathbf{M}}$, the mean catch rate per two subsamples (2 * 10kg approx) over all catches, and $\overline{\mathbf{F}}$, the mean scaling factor (over all catches) used to convert numbers per two subsamples to numbers per hectare.

In order to examine the distribution of taxa (caught in the observer surveys) throughout each region, we separated taxa based on catch rates (no.ha^{-1}), into five categories on a log scale. The categories were 'very rare' (0.001 ha^{-1} to 0.01 ha^{-1}), 'rare' (0.01 ha^{-1} to 0.1 ha^{-1}), 'common' (0.1 ha^{-1} to 1 ha^{-1}), 'abundant' (1 ha^{-1} to 10 ha^{-1}), 'very abundant' (>10 ha^{-1}). We examined the relative proportions of taxa recorded in each region and plot the frequency histograms.

For each observer trawl survey, we calculated the numbers and percentage of taxa in each region, for which we could detect the three levels of decline in mean catch rates. Furthermore, for every taxon recorded in both regions, we present (as an Appendix 3B and 3C) the number of trawls required to detect the three levels of decline for that taxon in that region. Where we refer to the number of trawls required (for a given region), the duration of these trawls is standardised to the mean duration and net size of the observer survey trawls completed in that region. We have further summarised these results by presenting the mean number of trawls required to detect the three levels of decline for taxa in each of five categories of catch rates ('very rare' to 'very abundant').

9.5.3 Results

In the 'North Mornington' region, a total of 1562.75 ha were swept during 154.12 h of trawling in the 52 survey trawls (Table 9.5.1). The total weight of bycatch taken by the sampled net was 17711 kg, for an average weight of 340.6 ± 18.5 kg per average trawl duration of 2.96 h. The total weight of bycatch subsampled was 1197.6 kg and on average, we subsampled 8.3 ± 0.67% of each catch weight (Table 9.5.2).

In the 'North Groote' region, a total of 1388.4 ha were swept during 137 h of trawling in the 43 survey trawls (Table 9.5.1). The total weight of bycatch taken by the sampled net, was 7395 kg for an average weight of 172 ± 15.4 kg per average trawl duration of 3.19 h. The total weight of bycatch subsampled was 1043.7 kg and on average, we subsampled 19.4± 1.8% of each catch weight. (Table 9.5.2).

Table 9.5.1 The start time, number of trawls, number of hours trawled, mean duration of trawls and the total area swept used in analyses to estimate the number of trawls required to detect declines in catch rates of bycatch taxa in two regions of the Northern Prawn Fishery, (a) 'North Mornington' and (b) 'North Groote'.

(a)

Start time (approx)	No of trawls	Total hours trawling	Mean duration (h) (± 1 se)	Swept area (hectares)
1845	16	52.15	3.26 ± 0.03	529.3
2215	15	45.25	3.02 ± 0.02	458.6
0130	13	38.55	2.97 ± 0.06	390.7
0445	8	18.17	2.27 ± 0.04	184.15
Totals	52	154.12		1562.75

(b)

1840	14	48.9	3.48 ± 0.02	496
2215	14	48.3	3.45 ± 0.04	489.5
0200	2	7.5	3.75 ± 0	76.0
0600	13	32.3	2.48 ± 0.02	326.9
Totals	43	137.0		1388.4

A total of 266 taxa (combined teleosts and invertebrates) were recorded in all subsamples in the 'North Mornington' region and 296 taxa at the 'North Groote' region (Figure 9.5.2). The total number of taxa recorded at each region continued to increase with increasing numbers of trawls and did not reach an asymptote even after around a tonne of bycatch was processed in each region. The rate of increase was higher for the 'North Mornington' region.

Around 56% of taxa at 'North Mornington' region and 68% of taxa at 'North Groote' region were recorded at catch rates of one or fewer individuals per 10 hectares (Figure 9.5.3a, b, 'rare' and 'very rare' categories). Only 19% of taxa at 'North Mornington' region and 12% of taxa at 'North Groote' region had catch rates of one or more individuals per hectare (Figure 9.5.3a, b, 'abundant' and 'very abundant' categories).

Table 9.5.2 Summary of trawl survey data for 'North Mornington' (52 trawls) and 'North Groote' (43 trawls) showing mean trawl duration, total weight of bycatch caught, mean weight of bycatch per trawl, total weight of subsamples, and percentage of total bycatch that was subsampled.

Region	Mean duration (h) of trawls (± se)	Total weight (kg) bycatch (one net only)	Mean weight (kg) bycatch per trawl (± se) (one net only)	Total weight (kg) of subsamples (one net only)	Percentage of total bycatch subsampled (± se)
'North Mornington'	2.96 ± 0.0	17711	340.6 ± 18.5	1197.6	8.3 ± 0.7
'North Groote'	3.19 ± 0.0	7395	172.0 ± 15.4	1043.7	19.4 ± 1.8

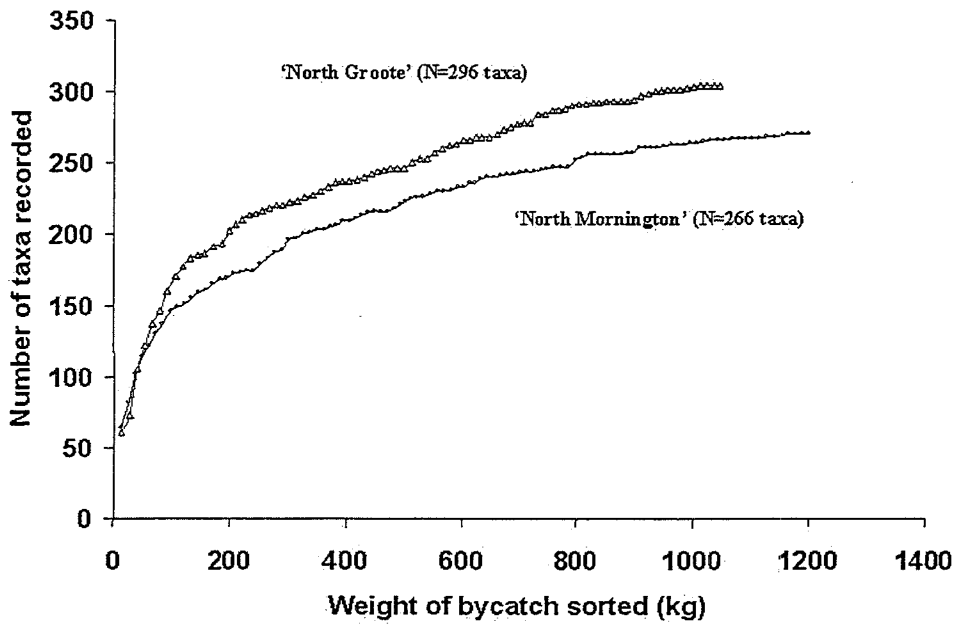


Figure 9.5.2 Species-area curves generated from observer trawl surveys in two NPF regions, 'North Mornington' (8.3% of catch weight subsampled from 52 trawls) and 'North Groote' (19.4% subsampled from 43 trawls).

Power of observer surveys to detect changes

Based on the variability of subsampling bycatch taxa from the 52 trawls at 'North Mornington' (at 8.3% of catch weight), we would be able to detect a 50% decline in catch rates (from baseline survey levels), for only 27 of the 266 taxa (10.1%), a 75% decline for 62 taxa (23%) and a 99.9% decline for 95 taxa (35.6%) (Table 9.5.3).

Based on the variability of subsampling bycatch taxa from the 43 trawls at 'North Groote' (at 19.4% of catch weight), we would be able to detect a 50% decline in catch rates (from baseline survey levels) for 16 of the 296 taxa (5.4%), a 75% decline for 56 taxa (18.9%) and a 99.9% decline for 84 taxa (28.4%) (Table 9.5.3).

Effort needed for a future baseline survey

For the 'North Mornington' region, the number of trawls required to detect changes ranged from 8 to 3276 for the 50% level, from 3 to 1213 trawls (for the 75% level) and from 2 to 548 trawls (for the 99.9% level) (Appendix 3B).

For the 'North Groote' region, the number of trawls required to detect changes ranged from 12 to 2709 for the 50% level, from 5 to 1003 trawls (75% level) and from 2 to 453 trawls (99.9% level) (Appendix 3C).

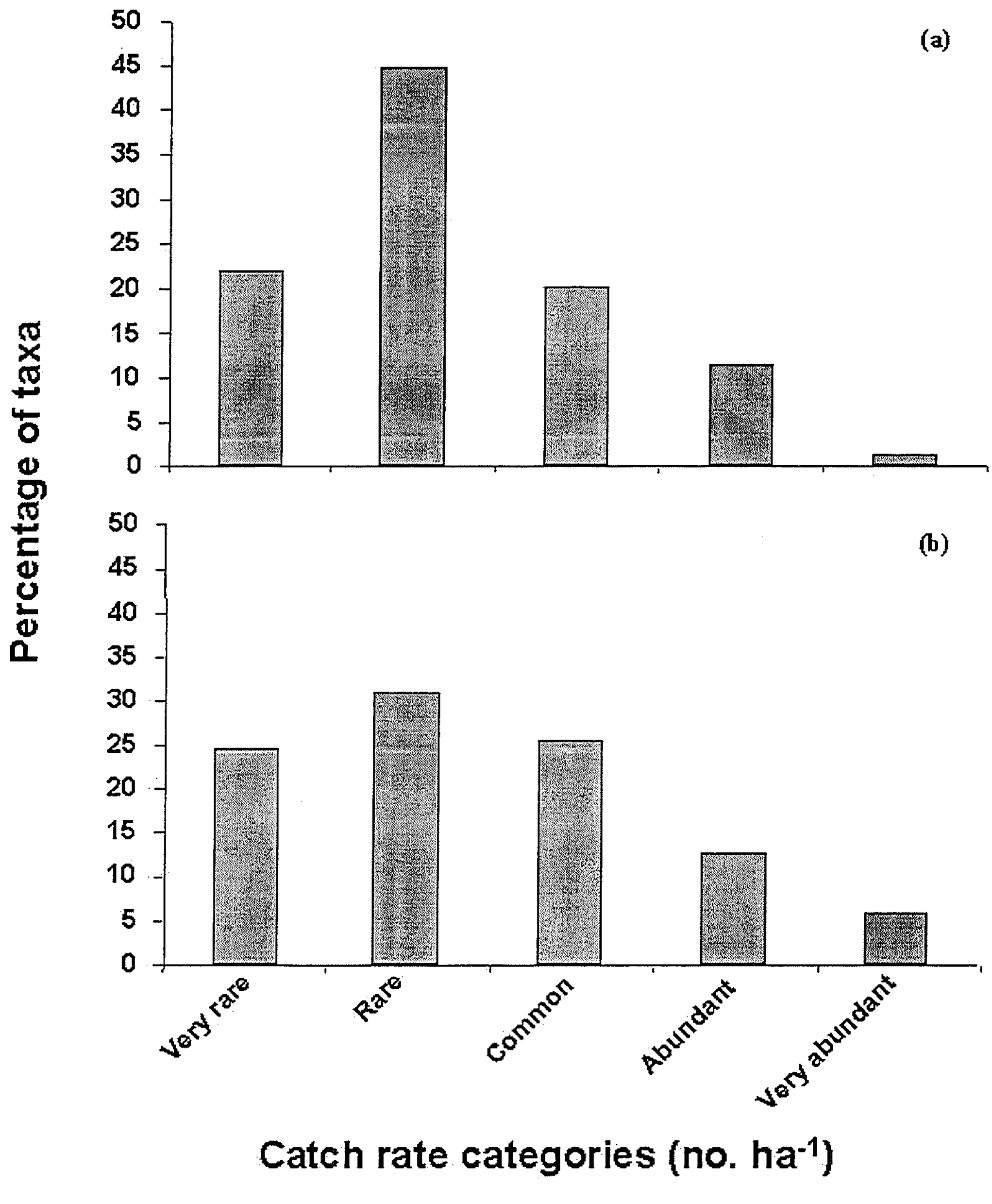


Figure 9.5.3 Histograms generated from observer trawl surveys in two NPF regions (a) 'North Mornington' (52) trawls and (b) 'North Groote' (43 trawls), showing the percentage distribution of taxa based on five categories of catch rates - 'Very rare', 'Rare', 'Common', 'Abundant', and 'Very abundant'

Table 9.5.3 The number and percentage of taxa for which a future annual trawl survey (of same size and time) could detect a decline of 50, 75 or 99.9% from the baseline survey mean catch rates. Estimates of effort were based on the variability of sampling taxa from 52 trawls at 'North Mornington' and 43 trawls at 'North Groote'.

Region	No. of trawls	No of taxa recorded	No and % of taxa we could detect 50% decline	No and % of taxa we could detect 75% decline	No and % of taxa we could detect 99.9% decline
'North Mornington'	52	267	27 (10.1%)	62 (23.2%)	95 (35.6%)
'North Groote'	43	296	16 (5.4%)	56 (18.9%)	84 (28.4%)

At 'North Mornington', the mean number of trawls needed to detect a 50% decline in mean catch rates ranged from 77 for the 'very abundant' to 3276 for the 'very rare' taxa; from 29 for the 'very abundant' to 1213 for the 'very rare' taxa for a 75% decline; and from 15 for the 'very abundant' to 548 for the 'very rare' taxa for the 99.9% decline (Table 9.5.4a).

At 'North Groote', the mean number of trawls needed to detect a 50% decline in mean catch rates ranged from 61 for the 'very abundant' to 2709 for the 'very rare' taxa; from 23 for the 'very abundant' to 1003 for the 'very rare' taxa for a 75% decline; and from 12 for the 'very abundant' to 453 for the 'very rare' taxa for the 99.9% decline (Table 9.5.4b).

Of the 41 taxa in both regions that had catch rates estimates higher than four per hectare, 28 of the taxa (68%) were recorded at 'North Mornington' and only 13 (32%) at 'North Groote'.

9.5.4 Discussion

The data collected by the observer trawl surveys in this project has allowed us to provide information on the number of trawls required to be able to detect changes in populations of 266 taxa in the 'North. Mornington' region and 296 taxa in the 'North Groote' region of the NPF. Although sampling levels are high, monitoring for a decline of 50% in catch rates from baseline levels is possible for all the small bycatch taxa of a region.

Subsampling from catches is necessary in order to monitor the hundreds of small bycatch taxa of the NPF. Subsamples must be frozen on board trawlers, and transported back to the laboratory for processing. From a feasibility of monitoring viewpoint, if we assume a maximum of 30 trawlers work in a region for one month (30 nights) completing four trawls each night, the maximum number of trawls that could be subsampled is 3600. This level of effort is similar to that required for detecting 50% declines for all taxa in both regions (3276 and 2709 trawls).

Table 9.5.4 For taxa (in five abundance categories) from (a) the 'North Mornington' and (b) the 'North Groote' region, the mean number of trawls required to detect either a 50, 75 or 99.9% decline in mean catch rates from a future baseline survey. Estimates of effort were based on the variability of sampling taxa from 52 trawls at 'North Mornington' and 43 trawls at 'North Groote'.

(a)

Abundance grouping	Abundance category (range in no. ha^{-1})	No. of taxa per category and % of total taxa	Mean no of trawls required to detect 50% decline	Standard deviation	Mean no of trawls required to detect 75% decline	Standard deviation	Mean no of trawls required to detect 99.9% decline	Standard deviation
'Very rare'	0.001 ha^{-1} to 0.01 ha^{-1}	66 (25%)	3276		1213		548	
'Rare'	0.01 ha^{-1} to 0.1 ha^{-1}	82 (31%)	1116	569	415	212	194	104
'Common'	0.1 ha^{-1} to 1 ha^{-1}	68 (25%)	290	358	108	135	53	70
'Abundant'	1 ha^{-1} to 10 ha^{-1}	34 (13%)	124	245	47	93	24	49
'Very abundant'	>10 ha^{-1}	16 (6%)	77	125	29	47	15	25
Totals		266 (100%)						

(b)

Abundance grouping	Abundance category (range in no. ha^{-1})	No. of taxa per category and % of total taxa	Mean no of trawls required to detect 50% decline	Standard deviation	Mean no of trawls required to detect 75% decline	Standard deviation	Mean no of trawls required to detect 99.9% decline	Standard deviation
'Very rare'	0.001 ha^{-1} to 0.01 ha^{-1}	67 (23%)	2709		1003		453	
'Rare'	0.01 ha^{-1} to 0.1 ha^{-1}	132 (45%)	863	509	321	190	151	93
'Common'	0.1 ha^{-1} to 1 ha^{-1}	59 (20%)	217	306	82	116	42	61
'Abundant'	1 ha^{-1} to 10 ha^{-1}	34 (11%)	88	73	33	28	17	15
'Very abundant'	>10 ha^{-1}	4 (1%)	61	34	23	13	12	7
Totals		296 (100%)						

9.5 Effect of sampling scale

The high variability in estimating catch rates and the resulting large survey size for a future baseline level, were not unexpected given the wide range of bycatch taxa examined, from extremely motile teleosts to sessile invertebrates. The variability is derived from two sources, the catchability at the trawl-taxa interface, and the on-deck subsampling techniques, and it is not clear what proportion is due to each source. However, we know from other studies in this report (Section 9.3), that sampling error for taxa occurring at less than one individual per 10 kg subsample, on average is greater than 70% (when subsampling 10-20% of catch weight). The trend in our data is for the 'very rare' taxa to have much higher variability, and require an order of magnitude higher number of trawls than the 'common' taxa.

The appendix (listing all taxa by region) is presented as a guideline on which the size of a fishery-dependent future baseline survey could be based. The levels of effort required are based on the precision of estimates of catch rates provided by the trawl, and not the true abundance of taxa on the seafloor. By including every trawl in the analysis, even where the taxa of interest is not recorded, we have integrated the estimate of catch rates over the same swept area for every taxa. This method will be more accurate for some ubiquitous species like *Saurida micropectoralis*, but less so for schooling taxa (eg some *Leiognathus splendens*). However, due to lack of understanding of how taxa are distributed within regions and their catchability by trawls, we have applied the same yardstick to all taxa. We recognise that these methods will over-estimate sampling effort required for some taxa and under estimate for others. However, the data presented in the appendix data represent a valid starting point when considering the size of a future survey large enough to detect a range of declines in NPF bycatch populations.

Practical considerations need to be understood in employing these estimates. For example, the level of cost and effort required to collect data on small bycatch taxa is so high (see Section 9.7) that selective sorting of taxa within subsamples is not cost effective. All subsamples must be frozen at sea and processed in the laboratory. It should be remembered that a survey estimating catch rates for 'rare' or 'very rare' taxa will, by default (as part of the sorting process), have detected the same level of decline for all the taxa caught at higher catch rates.

The precision of a baseline survey based on these results can be improved by the following actions. The survey should extend over a full lunar month in order to cover the full range of changes in catchability due to diel and lunar cycle behaviours likely to be encountered over such diverse taxa. Levels of subsampling should be standardised at a set percentage of catch weight. Larger sample sizes will give better precision. The size of trawl boards, headrope length, mesh size, ground tackle and speed of trawl should be standardised wherever possible. In order to improve accuracy of monitoring, the surveys should be completed at the same time of year (lunar month) and the same sites where possible. The levels of inter-annual variation for individual bycatch taxa will only be revealed after a period of many years monitoring. For this reason, it is critical that the sampling design for annual surveys be correct before the baseline study. The design must incorporate the long-term perspective of the outcomes of such monitoring.

Other factors that may influence survey results

How well the observer surveys represented the taxa of the respective larger rectangles bounding the trawl sites, is unclear. The shape of both species-area curves, although levelling out (particularly at 'North Mornington'), indicated that more taxa would have been recorded had more sites been sampled. However, it is equally likely that the majority of 'new' taxa recorded would have been in the 'rare' to 'very rare' category (57 to 66.4% of taxa were recorded in these categories). The number of trawls required to detect even large declines in catch rates for taxa not yet recorded in the surveys, are beyond the capacity of the fleet (in its present working mode) to collect the data.

The distribution of trawl sites was heavily aggregated in the 'North Groote' region, raising concerns about the effects of repeat trawling on estimates of catch rates. Repeat trawling effects are unknown for NPF bycatch taxa and may range from an attraction for some Sillaginid taxa from outside areas (Kaiser and Spencer 1994), to depletion for less motile taxa, especially invertebrates (Burridge *et al* in prep). It is of interest that repeated trawling at the most trawled 'North Groote' site did not affect catch rates of the target prawn species, *Penaeus semisulcatus* (pers obs) and fishers found it economically viable to remain at the same site.

There were almost twice as many taxa in the highest abundance category (>4/ ha^{-1}) at 'North Mornington' region, compared to 'North Groote' region (29:15 taxa), (but 34 more taxa were recorded at 'North Groote'). There are many factors included reduced geographical variation, changes in diel, lunar or seasonal cycles, or repeated trawling that may explain the lower catch rates at 'North Groote'.The higher number of taxa at 'North Groote' may be explained by the close proximity to reefs (for the majority of trawls) that probably support higher species diversity. In contrast, the sites at 'North Mornington' were well away from reefs.

However, it must be restated that the observer survey data was collected from trawlers engaged in commercial fishing and reflects real differences in harvesting strategies. Such strategies will be represented in future fishery-dependent monitoring programs if scientific observers or commercial fishers collect bycatch samples. When a trawler arrives at a different trawl site, the immediate trawl history of that site is often not known because of the competitive nature of commercial fishing. In fact, many trawlers may have intensively trawled the site in the preceding days or weeks, and the effects on the resident and itinerant bycatch at the site are unknown.

Collection of subsamples by scientific observers on commercial trawlers or by commercial fishers, may prove to be cost efficient and necessary methods of monitoring NPF small bycatch taxa (Section 9.7). However, these methods of data collection will introduce other bias into monitoring calculations. Fishing operations in the NPF have become highly aggregated since the introduction of GPS and trawling grounds are rarely fished randomly. Consequently, the data from both scientific observers and fishers will represent biased sampling strategies. Furthermore, fishers target prawns, not bycatch, and will actively avoid areas of high bycatch that can damage the prawns and cause longer sorting times. Consequently, any examination of the power to detect declines in bycatch populations is likely to be less robust than the same calculations for target species

9.5.5 Conclusions

- Most taxa were 'rare' or 'very rare'- 148 taxa (56%) at 'North Mornington' and 199 taxa (68%) at 'North Groote' occurred at a catch rate of one or fewer individuals per 10 hectares.Few taxa were 'abundant' or 'very abundant'- 50 taxa (19%) at 'North Mornington' and 38 taxa (12%) at 'North Groote' occurred at a catch rate of one or more individuals per hectare.

- To detect a 50% change in catch rates (from the baseline surveys) for all taxa recorded in the surveys, a total of 3276 trawls are required at 'North Mornington' and 2709 at 'North Groote'.

- To detect a 75% change in catch rates (from the baseline surveys) for all taxa recorded in the surveys, a total of 1213 trawls are required at 'North Mornington' and 1003 at 'North Groote'.

- To detect a 99.9% change in catch rates (from the baseline surveys) for all taxa recorded in the surveys, a total of 548 trawls are required at 'North Mornington' and 453 at 'North Groote'.

- The ability to sample the number of trawls needed to detect a 50% change for all taxa in one NPF region may be approaching the limits of fleet feasibility.

References

Azarovitz, T.R. 1981.A brief historical review of the Woods Hole trawl survey time series. *In* Bottom trawl surveys. *Edited by* W.G. Doubleday and D.Rivard. Can. Spec. Publ. Fish. Aquat. Sci. No 58, pp. 62-67.

Burridge, C. Y., Pitcher, C.R., Wassenberg, T.J., Poiner, I. P, Hill, B.J. In prep. Measurement of the rate of depletion of benthic fauna by prawn otter trawls: an experiment in the Great Barrier Reef, Australia.

Cyr, H., Downing, J.A., Lalonde, S., Baines, S.B., and Pace, M.L. 1992. Sampling larval fish populations: Choice of sample number and size. Trans. Am. Fish. Soc. 121:356-368.

Godo, O. R., Walsh, S.J., and Engas, A. 1999. Investigating density–dependent catchhability in bottom-trawl surveys. I.C.E.S J. Mar. Sci. 56: pp 292-298.

Halliday, R. G. and P. A. Koeller, 1981. A history of Canadian groundfish trawling surveys and data useage in ICNAF divisions 4TVWX. *In* Bottom trawl surveys. *Edited by* W.G. Doubleday and D.Rivard. Can. Spec. Publ. Fish. Aquat. Sci. No 58, pp. 27-42.

Kaiser, M. J., and Spencer, B. E., 1994. Fish scavenging behaviour in recently trawled areas. Mar. Ecol. Prog. Ser. 112:41-49.

Pitt, T. K., R. Wells and W. D. McKone, 1981. A critique of research vessel otter trawl surveys by the St. John's Research and Resource Services. *In* Bottom trawl surveys. *Edited by* W.G. Doubleday and D.Rivard. Can. Spec. Publ. Fish. Aquat. Sci. No 58, pp. 42-61.

Power, J.H., and Moser, E.B., 1999. Linear model analysis of net catch data using the negative binomial distribution. Can. J. Fish. Aquat. Sci. 56: 191-200.

Snedecor, G.W., and Cochran, W.G., 1989. Statistical Methods (8th ed.). pp103-104.

SAS Language 1993. Version 6, First Edn. Cary, NC: SAS Institute Inc., 1042pp.

9.6 Lunar and diel patterns

9.6.1 Introduction

The NPF is characterised by high species diversity and a range of different environments over its extensive geographical range. Interpreting changes in catch rates from prawn trawls in the NPF is complicated by variable catchability of the species mix. Catch rates of bycatch species may be affected by factors such as seasonality, time of night and lunar periodicity. It is important that any variation in catches due to these influences are accounted for when establishing a monitoring program to evaluate the influence of fishing mortality on these species. The first two factors, seasonality and time of night, can be accounted for by incorporating consistent timing. The third factor, lunar changes in catchability, is more difficult to avoid in this type of sampling program. However, it can be accounted for by either monitoring species that do not show such a pattern in catch rates or by designing sampling programs at a consistent moon phase. Lunar catchability is usually accounted for in ecological sampling programs by synchronising the sampling to obtain data at a particular moon phase (Clark, 1974; Somers et al., 1987a; Crocos and van der Velde, 1995).

Estimates of relative abundance are usually planned around assumed times of maximum catches for the species under investigation, or in some cases, with no allowance for moon phase (Somers et al., 1987b). This is especially true in penaeid prawn research programs in the Gulf of Carpentaria (GoC) where extensive field studies for tiger prawns (*Penaeus esculentus* and *P. semisulcatus*) centred the dates of sampling around the new moon for maximum catch rates (Somers et al., 1987a; Crocos and van der Velde, 1995). This ensured consistency in catchability from month to month.

Few studies are designed to measure the catch rates of any trawl species over a lunar cycle. However, catch rates and moon phase are known to be related for many species that are not trawled: Catch rates of Atlantic herring in the Gulf of Maine were highest during the dark phase of the moon (Anthony and Fogarty, 1985), yellow eels catch rates were lowest at full moon in an Italian brackish water lake (Corsi and Ardizzone, 1985), Gulf of Mexico butterfish catch rates peaked during first quarter moon (Render and Allen, 1987), several crabs in India had highest catch rates during new moon (Hamsa, 1978) and during new and full moons (Chatterji et al., 1994).

Information about changes in catch rates of prawn trawl bycatch measured over moon phases is limited to this study. Most tropical Australian trawl studies are based on prawn trawl fisheries, which do not record bycatch species catch rates. However, as commercial logbook data on prawn catches are available for the NPF, we have used prawns as a 'proxy' for bycatch species. This enabled us to compare catch rates and moon phase on a spatial scale at Weipa and other geographic areas within the Gulf of Carpentaria as well as over three months in some areas.

Other studies have also used commercial logbook data to investigate catch rates of prawn species over moon phases.Courtney et al., (1996) and Glaister (1983) used commercial logbook data in research on spawning behaviour in sub-tropical king prawns, *Penaeus plebejus*, on the Queensland east coast. They were able to demonstrate a link between catch rates and moon phase. Their data from commercial logbooks and research trawls taken from >100 m depth showed a peak in catch before a decline of about 50% following the full moon (Courtney et al., 1996). Racek (1959) found a peak of abundance around the new moon for the same species in shallow waters (<30 m).

A study of catch rates from research vessel trawls was used to investigate if there was

- evidence for changes in catch rates with moon phase
- species that are not influenced by moon phase.

9.6.2 Methods

This study made use of existing prawn trawl catch data from a previous FRDC project (FRDC project 93/179) investigating bycatch reduction devices suitable for the NPF. Full details of the sampling procedures and equipment used are available in Brewer et al. (1998).

Research trawls

Sampling commenced on the night of 11th October and finished on the morning of 5th November 1995. All trawls were conducted near Weipa, within a 6 x 22 n. mile box approximately 5 n. mile west of Duyfken Point, in the GoC(Figure 9.6.1). They were made in a north-south direction between 15 and 26 m depth. Trawls were conducted from the CSIRO's *RV Southern Surveyor*, using twin-rigged14 fathom Florida Flyer prawn nets. Four two-hour trawls were completed each night, the first commencing in complete darkness and the last finishing before first light. The original intention of the sampling was to compare the catch of nets withbycatch reduction devices to a standard net. The data analysed here come only from the standard net. These trawls were randomly distributed within the study site, through the night, and between the port or starboard sides of a paired trawl rig.

All large animals were removed from each catch, and the remainder sorted. For larger catches, the remaining catch was then sampled (about 30%). The total catch composition for each species was estimated by multiplying the sample results by a grossing factor based on the sample fraction of the catch.Individuals were identified to species, counted and weighed, and the information entered directly to an Oracle database. The 36 trawls made by the standard prawn trawl were used to select the most common (by frequency of occurrence) and most abundant (highest catch rates in n h^{-1}) species.These 26 species were used for all analyses.

Commercial catch

Extrapolating the results of the research trawls to the commercial fishery required a comparison with catches from commercial trawlers. Vessels from the commercial prawn trawl fishery maintain daily logbook records of fishing catch and effort (AFMA logbook). No information on bycatch species was available, however, the prawn catches are recorded. The prawn catch is composed of four main species two endeavour prawns (*Metapenaeus endeavouri* and *M. ensis*) and two tiger prawns (*Penaeus esculentus* and *P. semisulcatus*).

To compare patterns in the research trawl catch with the commercial logbook data, the average catch of commercial vessels in the same area at the same time was calculated. The prawn catches are recorded in the logbook as 'tigers' and 'endeavours' prawns.

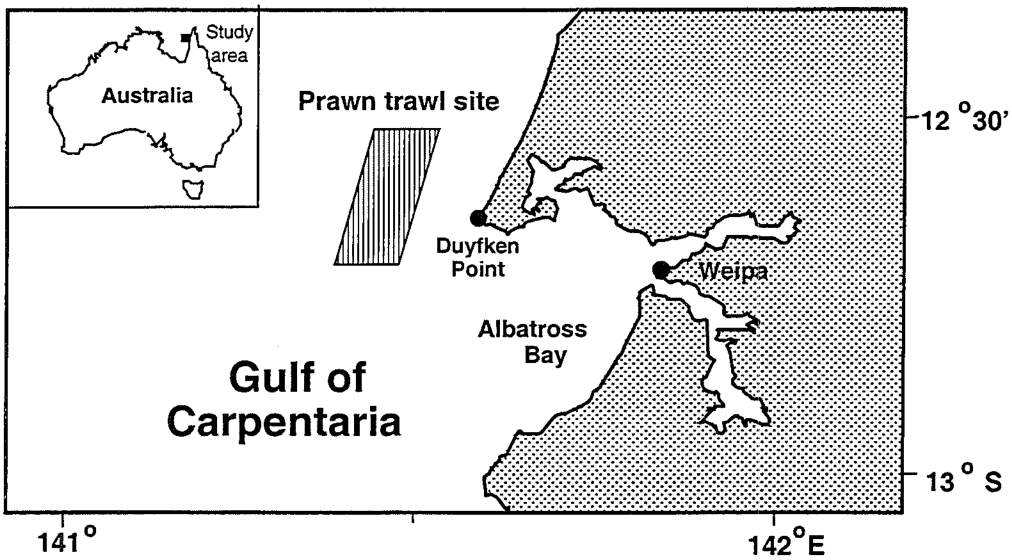


Figure 9.6.1 Location of the research trawl site approximately 5 nm west of Duyfken Point, near Weipa in the north eastern Gulf of Carpentaria.

The catch rates from commercial trawlers in different areas of the GoC were also examined to determine if the observed patterns of abundance over the lunar cycle were consistent across different geographic areas. To minimise temporal factors that could affect such a comparison, data for the 3 months (September to November) closest to the research sampling were used. Regions compared were: 'North Groote', 'Vanderlins', 'West Mornington' and 'East Mornington' (Figure 6.2.1). The NPF managed area is divided into 6 x 6 n. mile grids and catch data was used from grids where fishing effort was relatively high (8 grids in 'North Groote', 6 grids in 'Vanderlins', 3 grids in 'West Mornington' and 1 grid in 'East Mornington'). The Weipa data from both research and commercial vessels represented approximately 3 adjacent grids combined. The Weipa commercial effort data were combined over the 3 grids because the number of research trawls per grid was too low for analyses.

Data analysis

The catch rates (n h^{-1}) from research sampling for the 26 most abundant species (including prawns) were plotted over the 25 nights of trawling to look for patterns over the lunar cycle. The mean catch rates for each moon phase, last quarter, new moon, first quarter and full moon were calculated as means for the nights up to and including each astronomical phase. Last quarter occurred on 17th October, new moon on 24th October, first quarter on 31st October and full moon on 7th November 1995 (Australian National Tide Tables 1995). An unbalanced two-way ANOVA was performed on catch rates for eachof the top 26 species, with time of night and moon phase as independent variables. Time of night refers to four intervals of two hours each during which the 36 trawls occurred: from 2000-2200 h, 2200-2400 h, 0000-0200 h and 0200-0400 h.Because of the large number of comparisons involved in this analysis, probability values of 0.01 were used in tests of significance rather than the usual 0.05.

All commercial prawn logbook catch data (kg d^{-1}) were analysed with an unbalanced two-way ANOVA with month and moon phase as the independent variables. The analyses were performed on tiger and endeavour prawn catches from the 'North Groote', 'Vanderlins', 'West Mornington', 'East Mornington' and 'Weipa' regions.

9.6.3 Results

Research data
There were 26 species which occurred in at least 80% of the trawls, with 9 species occurring in all trawls (Table 9.6.1). The two prawn species (*Metapenaeus endeavouri* and *Penaeus esculentus*) occurred in all trawls but had relatively low catch rates (Table 9.6.1). The highest catch rate for a single trawl, 10,583 h^{-1}, occurred for *Leiognathus splendens* during first quarter moon phase. Trawl catch rates (n h^{-1}) for all species were not significantly different at different times of night. This allowed all trawls within moon phases to be treated independently of time of night. Only one species, the commercially unimportant prawn *Trachypenaeus* spp., had significantly different catch rates among the times of night, but since this result could be due to chance alone, this species was not considered further.

The average catch rate of individuals of all 26 species combined was plotted against moon phase to search for an overall pattern (Figure 9.6.2). This shows a sharp maximum for numbers during the first quarter or waxing moon. This overall pattern is also obvious for the most abundant species, *Leiognathus splendens* (Figure 9.6.3). This species represents about 47% of the total numbers of all 26 species (Table 9.6.1) and 58% of the total numbers at the first quarter maximum (Figure 9.6.3). Mean catch rates were significantly different ($P<0.01$) between moon phases for 10 of the 26 species (Table 9.6.2). However, there were different patterns of catch rate for different species.

In the species which showed a significant lunar effect, the most common pattern of catch rates was a first quarter peak. This was found for four fish species: *Gerres filamentosus*, *Johnius amblycephalus*, *Leiognathus splendens* and *Sardinella albella* (Figure 9.6.3). The next most common pattern was a last quarter peak. This occurred for three species, *Leiognathus moretoniensis*, *Penaeus esculentus* and *Torquigener whitleyi* (Figure 9.6.4). The pattern for *Sillago sihama* was a new and full moon minimum or a combination of the previous two patterns (Figure 9.6.5). The remaining patterns were: a waxing moon maximum, (first quarter and full moon), for *Metapenaeus ensis* and a new and full moon maximum for *Trachypenaeus* spp. (Figure 9.6.5). The combined catch rates of endeavour prawns (*Metapenaeus endeavouri* and *M. ensis*) were significantly different between moon phases (Table 9.6.3) with a full moon peak. The catch rates of tiger prawns (*Penaeus esculentus* and *P. semisulcatus*) showed a peak at last quarter moon but the catch rates were not significantly different between moon phase (Table 9.6.3).

Table 9.6.1 The total numbers and percentage occurrence of the 26 species used in the analyses. They represent the twenty-four most abundant species during this study and two species of penaeids that occurred in all 36 research trawls (100% occurrence).

Species	Total numbers	%Occurrence
Leiognathus splendens	177166	100
Leiognathus equulus	24240	92
Pomadasys maculatum	21599	92
Penaeus semisulcatus	13776	100
Sillago sihama	13161	92
Johnius vogleri	11555	100
Pomadasys trifasciatus	11524	89
Apogon poecilopterus	10467	100
Saurida sp 2	10447	89
Metapenaeus ensis	9542	100
Gerres filamentosus	9170	100
Leiognathus moretoniensis	9064	92
Sardinella albella	8673	89
Upeneus sulphureus	7745	92
Arius thalassinus	5271	94
Trachypeneus spp.	4959	100
Saurida micropectoralis	4660	94
Pomadasys kaakan	4317	81
Johnius amblycephalus	3576	83
Caranx bucculentus	3137	86
Upeneus sundaicus	3073	86
Anodontostoma chacunda	2997	86
Apogon elliotti	2865	81
Torquigener whitleyi	2335	86
Metapenaeus endearvouri	518	100
Penaeus esculentus	497	100

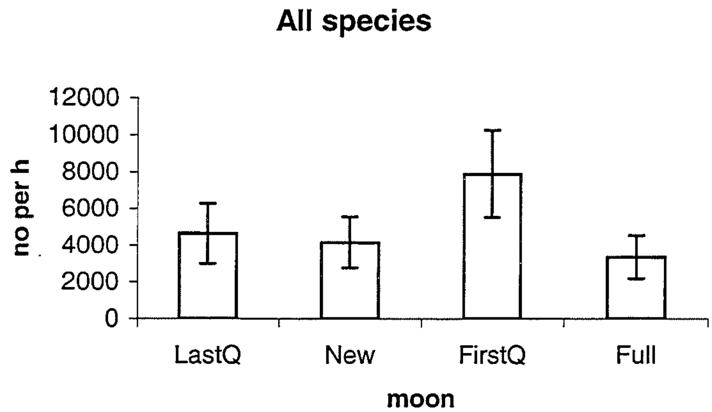


Figure 9.6.2 Aggregate catch rates (n h^{-1}) for all 26 species analysed from research trawls over 26 consecutive nights. FirstQ = first quarter moon phase, LastQ = last quarter moon phase.

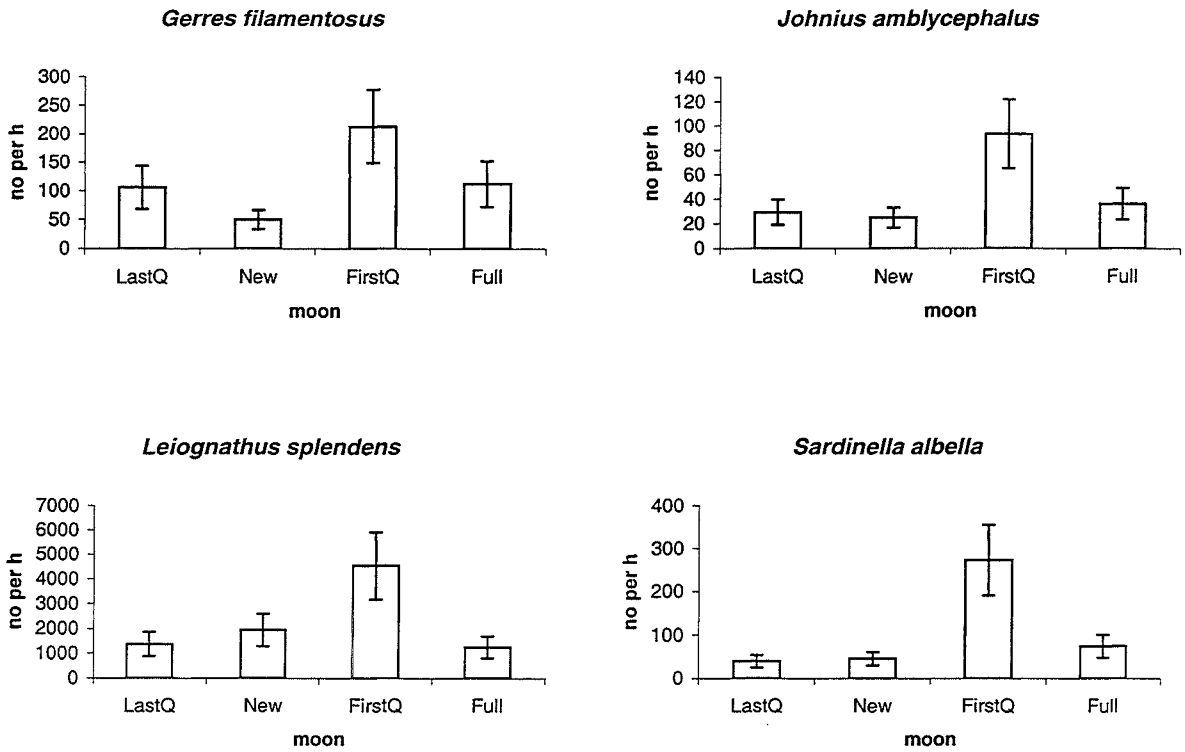


Figure 9.6.3 The four species with the most common pattern in catch rates during the research study, a first quarter moon phase maximum, observed from 36 trawls near Weipa. FirstQ = first quarter moon phase, LastQ = last quarter moon phase.

Table 9.6.2 Mean catch rates (n h^{-1}) and standard errors for all species combined (All spp) and ten species from research trawls with significant differences between moon phase catches (*P<0.01*). Sample size is the number of research trawls per moon phase. LastQ = last quarter moon phase, FirstQ =first quarter moon phase.

Species	**LastQ (se)**	**New (se)**	**FirstQ (se)**	**Full (se)**	**P**
Sample size	8	9	11	8	
All Spp	4637.9 (1639.4)	4146.1 (1382.0)	7866.6 (2371.9)	3344.1 (1182.3)	*0.004*
Gerres filamentosus	106.0 (37.5)	50.4 (16.8)	213.3 (64.3)	113.1 (40.0)	*0.012*
Johniusamblycephalus	29.1 (10.3)	24.8 (8.3)	93.6 (28.2)	36.4 (12.9)	*0.002*
Leiognathus moretoniensis	338.9 (119.8)	72.1 (24.0)	71.6 (21.6)	47.3 (16.7)	*0.000*
Leiognathus splendens	1363.6 (482.1)	1943.3 (647.8)	4544.0 (1370.1)	1252.3 (442.8)	*0.007*
Metapenaeus ensis	74.3 (26.3)	98.8 (32.9)	156.6 (47.2)	194.4 (68.7)	*0.001*
Penaeusesculentus	14.3 (5.0)	5.4 (1.8)	5.9 (1.8)	3.8 (1.3)	*0.007*
Sardinellaalbella	39.3 (13.9)	45.6 (15.2)	272.2 (82.1)	74.5 (26.3)	*0.001*
Sillago sihama	307.8 (108.8)	111.6 (37.2)	214.5 (64.7)	93.0 (32.9)	*0.005*
Torquigener whitleyi	63.6 (22.5)	27.4 (9.1)	23.2 (7.0)	19.1 (6.8)	*0.001*
Trachypenaeus spp.	32.4 (11.4)	103.1 (34.4)	38.5 (12.0)	109.5 (38.7)	*0.001*

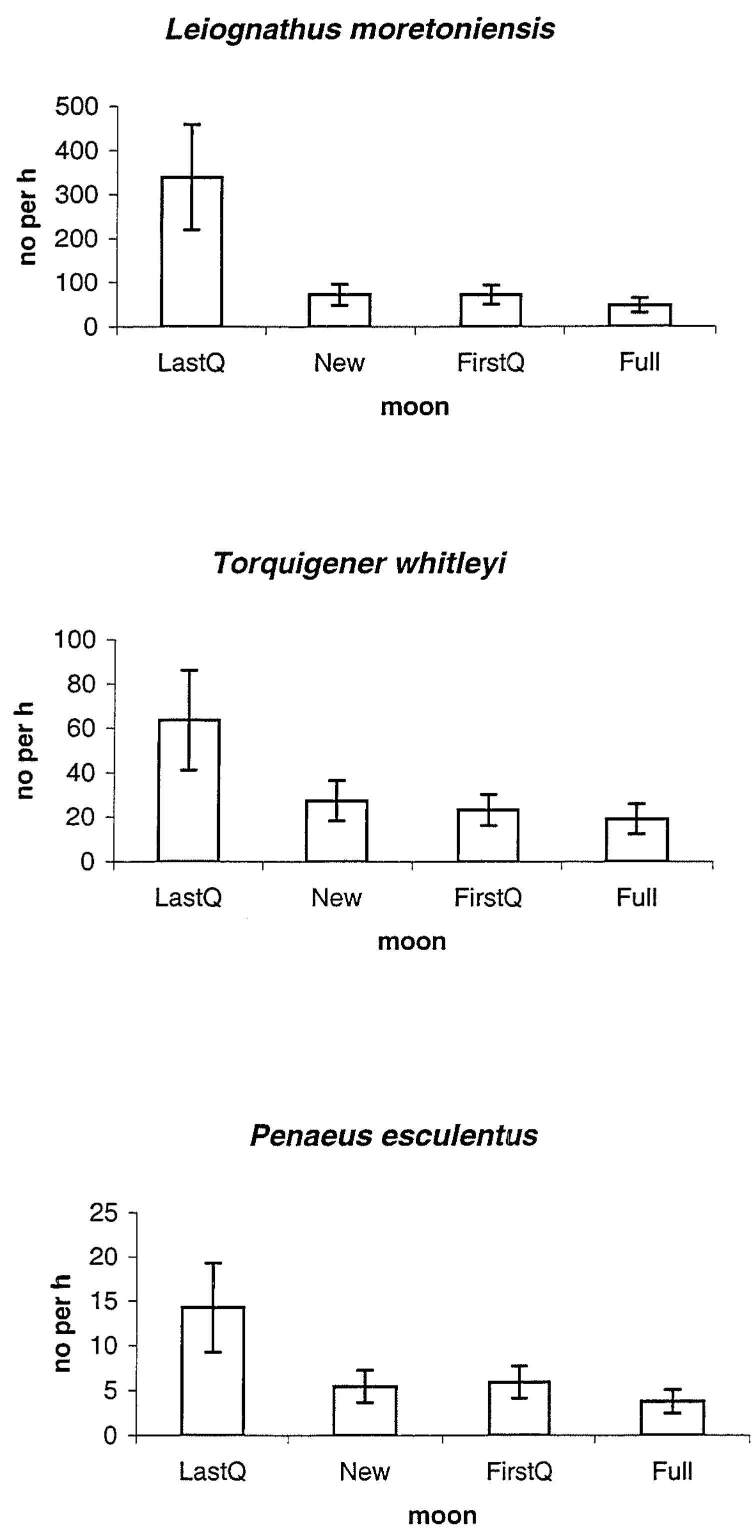


Figure 9.6.4 The three species with the second most common pattern in catch rates during the research study, a last quarter moon phase maximum, observed from 36 trawls near Weipa. FirstQ = first quarter moon phase, LastQ = last quarter moon phase

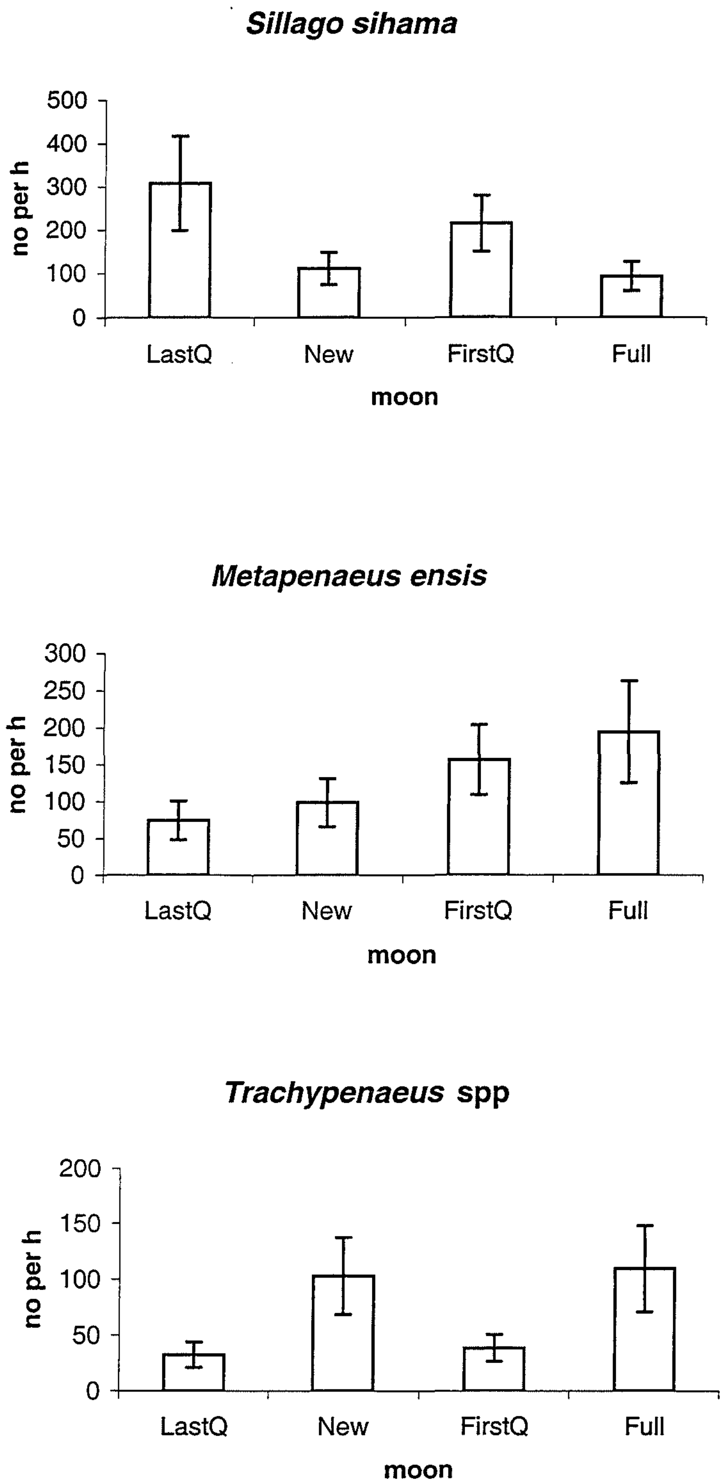


Figure 9.6.5 Individual species patterns in catch rates during the research study for three species. Observed from 36 trawls near Weipa. FirstQ = first quarter moon phase, LastQ = last quarter moon phase.

Table 9.6.3 Comparison of research and logbook endeavour and tiger prawns from the same month at Weipa. Research endeavour prawns is *M. endeavouri* and *M. ensis* combined, research tiger prawns is *P. esculentus* and *P. semisulcatus* combined. Research catch rates are in n h^{-1} and commercial logbook catch rates are in kg $boat^{-1}$ d^{-1}. Sample size, n, is the number of research trawls per moon phase and the number of commercial vessel days per moon phase.

Species	LastQ (se)	New (se)	FirstQ (se)	Full (se)	P
RESEARCH DATA					
Endeavour prawns	80.6 (28.5)	106.9 (35.6)	163.9 (49.4)	200.2 (70.8)	*0.001*
Tiger prawns	245.4 (86.8)	167.8 (55.9)	204.3 (61.6)	175.3 (62.0)	*0.052*
n	8	9	11	8	
LOGBOOK DATA					
Endeavour prawns	48.4 (20.4)	41.5 (18.9)	109.8 (18.9)	216.9 (22.3)	*0.001*
Tiger prawns	198.2 (16.0)	89.7 (14.9)	135.3 (14.9)	147.9 (17.6)	*0.001*
n	6	7	7	5	

Commercial logbook data

The logbook catch rates at Weipa for both endeavour and tiger prawns between moon phases were similar to the patterns from the research catch data for the combined tiger and endeavour species (Table 9.6.3). Commercial logbook and research vessel endeavour prawn catch rates increased during first quarter moon and peaked at full moon. Commercial logbook and research vessel tiger prawn catch rates were more consistent with a minimum during new moon phase than a full moon peak (Table 9.6.3).

Other regions of the GoC

Eight grids in 'North Groote', five grids in 'Vanderlins', three grids in 'West Mornington' and one grid in 'East Mornington' were tested for differences in catch rates between moon phases between September to November (Table 9.6.4). In 'North Groote', five endeavour prawn comparisons and three tiger prawn comparisonswere significantly different between moon phases. In 'Vanderlins', both endeavour prawn tests were significantly different between moon phases, but neither was significant for tiger prawns.In 'West Mornington', two grids for endeavour prawns and one grid for tiger prawns showedsignificant relationships between catch rates and moon phase. There was no relationship detectable for either species in 'East Mornington' where the data were very limited. Overall, these results indicate clear evidence for a relationship between catch rates and moon phase over a widespread area in the GoC.

Significant moon phase and month interactions were only found for endeavour prawns in four of the eight grids in 'North Groote'. For tiger prawns, only grid NG31 in 'North Groote' had a significant moon phase and month interaction, there was also a significant relationship between catch rate and moon phase (Table 9.6.4). When the moon month interactions are significant, then the monthly catch rate pattern changes over the three months, but is similar when the interaction is not significant. Tiger prawn catches in grids NG22 and NG24 showed a consistent full moon peak in all months, but in grid NG31 there was a clear peak at full moon for October only.Endeavour prawn catches in NG24, V55, V66 showed no significant moon/month interactions, but the catch rate patterns were less consistent than for tiger prawn catch rates.

Table 9.6.4 Probablity values from the ANOVA of the catch rates (kg $boat^{-1}$ d^{-1}) from commercial logbook data from 'North Groote' (NG), 'Vanderlins' (V), 'West Mornington' (WM) and 'East Mornington' (EM) (see Figure 6.2.1). Data are from September, October and November 1995 and are compared between moon phases and over these three months. Only grids with sufficient trawler days were used in the analysis. Grids around Mornington had only one month fishing effort.

LOCATION	GRID	Endeavour *P*		Tiger *P*	
		Moon	Moon:month	Moon	Moon:month
'North Groote'	NG21	*0.0392*	*0.0019*	ns	Ns
	NG22	ns	ns	*0.0019*	Ns
	NG23	*0.0005*	*0.0261*	ns	*0.0173*
	NG24	*0.0319*	ns	*0.0405*	Ns
	NG25	*0.0025*	*0.0001*	ns	Ns
	NG31	*0.0001*	*0.0001*	*0.0067*	*0.0310*
'Vanderlins'	V55	*0.0002*	Ns	Ns	*0.0013*
	V66	*0.0251*	Ns	ns	*ns*
'West Mornington'	WM124	*0.029*	Only 1 month	Ns	Only 1 month
	WM127	*0.053*	data	*0.044*	data
	WM128	*0.014*		ns	
'East Mornington'	EM141	Ns		ns	

9.6.4 Discussion

The research data showed that 16 of the 26 most abundant bycatch and target species were not influenced by moon phase. For the remaining 10 species, there was a significant relationship between catch rates and lunar cycle.Included in these 10 species were commercially important prawns. Commercial vessel logbook records supported the research findings of a significant relationship between prawn catch rates and moon phase over three months from both the same fishery area and areas throughout the GoC. However, endeavour prawn and tiger prawn catch rate maxima occurred at different lunar phases in different regions.

Few studies have examined changes in catch rates of trawled species with moon phase on the same scale as the present study. However, Anthony and Fogarty (1985) found that young Atlantic herring in the Gulf of Maine fishery are more available and vulnerable to fishing gear around new moon. This effect is more pronounced when abundance is low. In the North Island of New Zealand, Millar et al., (1997) found catch per unit effort was highest around new moon in recreational fishers catches of snapper, *Pagrus auratus* although this was not statistically significant. Peak catch rates of gulf butterfish, *Peprilus burti* in the Gulf of Mexico occurred in the first quarter moon phase (Render and Allen, 1987). This pattern was attributed to a difference in diel vertical movement of the fish in the water column during different moon phases. In a multiple regression model of longfinned eel activity in New Zealand, Jellyman (1991) found that incorporating moon phase improved the resolution of the model, but was not a statistically significant factor.

Because species composition of bycatch is not recorded in logbooks, little is known about the catch rates of adult teleosts among the bycatch species in the NPF. However, information about catch rates of penaeid prawns is recorded as part of the commercial logbook data and if there is a consistent trend in prawn catch rates, then it may suggest that some fish bycatch species will also show such trends. We have used combined research endeavour prawns (*Metapenaeus endeavouri* and *M. ensis*) and research tiger prawns (*Penaeus esculentus* and *P. semisulcatus*) from Weipa and logbook endeavour and tiger prawns catch rates as proxies for catch rates of bycatch species in this study. In the research trawls from the Weipa region, two species of commercial prawns were among the 10 species with significant differences in abundance between moon phases: the tiger prawn *Penaeus esculentus* and the endeavour prawn, *Metapenaeus ensis*.

Commercial logbook records for the same time and location (September-November in Weipa), showed a statistically significant relationship between catch rates for tiger and endeavour prawns and moon phase. Similarly, commercial logbook records for three areas around the Gulf of Carpentaria, 'North Groote', 'Vanderlins' and 'West Mornington', showed significant effects of moon phase on endeavour and tiger prawn catch rates. In some cases, these patterns differed between areas.

Other studies of penaeid prawns indicate that the lunar influence reported in this study is common. Courtney et al. (1996) studying king prawns, *P. latisulcatus*, also found a strong pattern of catchability over three months from both the research sampling and the fishers' logbooks. They found a decline in catch rate after the full moon, a time of decreasing ambient light. Maximum catches occurred during increasing moonlight. This pattern appears contrary to the findings of Wassenberg and Hill (1994) who found that *P. latisulcatus* (from the GoC) was the most light sensitive of eight commercial penaeids tested in the laboratory and could be expected to be most active at new moon. Cross et al. (1997) found a significant reduction in the commercial catch of *P. latisulcatus* and endeavour prawns, but no reduction in catch rates of *P. esculentus* during the full moon in the Shark Bay and Exmouth Gulf fisheries of Western Australia.

Because of the nocturnal activity of endeavour and tiger prawns (Wassenberg and Hill, 1994), we expected a catch rate maximum at or near new moon. Instead we found minimum catches at new moon for both endeavour and tiger prawns in the fishery, although this was more pronounced in logbook data than in our research data (Table 9.6.3). The tiger prawn logbook data from around the GoC showed full moon maxima in 'North Groote', but the patterns for endeavour prawns were not consistent across months. The peaks of abundance at new and full moons for *Trachypenaeus* spp may be a result of having more than one species represented by this category, rather than a moon phase-driven pattern.

Our findings showing a moon phase and catch rate relationship for several species of prawns is supported by previous work. White (1975) analysed *Penaeus esculentus* catch per unit effort of commercial trawlers and moon phase over three years in Exmouth Gulf, Western Australia. He found minimum catches at or near new moon and maximum catches 3-4 days prior to full moon. This lunar pattern occurred simultaneously over three years in six different areas within the fishery, but differed in phase from our *P. esculentus* maximum catches during last quarter moon. The commercial logbook data around the Gulf of Carpentaria supports his finding. In the offshore eastern king prawn fishery (*P. latisulcatus*), the catch rate dropped significantly during the 7 days after full moon (Glaister, 1983; Courtney et al., 1996), although Racek (1959) found maximum catches approaching new moon in the nearshore fishery (<30 m depth). Although *P. latisulcatus* did not occur in our data, the offshore pattern is similar to that for *Metapenaeus ensis* in this study, from both logbook and research data.

Our results suggest that studies which do not account for lunar variability of the target species, may have biased their findings where sampling occurs over more than one moon phase. In the Torres Straits where *P. esculentus* is 99% of the tiger prawn catch, Somers et al., (1987b) compared prawn species composition from fishery logbooks with species composition derived from trawl survey data. The trawl survey data were obtained from four monthly samples, but with no account for moon phase. Their proportion of tiger prawns, 41% in December, was not comparable to the 79% tiger prawns in the catch from the commercial fishery. We found that *P. esculentus* catch rates differed significantly between moon phases, and this may account for this large discrepancy in the tiger prawn component of catch reported by Somers et al. (1987b).

Ten of 26 bycatch species have different catch rates during different phases of the lunar cycle. Thus, any sampling or monitoring program which aims to obtain reliable estimates of catch abundances of bycatch species, will need to account for lunar variability in their sample design for some species. Most of the 10 species had catch rate peaks 2 to 5 times the next highest lunar catch rate (Figures 3 and 4). The corollary is that the other 16 species whose catchability is independent of lunar cycles, can be considered reliable species for monitoring changes in abundance independently of catchability factors associated with moon phase. Having identified which species have variable catch rates over moon phases, future sampling strategies in the Weipa region can be planned to account for these species. The evidence from logbook catch rates of prawns suggests that when there is a lunar pattern in catch rates, the pattern may be different across regions within the Gulf of Carpentaria.

9.6.5 Conclusions

- Ten out of 26 species tested had significantly different catch rates between moon phases
- The 10 species should not be considered reliable indicators of changes in species abundance in trawling studies, unless moon phase is accounted for in the sample design.
- Catches of the other 16 species were unaffected by moon phase
- In the Weipa region, these 16 species can be used for monitoring trawl bycatch when moon phase is difficult or impossible to incorporate into the sample design

References

Anthony, V.C. and Fogarty, M.J. 1985. Environmental effects on recruitment, growth, and vulnerability of Atlantic herring (*Clupea harengus harengus*) in the Gulf of Maine region. Proceedings of the symposium on the biological characteristics of herring and their implications for management. Can. J. of Aquat. Sci. 42(1), 158-173.

Brewer, D. T., Rawlinson, N., Eayrs, S. and Burridge, C. 1998. An assessment of Bycatch Reduction Devices in a tropical Australian prawn trawl fishery. Fish. Res. 36, 195-215.

Clark, S. H. 1974. A study of variation in trawl data collected inn Everglades National Park, Florida. Trans. Amer. Fish. Soc. 103(4), 777-785.

Chatterji, A., Ansari, Z.A., Ingole, B.S., Sreepada, R.A., Kanti, A. and Parulekar, A.H. 1994. Effect of lunar periodicity on the abundance of crabs from the Goa coast. Ind. J. of Mar. Sci. 23(3), 180-181.

Corsi, F. and Ardizzone G. D. (1985). Some environmental conditions affecting yellow eels catchability. Oebalia 11, 561-571.

Courteney A. J., Die D. J. and McGilvray, J. G. 1996. Lunar periodicity in catch rate and reproductive condition of adult eastern King prawns *Penaeus plebejus* in coastal waters of south-eastern Queensland, Australia. Mar. Freshw. Res. 47, 67-76.

Crocos, P. J. and Van der Velde, T. D. 1995. Seasonal, spatial and interannual variability in the reproductive dynamics of the grooved tiger prawn *Penaeus semisulcatus* in Albatross Bay, Gulf of Carpentaria, Australia: the concept of effective spawning. Mar. Biol. 122, 557-570.

Cross, J. M., Caputi, N., Fernandez, J. A. and Watson, R. A. 1997 A preliminary assessment of the impact of moon phase on the catch rate for penaeid prawns in two Western Australian fisheries. 1997 World Conference on Natural Resource Modelling, CSIRO Marine Research, Castray Esplanade, Hobart, Tasmania.

Glaister, J. P. 1983. Dynamics of the eastern king prawn population. Ph.D. Thesis, University of New South Wales, Kensington. 251 pp.

Hamsa, K.M.S.A. 1978. On the meat content of *Portunus pelagicus* with some observations on lunar periodicity in relation to abundance, weight and moulting. Ind. J. Fish. 25(1-2), 165-170.

Jellyman, D. J. 1991. Factors affecting the activity of two species of eel (Anguilla spp.) in a small New Zealand lake. J. F. Biol. 39(1), 7-14.

Millar, R. B., McKenzie, J. E., Bell, J. D. and Tierney, L. D. 1997. Evaluation of an indigenous fishing calendar using recreational catch rates of snapper *Pagrus auratus* in the North Island of New Zealand. Mar. Ecol. Prog. Ser. 151, 219-224.

Racek, A. A. 1959. Prawn investigations in eastern Australia. Research Bulletin State Fisheries of N.S.W., 94, 277-287.

Render, J. H. and Allen, R. L. 1987. The relationship between lunar phase and gulf butterfish, *Peprilus burti*, catch rate. Fish. Bull. 85(4), 817-819.

Somers, I. F., Crocos, P. J. and Hill, B. J. 1987a. Distribution and abundance of the tiger prawns *Penaeus esculentus* and *P. semisulcatus* in the north-western Gulf of Carpentaria, Australia. Aust. J. Mar. Freshw. Res. 38, 63-78.

Somers, I. F., Poiner, I. R. and Harris, A. 1987b. A study of the species composition and distribution of commercial penaeid prawns of Torres Strait. Aust. J. Mar. Freshw. Res. 38, 47-61.

Wassenberg, T. J. and Hill, B. J. 1994. Laboratory study of the effect of light on the emergence behaviour of eight species of commercially important adult penaeid prawns. Aust. J. Mar. Freshw. Res. 45, 43-50.

White, T. 1975. Factors affecting the catchability of a penaeid shrimp *Penaeus esculentus*. First Australian National Prawn Seminar, Maroochydore, Queensland, 22-27 November, 1973. Australian Government Publishing Service, Canberra, P. C. Young, Editor.

9.7 Evaluating methods for monitoring bycatch

9.7.1 Introduction

This section has the following main objectives:

- To describe the requirements of a bycatch monitoring program.
- To compare the three most likely methods that can be used to collect data on NPF bycatch, mainly in terms of their accuracy, feasibility, stakeholder acceptance and cost.

Firstly we describe the status of bycatch monitoring in Australia, then some of the most important issues that influence the requirement for monitoring bycatch in the NPF. The range of other project outcomes that lend information to this assessment are then summarised, followed by a general description of the process required by a bycatch monitoring program for a large, high-profile fishery such as the NPF. We then compare the three main methods that could be used for monitoring bycatch: scientific surveys, trained observer collections and crew-member observer collections. This is done by firstly comparing the four most important issues: data reliability and accuracy, feasibility of data collection, stakeholder acceptance and cost. Other important issues are then flagged and described followed by the main conclusions.

(i) Current status of bycatch monitoring in Australia

Concern for the impacts of fishing on bycatch species has increased considerably over the last decade. However, in most of Australia's fisheries this concern has not been great enough yet to initiate programs to monitor bycatch, although all Commonwealth fisheries are now required to develop an appropriate Bycatch Action Plan. Only the South East Trawl Fishery, the Heard Island and McDonald Islands Fishery, the Macquarie Island Fishery and the Northern Prawn Fishery currently have some form of bycatch monitoring in place. These fisheries have been examined for similarities with the NPF, to assist the assessment of methods for monitoring its bycatch.

The South East Trawl Fishery uses trained observers to monitor catches of both target and discarded species (Knuckey and Liggins, 1999). This observer program records catch estimates for target and discarded species, size composition of all fish species from subsamples, as well as otoliths from selected target and discarded species. This fishery includes a range of different trawl grounds and target species, and levels of discarded bycatch vary greatly from almost none per trawl to about 50% of the catch. Where the bycatch is highest there may be more than 100 species of fish and invertebrates discarded (I. Knuckey, pers comm).

The Heard Island and McDonald Islands Fishery and the Macquarie Island Fishery mainly target Patagonian tooth fish and both operate a similar observer program. Trained observers record the species composition and abundances of both retained and discarded species. However, on average, less than 2% of the catch is discarded and this usually consists of less than five species of fish or invertebrates (Martin Scott, AFMA. pers comm).

The Northern Prawn Fishery is the only Australian prawn trawl fishery with some form of bycatch monitoring program. This program uses crew-member observers (trained fishers) on NPF vessels to collect information on sea turtles, and to a lesser degree, sawfishes and sea snakes. Turtle captures are also recorded in logbooks, but the data are not used in any monitoring procedure. Previous estimates of total captures and trawl-induced mortality were made between 1979 and 1988 (Poiner *et al.,* 1990) and again in 1989 and 1990 (Poiner and Harris, 1996), using information from a group of crew-member observers. These studies concluded that trawl-induced drowning is not a major factor affecting the populations of five species of sea turtle. The current turtle monitoring program follows up this research (FRDC 98/202). It will produce estimates of capture and mortality due to prawn trawling in the NPF. However, the bulk of NPF bycatch is made up of fish, elasmobranchs and invertebrates (Section 6.2) for which there is currently no monitoring program in place.

The only other bycatch monitoring program in an Australian prawn trawl fishery was undertaken in winter 1990 to autumn 1992 in the NSW oceanic prawn trawl fishery (Kennelly *et al.,* 1998). This program used trained observers to sample the bycatch composition from four of the most important fleets in this fishery. Although it was short term the detailed catch data collected on individual bycatch species should provide a useful data set for any future monitoring program.

The Coral Sea mixed species trawl fishery has no formal bycatch monitoring in place. However, fishers are currently providing data on the estimated weight of bycatch caught in trawls.

The Tuna longline fishery has been the subject of an assessment under the *Endangered Species Protection Act 1992* for its impact on endangered seabirds. Although there is currently no bycatch monitoring program in place, a pilot observer program will commence in mid-2000.

(ii) Why the NPF is different

The bycatch of the NPF is a of diverse collection of more than 700 species of animals, including small and large fish (411 species, Section 7.2); sharks, stingrays and other elasmobranchs (56 species, Section 7.3), sea snakes (13 species, Section 7.4), sea turtles (five species, Poiner and Harris 1996) and a wide range of invertebrates (234 species, Section 6.2). This suite of animals is far more numerous and diverse than the bycatch of any fishery already using some form of bycatch monitoring program. These differences make it impossible to simply replicate or transfer the methods of another fishery into the NPF. Instead, the method used to monitor NPF bycatch will need to be tailored specifically, and the comparison of methods presented in this section provides information for such a process.

(iii) Why assess methods for monitoring bycatch

There are no published studies that compare different methods for monitoring a trawl fishery. This may be because, in most cases, the catch monitoring involves relatively simple decisions and choosing the best method is usually a relatively straightforward task not requiring an in-depth comparison of methods. There is usually only one or a few species involved, normally target species. These data can sometimes be obtained from logbook information or from the amount of product stored or sold. Alternatively, either scientific surveys (Azarovitz 1981; Halliday and Koeller 1981, Pitt 1981) or trained observers (Kennelly *et al.,* 1998) are usually used to ensure the completeness and integrity of data collected. In most previous monitoring programs the process for choosing which method to use has probably been based on subjective assessments and the data requirements of the program.

The complex nature of the NPF and its bycatch is such that monitoring will not be straightforward or cheap and there is no obvious best method. However, the comparison of monitoring methods presented in this section provides data and information on the most important issues that should be addressed in making any assessment.

(iv) Obligations for monitoring bycatch in the NPF

It is clear from the legislation that the NPF has an obligation to measure and report on the status of the impacted non-target species (see Section 2). The most obvious of these are bycatch caught during trawling operations. The only way to fulfil this obligation is to set up a monitoring program that can measure a change in the status of catches that may impact populations or community assemblages. This requirement for monitoring bycatch is also listed as the third aim of the NPF Bycatch Action Plan (Anon 1998). It states that "*By the year 2001, NORMAC and AFMA will introduce an effective monitoring system acceptable to all stakeholders to monitor the amounts and composition of bycatch*".

The nature of such a monitoring system depends on many factors, many of which are addressed and/or compared in the remainder of this section. However, the implementation of a monitoring program requires careful planning to ensure that its methods are cost-effective and that the data collected are accurate, statistically robust and able to address its objectives. They must also be acceptable to the range of stakeholders that are concerned with the NPF and its impacts on the marine environment. This section of the report addresses these issues.

(v) Bycatch Reduction Devices and monitoring

The use of Bycatch Reduction Devices will be compulsory in the NPF and will begin two weeks after the start of the 2000 season. This requirement includes the simultaneous use of a Turtle Excluder Device (TED) – to exclude turtles and other large animals such as large sharks, stingrays and sponges – and a Bycatch Reduction Device (BRD) to exclude smaller animals, including fish and sea snakes. Their ability to exclude animals depends on the type of device used and other factors such as environmental conditions and habitat type (Eayrs *et al.,* 1997).

The use of BRDs and TEDs should (i) dramatically reduce the number of large animals caught (e.g. >95% exclusion of sea turtles is expected), and (ii) reduce the numbers of small fish and other animals - probably by 15 to 30% initially (estimated from the range of results to date). Although the use of BRDs and TEDs may reduce the impacts of prawn trawling for many species, there will remain a need to monitor catches for the following reasons:

(i) The reduced catch of some species (via use of TEDs or BRDs) does not necessarily result in a non-significant impact on their natural population levels.

(ii) It is likely that many species will show little or no reduction in numbers caught after the introduction of BRDs and TEDs.

(iii) Selective escapement of species through BRDs and TEDs may cause a new imbalance in demersal community assemblages (as reported for the N.W. Shelf by Sainsbury (1987)).

9.7.2. Review of other project outcomes with implications for monitoring bycatch

The nature of the NPF and its large and diverse bycatch inevitably means that any major gains in our knowledge will require a relatively complex methodology and significant resources. And yet without this and a detailed knowledge of the fishery processes, it would be difficult to design a suitable and acceptable program to adequately monitor the fishery's bycatch. Although a few previous studies have contributed to our knowledge of the NPF and its bycatch (summarised in Section 5), the current study has added large amounts of new information that is crucial to the management of the bycatch issues in the NPF. Much of this knowledge has implications for our assessment of a bycatch monitoring program and these are summarised below.

(i) Monitoring and managing a very large and diverse suite of species.
The bycatch of the NPF is made up of a diverse suite of more than 480 species of vertebrates (Section 7) and more than 230 identifiable invertebrate taxa (Section 6.2), most (>90%) of which are relatively rare. We have very little detailed knowledge about the biology and ecology of most of these species, and it is impractical to make a detailed study of each as one would for a target species. Instead, an alternative strategy is required that can recognise, from catch data only, when any individual species (whether rare or common) is dangerously overfished. In this way, any more costly information that may be required to assess the species sustainability can be restricted to a much smaller subset of species.

The NPF bycatch also includes species that differ in the way that information about them can be collected. The majority of species need only have information collected about them from subsamples of the trawl catch. These include hundreds of species of small fish and invertebrates. These samples can be frozen and sent to a laboratory. Other species can only feasibly have information recorded about them while on the fishing vessel. These include a group of conspicuous species that may be too large to be frozen and sent to laboratories, and charismatic or protected species that should be returned to the sea alive. This group includes sea turtles, sharks, stingrays, sawfishes, sea snakes and large invertebrates such as sponges. Most of these conspicuous species are also difficult to identify taxonomically. Hence the requirement to record data about them on board the fishing vessel poses a further challenge to any effective monitoring program. Because of the large and diverse suite of species that will need to be assessed in the NPF an effective bycatch monitoring program will need to use more than one method of collecting data.

(ii) Detecting change in catches of many species
Another difficulty with designing a monitoring program to suit a number of different species is deciding how to choose a level of sampling effort. Species with different levels of abundance and between-trawl variability require different levels of sampling effort in order to detect changes in abundance over time. As part of the current study, data were collected and analysed to define this sampling effort for a large suite of bycatch species, ranging from very abundant to very rare (Section 9.5), and these data are used to help design the monitoring requirements presented later in this section.

In order to determine the sampling effort required to measure a change in the catch rates of bycatch species, catch data on the bycatch of the NPF were collected from two high effort areas ('North Groote' and 'North Mornington'). This study is described in detail in Section 9.5. Here we report the number of trawls that need to be sampled in order to show a statistically robust change in the catch rates. These data are presented for each species and for three different levels of change in catch rates: 50%, 75% and 99.9%. It would be possible to detect smaller changes in catches of the more abundant, less variable species (e.g. a 25% drop in abundance). However, catches are dominated by the rarer species and the levels of effort required to detect change for these are not feasible.

This monitoring effort data provide performance measures and the guidelines that allow comparisons of catches of species between years. Thus, the performance measure (ie. a nominated percentage change in catch between one or more years) can be selected by the fishery manager and used to determine the sustainability of bycatch species over time.

(iii) Identifying bycatch communities in the NPF

Although the NPF and Torres Strait Prawn Fishery (TSPF) are separated into 11 different regions for management purposes, it may not be feasible or necessary to monitor the bycatch from each of them. Besides the logistic difficulty of obtaining enough data from each region from any method, it would be extremely expensive. We show elsewhere in this section that considerable effort and expense are required to adequately monitor the bycatch for one region only. Thus, it would be more desirable to restrict any bycatch monitoring program to as few of these regions as possible. These regions should be sampled well enough to be able to detect changes in selected species and act as surrogate regions for the entire NPF and TSPF.

In Section 6.2 we have shown that there are two main bycatch species associations in the NPF. These are associated with the separate distribution of two of the main target species: *Penaeus semisulcatus* and *P. esculentus*. Given that different bycatch species associations may respond differently to fishing pressure, an adequate monitoring program would need to have a suitable monitoring effort for each of these.

For the majority of NPF bycatch species it is important that sampling effort for monitoring be compartmentalised to these individual regions to maximise the ability to detect meaningful change in populations. However, some species, such as sea turtles and elasmobranchs, range much more widely than the majority of bycatch species (mostly small fish) and it is likely that their populations should be at a broader spatial scale, possibly over the range of the whole fishery. Consequently, any monitoring program may need to have separate sampling strategies for at least two separate spatial scales to maximise the quality and quality of data collected for different bycatch groups.

(iv) Lunar periodicity of catches

This study also included an analysis of lunar periodicity in species caught in prawn trawl catches in the NPF using previous data sets collected by CSIRO Marine Research (Section 9.6). The results of this work have implications for the sample design of any future bycatch monitoring program. It provides the first evidence that the catchability of 40% of bycatch species shows lunar periodicity. The implications for monitoring include a requirement to account for this source of variability in any sampling design, by ensuring consistency in the period of the lunar cycle that bycatch data is collected from year to year. A less likely option is for monitoring to be directed only at species that do not show this lunar periodicity. However, there is probably not enough information on individual species for this approach to be useful.

(v) Diel periodicity
In Section 7.2 we report that 82% of fish species show significant differences in catch rates between day and night. This information should be used when deciding which trawls should be used for monitoring bycatch. For example, in the NPF, fishers can trawl during both day and night for the first half of the year, and from 1830 to 0800 in the second half of the year. However, most effort (and subsequent impact on bycatch) is made at night in the tiger prawn, pattern-trawl fishery. When designing a monitoring program, the amount of sampling effort required to detect changes in species abundances is higher when the between-trawl variability in catch rates is greater. This variability could be substantially reduced, for example, by not including trawls made during daylight. Our preliminary power analyses have shown that removing the "dawn shot" from the data probably results in a significant decrease in the number of trawls required to detect changes in catch rates. This difference in sampling effort could translate to large savings in the costs of monitoring for this fishery. Thus, the impacts of including day trawls in any monitoring program should be further examined and carefully considered.

(vi) Methods and implications of subsampling catches
The amount and diversity of bycatch taken in NPF catches is such that reliable catch data for individual species may only be obtainable by taking subsamples of catches for subsequent processing in a laboratory. However, before the studies described in Sections 9.2 – 9.5, there was no information that quantified the ability of subsamples to represent trawl catches. The results of these studies have led to the design of methods that give unbiased and predictable sampling strategies for monitoring NPF bycatch, and these are used in the comparisons of methods for monitoring described in a later section.

9.7.3 The components of a bycatch monitoring program

In this section we explain the main components of any large-scale bycatch monitoring program. These are described under the following topics:

- The aim of a bycatch monitoring program.
- Timeframes for bycatch monitoring programs.
- A formal process for identifying and responding to population change.
- Data reliability and accuracy.
- Acceptability to stakeholders.
- Feasibility of data collection.
- Cost-effectiveness.

(i) The aim of a bycatch monitoring program

A monitoring program should have the following main aims:

(a) To describe the species of bycatch caught, and some measure of their abundance.

(b) To collect information that will enable the detection of change in species populations. The program should be able to detect any significant decline in the catch of a species that correspond to a drop in population levels that is unsustainable, either locally or throughout their distributions. However, significant increases in populations may also be an indication of change in the balance of the composition of species in the marine community. To this end it is important that there be a process for interpreting changes in catches in terms of real population levels.

(ii) Timeframes for bycatch monitoring programs

One of the greatest difficulties with detecting change in populations of marine species over time is separating change due to the impact of fishing from other more natural sources of variability. Although some sources of natural variability can be minimised in a well-constructed sample design (e.g. diel or lunar catchability), variability from year to year is more difficult to accommodate. For this reason it is critical that any monitoring program should collect data over the long term. Although any changes in catches can be measured from year to year, without a long-term data set it may be unclear whether the changes represent a consistent and concerning trend.

(iii) A formal process for identifying and responding to population change

In conjunction with the collection of long-term data sets to detect meaningful change, there also needs to be a formal process for identifying changes. Processes or triggers should be put in place to validate the change and/or address the issue. Sainsbury *et al.* (1999) described an appropriate and nationally accepted process for managing species, which should also be applied to the management of bycatch in the NPF. They define three key terms that are used to indicate species sustainability:

<u>Sustainability indicator</u>: a quality that can be measured and used to track changes in the status of a key component of the system that is thought to relate to sustainability.

<u>Reference point</u>: the value of a sustainability indicator that corresponds to some agreed management, limit or trigger for management action.

<u>Performance measure</u>: a quality that can be used to measure management performance against objectives, and particularly the value of a sustainability indicator in relation to a reference point.

An example of the relationship between these terms is depicted in Figure 9.7.1. An estimate of current biomass is used as the sustainability indicator. This may be a feasible indicator for the target species in most Australian fisheries, but is probably not feasible for the hundreds of bycatch species in the NPF for which very little is known about their biology and ecology. Biomass estimates of most bycatch species would also be difficult to obtain with fishery-dependent methods which fish very selected areas and do not target these species.

It is also important to realise that current biomass levels of bycatch species in the NPF are the result of more than 30 years of fishing pressure. The virgin biomasses of bycatch species have probably been substantially impacted since the fishery began. These impacts have been through direct harvesting of their populations and indirectly through habitat modification by prawn trawling activities. As well as acknowledging that bycatch populations have and will continue to be impacted by fishing, their current population levels should not be treated being sustainable if nothing changes, as this may not be the case.

Choosing appropriate sustainability indicators is an important step towards setting up a monitoring program for NPF bycatch. NORMAC's Bycatch Action Plan describes the requirement for sustainability indicators and these will have to chosen carefully by the appropriate management group (NORMAC 1998). Although choosing sustainability indicators for the NPF is a complex issue, the data provided in this report will greatly assist the decision processes required to set up this part of the bycatch monitoring program.

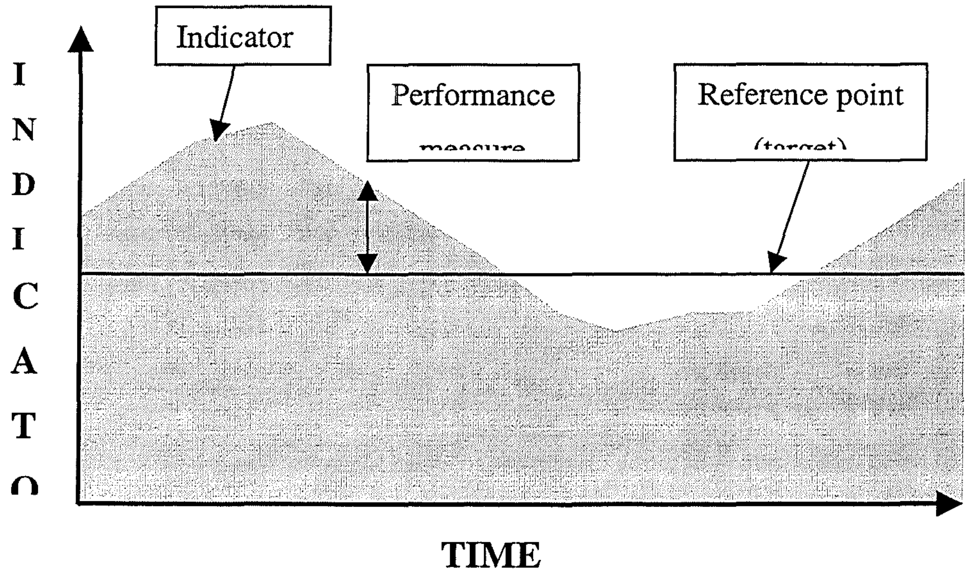


Figure 9.7.1 An example of the relationship between an indicator, a target Reference Point and a Performance Measure over time. The indicator is a quantity of relevance selected for measurement, the appropriate target reference point for this indicator is derived from the management objectives, and the performance measure is (in this case) the difference between the indicator and the target reference point. Note that in practice indicators are measured with error (both bias and noise) which accounts for some of the variation over time. (reproduced from Sainsbury *et al.* 1999)

Suitable reference points should relate to some sustainable level of catch. However, this requires detailed knowledge of aspects of the biology of each species and their interaction with the fishing procedure. This is not likely to be feasible for the hundreds of species caught in the bycatch of the NPF. Instead, the sustainability of bycatch species could be examined, for example by using current catch data as reference points and monitoring for change in subsequent years. Under this scenario, performance measures will need to be carefully set to ensure that declines in catches that are unsustainable can be recognised as soon as possible. These performance measures should be set and monitored by the fishery manager as an objective of any monitoring program. As described in Sainsbury *et al.* (1999), performance measures may be linked to response strategies that either validate or refute the presence of the threat and, if necessary, reduce or remove fishing effort on the species showing an unsustainable decline in catch.

A series of management options or triggers should also be established so that an appropriate management response is followed if bycatch populations appear to be declining in an unsustainable way. For example, triggers or responses for a species in apparent steady decline may include (i) close examination of its population dynamics to improve our knowledge of its susceptibility to trawling, or (ii) an examination of its abundance in adjacent low or no effort areas. Triggers or responses for a species in an apparent severe decline may include (i) the responses listed for above, (ii) determine ways to minimise the fishing impact on the species (e.g. specific BRDs or closed areas), and/or (iii) determine ways to completely halt the impact on the species (e.g. closed areas).

The above recommendation for establishing sustainability indicators, reference points and performance measures is important for any bycatch monitoring program for the NPF. A detailed consideration of these methods is beyond the scope of this study. However it is critical, that the fishery manager ensure that these formal processes for identifying change and making appropriate management responses be put in place during the planning stages of any bycatch monitoring program.

(iv) Data reliability and accuracy

It is important that any data collected from monitoring catches are reliable (e.g. consistently collected from the right place at the right time) and accurate (e.g. correct species identifications, accurate counts etc). The different methods that can be used to monitor fishery bycatch will vary in their reliability and accuracy, but this will also vary from fishery to fishery. Sometimes the more reliable and accurate methods of data collection are also the most costly, and a balance may need to be found between cost and data reliability and accuracy. Unreliable data collection methods can lead to incomplete data sets that restrict or cripple the performance of the program, and may subsequently lead to inappropriate or poor decisions about managing the fishing impact on bycatch species.

(v) Acceptability to stakeholders

The results of monitoring should be acceptable to all stakeholders of the fishing industry. The main stakeholders of a fishery usually include a wide range of groups such as the fishing industry themselves, associated feeder industries, fishery managers, research organisations, conservation organisations, politicians, and the broader community. Some of these groups (e.g. conservation organisations and politicians) can wield a strong influence on the management of a fishery and so it is important that any monitoring program is trusted and accepted by as many non-industry stakeholders as possible. On the other hand, if the industry does not accept the method for monitoring, they may withdraw their co-operation or assert their own political pressure to try and remove the monitoring program.

Obtaining stakeholder acceptance can be enhanced by involving them in the planning and/or data collection stages of the monitoring program, and having a widespread communication program that educates them in the benefits of monitoring.

(vi) Feasibility of data collection

When planning a monitoring program there are many issues about the feasibility of the method that should be considered. These issues are often not initially obvious and usually can only be dealt with by having a detailed knowledge of the specific fishery. These can often be described as "what is realistically possible" and may include assessments of limitations to data collection such as (i) the expected level of co-operation by industry, (ii) the level of intrusion on the fishing operation by trained observers, (iii) the amount of extra workload that can be carried by crew-member observers, (iv) the cost of monitoring compared to fishery profitability, (v) the number of vessels available as data collection platforms compared to the number required to collect the minimum amount of data that is required to monitor bycatch. These types of issues must be addressed when assessing the type of bycatch monitoring program to implement.

(vii) Cost-effectiveness

The choice of methods for monitoring will usually also require a comparison of the costs and benefits of each method. However, the constraints placed on the selection of an appropriate monitoring strategy by other requirements (described above) may override many of the potential financial considerations. For example, although a cheaper monitoring strategy may be preferred, it's inability to collect reliable or accurate data should exclude its use.

There may be some flexibility in the costs and benefits associated with the amount of monitoring effort used. A larger effort (e.g. more trained observers or more samples collected and processed) requires greater cost, but usually provides greater precision or ability to detect changes in species populations. Thus the benefit gained from a more costly monitoring program may be the subject of a value judgement made by the fishery manager.

An analysis of the costs associated with different monitoring strategies also requires a detailed and comprehensive budgeting process based on knowledge of the entire monitoring process. This process may include components such as pre-monitoring training of observers and/or fishers, costs of the design and management of databases and sampling protocol, costs of collecting data, storing, transporting and processing samples, costs of analysing data and producing outputs and costs of educating and informing stakeholders.

9.7.4 Comparing monitoring strategies for use in the NPF

This section involves a comparison of the three most likely methods that could be used to monitor bycatch: (i) collection by crew-member observers; (ii) collection by trained observers; and (iii) collection by research surveys. They are compared using the following criteria: data reliability and accuracy, data feasibility, stakeholder acceptance and cost (Figure 9.7.2). Each assessment also describes the different sampling requirements needed for each different group of bycatch species.

The information is meant to provide the framework that allows the fishery manager to choose the most appropriate method to monitor bycatch in the NPF and to design a suitable monitoring program. Although some scenarios for monitoring are also presented, this document does not provide the actual recommendations or decisions about which method to use, as this will vary depending on the specific objectives of the monitoring program.

In order to compare the procedures and information for each of the data collection methods, we designed and implemented a data collection program for each. The procedures and data collected from the research surveys are described in Section 6.2. A general description of the procedures and data collected by trained observers on NPF vessels is given in Sections 9.4.2 and 9.5.2. The procedures and data collected by the crew-member observer collections are described in Appendix 3D.

(i) Data reliability and accuracy

Our assessment of data reliability was collated from previous experiences of project staff in the NPF and other fisheries, and from subjective data gathered during the course of this project. Data reliability is an assessment of several factors including (i) the likelihood that the data collected are accurate (e.g. correct species identification, accurate station log data), and (ii) the likelihood that data are collected in an unbiased way (e.g. collecting unbiased samples, recording samples in the correct frequency). A more detailed, statistically robust comparison of data reliability may improve the accuracy of our assessments. However, this level of comparison requires considerable resources and was beyond the scope of this study.

The assessment of the reliability of the data collected from each method is summarised in Tables 9.7.1 to 9.7.3. The reliability of data collected by trained observers or research surveys is higher than the collections made by crew-member observers. This is due to several factors:

- Scientists and trained observers are more likely to be trained in the taxonomic identification of species.
- Scientists and trained observers are dedicated to the tasks of data collection, but these tasks are secondary for crew-member observers after catching, sorting and packaging the target species.

However, the collection of samples required to assess the abundance of the many small species caught by prawn trawls, may be reliably collected by all three methods. For species that are assessed from samples (most of the smaller organisms), the reliability of each collection method hinges on two things: the amount of bias in the sample collection, and the accuracy of the processing procedure. Both should be the same for each method. All three methods should equally be able to collect 10 kg samples of the catch by using a shovelling process into a carton or other container. Furthermore, we have shown in Section 9.2 that these samples can be taken from any part of the catch without bias. An exception would be boats with hoppers. These will need to divert some of the catch onto a separate tray to avoid the bias encountered by taking samples of bycatch from the conveyor belt sorting system (see section 9.3). All three methods would also rely on the processing of these samples by trained technicians; either on board the vessel (research surveys) or by sending them to a scientific laboratory. Thus the accuracy of the data collected on small organisms should be high for all three sampling methods.

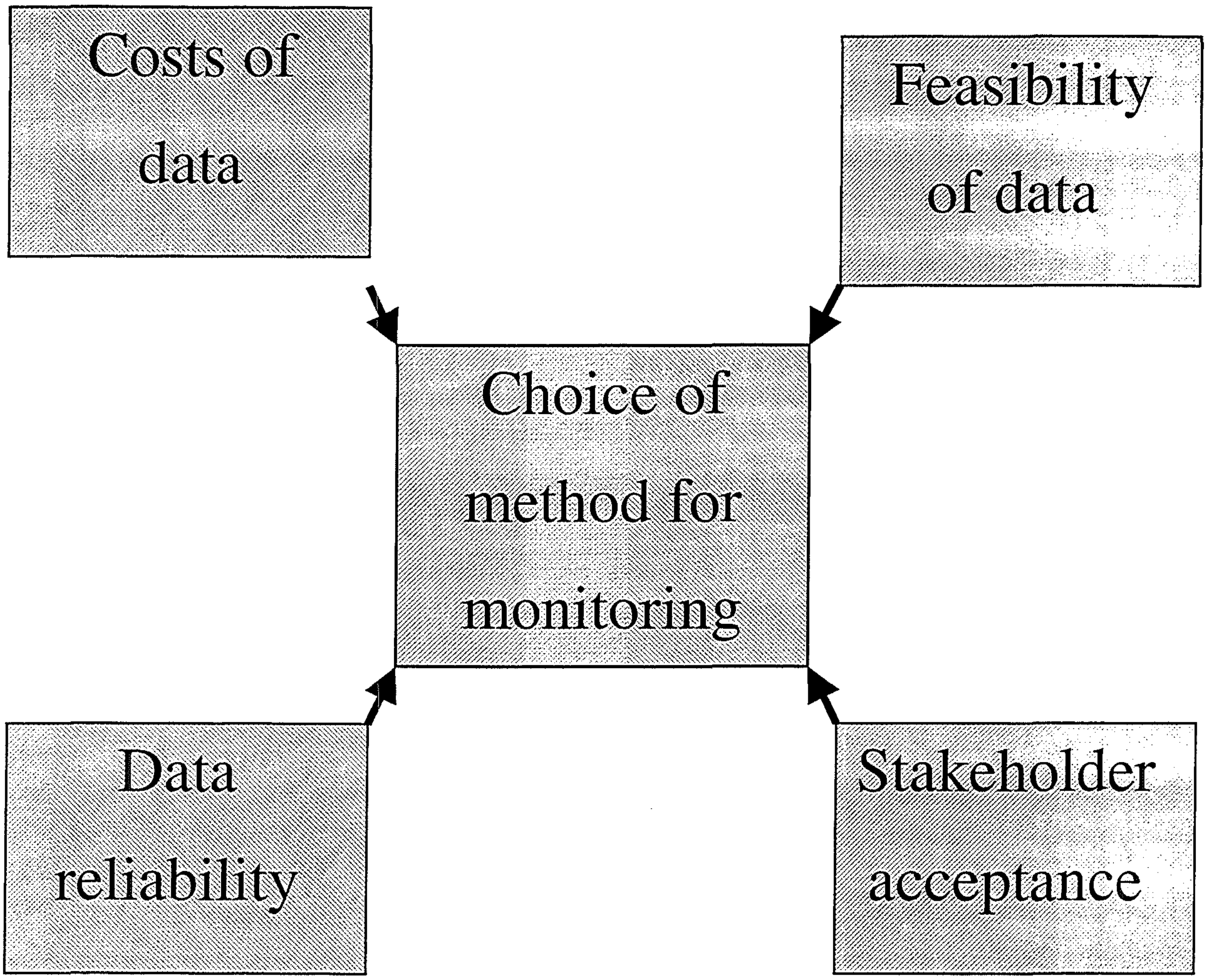


Figure 9.7.2 Diagram showing the four main criteria that are assessed in the comparison of different methods for monitoring bycatch in the Northern Prawn Fishery.

The other bycatch groups that may also have a high reliability ranking for all three methods are sea snakes. This is only the case if they are kept and sent to a scientific laboratory for identification. We have assumed that the bycatch groups that do not have a high reliability ranking for crew-member observer collections are either too large to send to a laboratory, and hence need to be identified and processed on board (e.g. turtles, sawfish), and may also be difficult to identify to species (e.g. sharks, rays and many invertebrates).

(ii) Feasibility of data collection

Information on the feasibility of data collection was collected during the course of the project as these issues arose. In most cases they are straightforward restrictions on data collection based on the capability of the sampling procedures.

The assessment of the feasibility of the data collection methods is summarised in Tables 9.7.4 to 9.7.6. The main issues that may affect the feasibility of data collection are:

- The sampling effort required to measure a change in abundance of a species compared to the capacity of the method to collect data.
- The ability of the method to collect data on each of the species groups simultaneously (although this is not reflected in the tabulated rankings)
- The ability of vessels to process or store large amounts of frozen samples (although this is not expected to restrict any of the methods).

Collections by crew-member observers have the capacity to contribute large volumes of information. The main restrictions on the number of trawls that can be sampled may be:

- the number of trawlers in one region of the NPF in any one time (maximum of 20-30 in the highest effort areas);
- the number of tasks to be undertaken (e.g. the number of species groups that can be processed simultaneously) without hindering the trawl operation;
- the number of samples that can be stored in the freezer hold of trawlers without hindering storage of frozen product and
- the time and effort needed to process large numbers of subsamples in the laboratory.

The first two issues are the most likely to pose a hindrance to a crew-member observer based monitoring program. The first (requiring 20-30 trawlers in one region in a limited time period), is at the limit of the fleets capacity, and its feasibility can change with changes in fleet behaviour; and the second (processing many bycatch groups) will depend on the requirements of the monitoring program. Despite these uncertainties, crew-member observer collections have received high feasibility rankings for all bycatch groups although this may be subject to change (Table 9.7.4).

The same issues listed for crew-member observer collections may also restrict collections by trained observers. However, a trained observer is more capable of processing a range of bycatch groups simultaneously. A specific issue for trained observer collections may be the number of berths on some NPF trawlers. However, like the other issues above, this is not expected to seriously impede a trained observer monitoring program, and we have assigned high feasibility rankings for all bycatch groups for this method (Table 9.7.5).

Research surveys are best equipped to collect data on all of the species groups simultaneously. However, they are limited in their capacity to collect the large numbers of samples required to detect differences in catches of the very rare species over time. The very rare species require six sampling units (six research vessels or chartered trawlers sampling for a month simultaneously) to collect enough data to detect differences in catches over time in one region only (calculated from Table 9.5.4). However, in Australia, there is a very limited pool of scientific vessels with trawling capability and numbers of skilled scientific staff are also limited. It may also be difficult to obtain the numbers of trawlers required for charter..

Table 9.7.1 A summary assessment of the reliability and accuracy of data collected by crew-member observers in the Northern Prawn Fishery for the purposes of monitoring prawn trawl bycatch.

Bycatch group	**Collectable data**	**Suggested Data reliability ranking**	**Justification**
Sea turtles	Spp id, wts, nos and lengths	Medium	Depending on participation in training programs – currently underway
Sea snakes	Spp id, wts, nos and lengths on board	Low	Depending on participation in training programs – identification to species is difficult
Sea snakes (least likely option)	*Samples sent to the laboratory*	*High*	*Dedicated processing time in the lab*
Sharks, rays and sawfish	Spp id, wts, nos and lengths	Low	Depending on participation in training programs – identification to species is difficult
Large inverts	Spp id, wts and nos	Low	Requires specialists to identify most species
Small bycatch	Samples to lab	High	Dedicated processing time in the lab

Table 9.7.2 A summary assessment of the reliability and accuracy of data collected by trained observers on Northern Prawn Fishery vessels for the purposes of monitoring prawn trawl bycatch.

Bycatch group	**Collectable data**	**Suggested Data reliability ranking**	**Justification**
Sea turtles	Spp id, wts, nos and lengths	High	Trained staff
Sea snakes	Spp id, wts, nos and lengths or samples to lab	High	Trained staff and dedicated processing time in the lab
Sharks, rays and sawfish	Spp id, wts, nos and lengths	High	Trained staff
Large inverts	Spp id, wts, nos and lengths or samples to lab	High	Trained staff and dedicated processing time in the lab
Small bycatch	Samples to lab	High	Dedicated processing time in the lab

Table 9.7.3 A summary assessment of the reliability and accuracy of data collected by scientific surveys (e.g. using a chartered trawler or scientific research vessel) for the purposes of monitoring prawn trawl bycatch in the Northern Prawn Fishery.

Bycatch group	**Collectable data**	**Suggested Data reliability ranking**	**Justification**
Sea turtles	Spp id, wts, nos and lengths	High	Trained staff and dedicated processing time
Sea snakes	Spp id, wts, nos and lengths or samples to lab	High	Trained staff and dedicated processing time
Sharks, rays, sawfish and large invertebrates	Spp id, wts, nos and lengths or samples to lab	High	Trained staff and dedicated processing time in the lab
Large inverts	Spp id, wts, nos and lengths or samples to lab	High	Trained staff and dedicated processing time in the lab
Small bycatch	Spp id, wts, nos and lengths	High	Dedicated processing time in the lab

Table 9.7.4 A summary assessment of the feasibility of data collection by crew-member observers in the Northern Prawn Fishery for the purposes of monitoring prawn trawl bycatch.

Bycatch group	**Collectable data**	**Suggested data feasibility ranking***	**Justification**
Sea turtles	Spp id, wts, nos and lengths	High	High enough effort capacity of the fleet for most species
Sea snakes	Spp id, wts, nos and lengths	High	High enough effort capacity of the fleet for most species
Sea snakes (least likely option)	*Samples for lab analyses*	*High*	*High effort capacity of the fleet*
Sharks, rays and sawfish	Spp id, wts, nos and lengths	High	High enough effort capacity of the fleet for most species
Sharks, rays and sawfish (least likely option)	*Samples for lab analyses*	*High*	*High enough effort capacity of the fleet for most species*
Large invertebrates	Spp id, wts, nos and lengths	High	High enough effort capacity of the fleet for most species
Large invertebrates (least likely option)	*Samples for lab analyses*	*High*	*High effort capacity of the fleet*
Small bycatch	Samples to lab	High	High enough effort capacity of the fleet for most species

* The feasibility of collecting data for any one group may be reduced by the crew-member observers ability to collect concurrent data on many bycatch groups

Table 9.7.5 A summary assessment of the feasibility of data collection by trained observers on Northern Prawn Fishery vessels for the purposes of monitoring prawn trawl bycatch.

Bycatch group	Collectable data	Suggested data feasibility ranking	Justification
Sea turtles	Spp id, wts, nos and lengths	High	High enough effort capacity of the fleet for most species
Sea snakes	Spp id, wts, nos and lengths or samples to lab	High	High enough effort capacity of the fleet for most species
Sharks, rays and sawfish	Spp id, wts, nos and lengths	High	High enough effort capacity of the fleet for most species
Large inverts	Spp id, wts, nos and lengths or samples to lab	High	High enough effort capacity of the fleet for most species
Small bycatch	Samples to lab	High	High enough effort capacity of the fleet for most species

Table 9.7.6 A summary assessment of the feasibility of data collection by scientific surveys for the purposes of monitoring prawn trawl bycatch in the Northern Prawn Fishery.

Bycatch group	Collectable data	Suggested Data feasibility ranking	Justification
Sea turtles	Spp id, wts, nos and lengths	Low	Effort capacity probably doesn't exist for the rarer species
Sea snakes	Spp id, wts, nos and lengths or samples to lab	Low	Effort capacity probably doesn't exist for the rarer species.
Sharks, rays and sawfish	Spp id, wts, nos and lengths or samples to lab	Low	Effort capacity probably doesn't exist for the rarer species.
Large inverts	Spp id, wts, nos and lengths or samples to lab	Low	Effort capacity probably doesn't exist for the rarer species.
Small bycatch	Spp id, wts, nos and lengths	Low	Effort capacity probably doesn't exist for the rarer species.

This limitation is the main reason for the 'low' feasibility ranking assigned to research surveys as a monitoring method (Table 9.7.6). Research surveys would not usually be restricted by sample storage space as most of the data can be processed on board.

(iii) Stakeholder acceptance

Our assessment of stakeholder acceptance was collated from experienced project staff and subjective data gathered during the project. The primary aim of presenting this information was to demonstrate the importance of this factor when deciding how to monitor bycatch. The fishery manager may improve our assessments by using a consultative process with stakeholders of the fishery or by surveying for their opinions.

An assessment of the stakeholder acceptance of the data collection methods is summarised in Tables 9.7.7 and 9.7.8. Table 9.7.7 summarises some of the key issues affecting the acceptance of each method by the fishing industry. Table 9.7.8 summarises some of the key issues affecting the acceptance of each method by three other important stakeholders: conservationists, scientists and the general public. Although these levels of acceptance may vary over time or may improve in accuracy following extensive, controlled surveys of the stakeholders, the data we provide here should act as a guidepost for the fishery manager when having to select an acceptable method for monitoring NPF bycatch.

Industry acceptance is presented as three main factors: industry trust in the data, imposition to fishers and financial cost to industry. These individual issues are also summarised in Table 9.7.7 to provide a general guide to the acceptance of each monitoring method by industry stakeholders. The summary rankings simply reflect the combination of the three issues. Although these issues may vary in their importance to fishers, they have been weighted evenly to provide the summarised ranking of the likely industry acceptance for each of the monitoring methods.

Industry trust in the data reflects at least two main factors:

- Whether the data is collected on industry vessels (more involvement in the process = a higher level of trust in the data), and
- The difficulty in collecting accurate data (e.g. organisms that are difficult to identify will lead to lower trust in the data by fishers involved in the data collection).

Hence, research surveys are presented as having 'medium' level of trust, whereas trained observer or crew-member observer collected data received a 'high' or 'medium' depending on the difficulty in processing the particular bycatch group.

The rankings assigned for "Imposition to crew-member observers" (Table 9.7.7) are a reflection of the imposition on the fishing operation. Examples include having to accommodate a trained observer on board, having to take time from their normal operations to collect information or samples of bycatch, having to give up freezer storage space for bycatch samples, and a much greater effort unloading to freezer boats. Research surveys received a 'high' ranking for their lack of imposition on crew-member observers, trained observer collections rank as 'medium' because fishers must accommodate a trained observer and their activities, and crew-member observer collections received a 'low' rank due to their having additional tasks (collecting bycatch data and/or samples) on top of their normal fishing

activities (Table 9.7.7). These additional tasks could be a major impediment to crew-member observer collections of bycatch data, especially if data and/or samples need to be collected for many different groups of species. Trained observer and crew-member observer collections may also be inconvenienced by having to use large amounts of freezer space for subsamples of small bycatch. However, our experience is that the rate of offloading to motherships is frequent enough that subsamples should not impinge upon the freezer space required for cartons of commercially valuable prawns.

The financial cost to industry has been ranked with the lowest industry acceptance where the costs are highest, and vice versa. These data are taken from Tables 9.7.13 (described below). In general, the crew-member observer collections are cheapest and received a 'high' acceptance, trained observer costs receive a 'medium' ranking and research surveys, a low acceptance ranking.

The data we present for conservationists, scientists and general public simply reflect the likely trust in data collected by parties that are more independent of the fishing business compared to people within the industry. Hence, research surveys and trained observer collections have a high ranking, and crew-member observer collections were assigned a medium level of acceptance for all three non-industry stakeholders. The lower acceptance of crew-member observer collections was based on the expectation that fishers may not collect reliable information on bycatch given that (i) their primary focus is sorting the catch for the target species and (ii) they are perceived to have a vested interest that focuses on maximising prawn catches not conserving the bycatch.

(iv) Costs of monitoring

The capital costs associated with the various monitoring strategies were recorded or calculated from the pilot sampling in this study, or were obtained from other current sources. It is important to note that many of the costs may vary with factors such as the source of supplier and time of purchase.

No attempt has been made to estimate whether there may be opportunity costs born by industry, such as loss of income due to the diversion of crew from income generating activities to bycatch sample collection. However, the imposition of this bycatch sample collection on the fishing operation has been incorporated into the sections on stakeholder acceptance and feasibility of data collection.

Where possible, standardised units of measure are used to compare the costs of each method (for example the cost of collecting and processing one 10 kg sample of bycatch) (see Tables 9.7.9 to 9.7.13).

Table 9.7.7 Suggested levels of industry acceptance for three methods of monitoring bycatch in the Northern Prawn Fishery. Costs to industry are defined as follows: up to $100,000/year = low (= 'High' acceptance); $100,001-$1,000,000 = medium (= 'Medium' acceptance); >$1,000,000 = high (= 'Low' acceptance). All bycatch groups contain some 'very rare' species and so the costs for monitoring this group has been used here (see Tables 9.7.13(a)-(d)).

Bycatch group	Method	Industry trust in the data	Acceptance due to Imposition to crew-member observers[1]	Acceptance due to Financial cost to Industry[2]	Summary
Sea turtles (conspicuous animals)	Crew-member observer	High	Medium	High	High/Med
	Trained observer	High	Medium	**Medium**	Med/High
	Scientific surveys	Medium	High	Low	Medium
Sea snakes (conspicuous animals)	Crew-member observer	Medium	Low	High	Medium
	Trained observer	High	Medium	**Medium**	Med/High
	Scientific surveys	Medium	High	Low	Medium
Sharks, sawfish and rays (conspicuous animals)	Crew-member observer	Medium	Low	High	Medium
	Trained observer	High	Medium	**Medium**	Med/High
	Scientific surveys	Medium	High	Low	Medium
Large invertebrates (conspicuous animals)	Crew-member observer	Medium	Low	High	Medium
	Trained observer	High	Medium	**Medium**	Med/High
	Scientific surveys	Medium	High	Low	Medium
Small bycatch (sampled using subsamples)	Crew-member observer	High	Low	Medium	Medium
	Trained observer	High	Medium	**Medium**	Med/High
	Scientific surveys	Medium	High	Low	Medium

1 – High acceptance recorded here = low imposition to crew-member observers and vice versa.

2 – High acceptance recorded here = low cost to industry.

Table 9.7.8 Suggested levels of stakeholder acceptance (other than the fishing industry) for the three methods of monitoring bycatch in the Northern Prawn Fishery.

Bycatch group	Method	Conservat-ionists	Scientists	General public	Summary
Sea turtles	Crew-member observer	Medium	Medium	Medium	Medium
	Trained observer	High	High	High	High
	Scientific surveys	High	High	High	High
Sea snakes	Crew-member observer	Medium	Medium	Medium	Medium
	Trained observer	High	High	High	High
	Scientific surveys	High	High	High	High
Sharks, Sawfish and rays	Crew-member observer	Medium	Medium	Medium	Medium
	Trained observer	High	High	High	High
	Scientific surveys	High	High	High	High
Large Invertebrates	Crew-member observer	Medium	Medium	Medium	Medium
	Trained observer	High	High	High	High
	Scientific surveys	High	High	High	High
Small bycatch	Crew-member observer	Medium	Medium	Medium	Medium
	Trained observer	High	High	High	High
	Scientific surveys	High	High	High	High

The costs of monitoring bycatch are compared here between the three main methods of data collection: collections by crew-member observers, collections by trained observers and research surveys. The costs presented for each method are derived from the accumulation of the costs of the activities presented in Table 9.7.9(a) and (b). Separate data are presented for (i) the more conspicuous species that may only be able to be processed on board and consequently might not incur large amounts of storage and processing in a laboratory, and (ii) for the small bycatch species that may require subsampling, storage and processing in a laboratory. Tables 9.7.9(a) and (b) show the costs of monitoring for one standard monthly unit of sampling. The final costs of monitoring different species groups (described below) are a combination of the unit costs for each method and the number of units or months required to collect an appropriate amount of data. Costs that have not been included are listed in Table 9.7.10. In order to assist the comparability between methods some standard units of measure have been used and are described in Tables 9.7.11 and 9.7.12.

Most of the costs of monitoring shown in Table 9.7.9(a) and (b) are subject to some variation. In some cases, changes in the costs can result in quite large changes in the overall costs of monitoring (e.g. vessel charter costs, trained observer and technician salaries, at-sea allowances). In the development of a monitoring program, costs may be presented differently. For example, if a private company were contracted to provide the trained observers for the program, they may quote a daily cost that would have many of the separate costs included (e.g. salary, on-costs, allowances and travel). However, the data presented in Table 9.7.9(a) and (b) allow a valid comparison of the costs of monitoring by different methods, and are presented in a way that permits variations to individual items and new costs to be calculated and included.

There is a large variation in the unit costs of monitoring conspicuous bycatch species between the methods presented in Table 9.7.9(a). Collections by crew-member observers are the cheapest at just under $3,000 for one monthly unit of sampling for conspicuous bycatch species (sampling 120 trawls from one trawler in one month). Trained observer collections are also relatively low at $13,200 per monthly unit. Collections by research surveys are more expensive. They incur costs for salaries and allowances of technical and scientific staff and costs for vessel charter. Chartering a trawler costs about $160,000 per month and a scientific vessel costs about three times that - $450,000 per month.

The differences in the unit costs between methods are similar for the small bycatch species (Table 9.7.9(b)). Collections by crew-member observers were cheapest at $29,527 per month. Trained observer collections are also relatively low at $35,309 per monthly unit. These costs are much higher than the costs of monitoring the conspicuous species, mainly due to the costs of freighting, storing and processing subsamples of small bycatch species. These costs also inflate the overall cost of research surveys using chartered trawlers ($249,362 per one monthly unit of sampling) compared to the cheaper cost of monitoring conspicuous bycatch species. However, the research surveys from scientific vessels are similar in cost for both categories of bycatch species.

Table 9.7.13(a)-(d) summarises the costs for monitoring bycatch species of different levels of abundance for each monitoring method, for one region of the NPF. Each cost is a function of the average number of sampling units required and the cost of a monthly sampling unit. The number of sampling units required reflects the number of trawls required to detect a change over time as a proportion of the total number of trawls in a single monthly sampling unit:

$$\text{Total cost} = \frac{\text{Number of trawls to detect change}}{\text{Number of trawls per sampling unit}} \times \text{Cost of one sampling unit}$$

The number of sampling units refers to the number of trawlers, trained observers or research vessels that are required to simultaneously collect reliable and accurate bycatch data from a designated region.

The number of trawls required to detect a change for small bycatch species (requiring subsampling) has been based on the scenario presented for 'North Mornington' in Table 9.5.4. The number of trawls required to detect a change for conspicuous species that can have all individuals removed from the catch has also been based on the scenario presented for 'North Mornington'. These conspicuous species are only present in the 'rare' and 'very rare' categories. These levels of effort for detecting change in the conspicuous bycatch species have been calculated based on data collected from two trawl nets combined (Tables 9.7.13(a) & (b)). Consequently, the number of trawls presented here to detect change for conspicuous bycatch species refers to the number of pairs of trawls.

The same scenarios from the 'North Groote' sampling effort estimations require lower numbers of trawls (Table 9.5.4), and hence, would lead to cheaper monitoring costs. However, for the sake of brevity all estimations of effort have been based on the more conservative data from 'North Mornington' only.

Table 9.7.13(a) describes the estimated costs to detect a 50% change in the catch rates of conspicuous bycatch species at different levels of abundance. Table 9.7.13(b) describes the estimated costs to detect a 99.9% change in the catch rates of conspicuous bycatch species at different levels of abundance. Table 9.7.13(c) describes the estimated costs to detect a 50% change in the catch rates of small bycatch species (collected in subsamples) at different levels of abundance. Table 9.7.13(d) describes the estimated costs to detect a 99.9% change in the catch rates of small bycatch species (collected in subsamples) at different levels of abundance. Costs are also presented in these tables as a percentage of an estimate of the total "boat business profit" of the fishery, for all four scenarios (ABARE 1999). Costs for detecting a 75% change in the catch rates of species are not presented here but can also be calculated from the data presented in this section and in Section 9.5.

In each of these monitoring scenarios costs vary greatly from the cheapest cost for conspicuous bycatch species collected by crew-member observers ($420), to the most expensive for very rare small bycatch species collected during research surveys ($2,947,000). These values represent 0.001% to 9.6%, respectively, of the total business boat profit of the fishery. However, it should be noted that the costs described here may be reduced by removing variability (and therefore number of trawls to detect change) due to the effect of day time trawls (see Section 9.7.2. (v)).

Table 9.7.9(a) Costs of monitoring conspicuous bycatch species (no subsamples and lab processing required) per unit month of sample collection for four methods of data collection.

Item	Unit cost[1]	Justification	Method of data collection			
			Scientific collections (chartered trawler)	Scientific collections (scientific vessel)	Trained observer collections	Crew-member observer collections
No. of people employed			3	8	1	Nil
Salary and on-costs	\$3000/mth or \$5000/mth	Fisheries technician Fisheries scientist	\$9000	\$40,000[2]	\$3000	Nil
Airfares	\$1200 return	Ex-Brisbane to NPF Motherships port	\$3600	\$9,600	\$1200	Nil
On-land allowances	\$150/day (2 days/trip)	accommodation, meals and other allowances	\$900	\$2,400	\$300	Nil
Mothership accommodation	\$100/day	Cost of food and a berth	Nil	Nil	\$600	Nil
Trawler accommodation	\$20/day	Cost of food mainly	Nil	Nil	\$600	Nil
At-sea allowances	\$150/day	Varies greatly between employers	\$14400	\$36,000	\$4,500	Nil
Vessel charter	\$5000/day or \$15000/day	(trawler) (scientific vessel)	\$160,000	\$450,000	Nil	Nil
Materials	\$1500	1000 Waxed cardboard cartons with liners etc	Nil	Nil	Nil	Nil
Sea freight	\$230/m^3	60, 10 kg cartons m^{-3}	Nil	Nil	Nil	Nil
Land freight	\$180/m^3	As above	Nil	Nil	Nil	Nil
Cold storage	\$11/m^3/week		Nil	Nil	Nil	Nil
Sample processing	\$3000/month /person	Technicians salary and on-costs	Nil	Nil	3000[3]	3000[3]
Total cost			**\$174,400**	**\$538,008**	**\$13,201**	**\$3000**

1. Costs for 1 person only, where appropriate.

2. Assumes \$5000/month/person for 8 people (day and night shifts).

3. Salaries and on-costs of one scientific expert (\$5,000/month) for one week to process rarer 'difficult' species.

Table 9.7.9(b) Costs of monitoring small bycatch species (subsamples and lab processing required) per unit month of sample collection for four methods of data collection.

Item	Unit cost[1]	Justification	Method of data collection			
			Scientific collections (chartered trawler)	Scientific collections (scientific vessel)	Trained observer collections	Crew-member observer collections
No. of people employed			3	8	1	Nil
Salary and on-costs	\$3000/mth or (\$5000/mth)	Fisheries technician (Fisheries scientist)	\$9000	\$40,000[4]	\$3000	Nil
Airfares	\$1200 return	Ex-Brisbane to NPF Mothership port	\$3600	\$9,600	\$1200	Nil
On-land allowances	\$150/day (2 days/trip)	accommodation, meals and other allowances	\$900	\$2,400	\$300	Nil
Mothership accommodation	\$100/day	Cost of food and a berth	Nil	Nil	\$600	Nil
Trawler accommodation	\$20/day	Cost of food mainly	Nil	Nil	\$600	Nil
At-sea allowances	\$150/day	Varies greatly between employers	\$14400	\$36,000	\$4,500	Nil
Vessel charter	\$5000/day or \$15000/day	(trawler) (scientific vessel)	\$160,000	\$450,000	Nil	Nil
Materials	\$1500	1000 Waxed cardboard cartons with liners etc	\$1350 (900 cartons)	\$150 (100 cartons)	\$540 (360 cartons)	\$1,080[5] (720 cartons)
Sea freight	$\$230/m^3$	60, 10 kg cartons/m^3	Nil	Nil	\$1380	\$2,720
Land freight	$\$180/m^3$	As above	\$3060	\$300	\$1080	\$2,160
Cold storage	$\$11/m^3$/week		\$3052[2]	\$100	\$509[6]	\$1,967[7]
Sample processing	\$3000/month/person	Technicians salary and on-costs	\$54,000[3]	\$1250[8]	\$21,600[9]	\$21,600[10]
Total cost			**\$249,362**	**\$539,800**	**\$35,309**	**\$29,527**

1. Costs for 1 person only, where appropriate.
2. Calculating on a decreasing cost per week as samples are sorted (25 cartons of bycatch/week, beginning with 900 cartons @ \$11 per week per m^3).
3. Salaries and on-costs for 2 technicians processing bycatch for 9 months (900 cartons of bycatch @ 100 cartons per month).
4. Assumes \$5000/month/person for 8 people (day and night shifts).
5. Need to give out at least a 100% excess of the number of sample collection cartons.
6. Calculating on a decreasing cost per week as samples are sorted (25 cartons/week, beginning with 360 cartons @ \$11 per week per m^3).
7. Calculating on a decreasing cost per week as samples are sorted (25 cartons/week, beginning with 720 cartons @ \$11 per week per m^3).
8. Salaries and on-costs of one scientific expert (\$5,000/month) for one week to process rarer 'difficult' species.

9. Salaries and on-costs for 2 technicians processing bycatch for 3.6 months (360 cartons of bycatch @ 100 cartons per month).

10. Salaries and on-costs for 2 technicians processing bycatch for 3.6 months (360 cartons of bycatch @ 100 cartons per month). This assumes that only 360 of the 720 cartons that were given to crew-member observers for subsample collection are selected for processing.

Table 9.7.10 Activities not included in costings for monitoring bycatch in the NPF.

Activity	Justification
1. Cost of designing databases and programs for data analyses	These are once off costs that are the same for each method
2. Costs of materials for processing samples (e.g. balances, species identification books and keys etc)	Assumed that these will be provided by the contracted organisation
3. Cost of data analyses and production of data summaries and other reports	These are the same for each method and considered here as 'post-monitoring'

Table 9.7.11 Descriptions of the standard units used in the comparison of monitoring methods.

Standard sampling unit	Description
One 10 kg carton of small bycatch	One waxed carton (190 mm x 220 mm x 460 mm) has been used as the sampling unit to subsample bycatch from trawl catches. Subsamples were taken and the animals placed in the carton until it was almost full. When almost full the cartons weighs about 10 to 12 kg. This method can only adequately sample the smaller animals that fit into the waxed carton.
Catch per hectare	Refers to the weight or numbers of anything caught in a single 14 fathom Florida Flyer prawn trawl net and standardised to a one hectare area swept by the mouth of the net. These catches will be expressed as kg h^{-1} (kilograms per hectare) or n ha^{-1} (number per hectare).
Total catch	Refers to the entire catch of anything from both nets of an NPF trawler. This is usually used for either the total weight of the catch (as measured by a load cell or some other method), or the total weight or numbers of larger and/or rarer animals (e.g. sharks, rays, turtles, sea snakes, sponges) that can't or should not be subsampled. Sampling the entire catch is often necessary to obtain reasonable sample sizes.

The very large differences between these monitoring scenarios ensure that the costs will not be ignored when selecting the most suitable method for monitoring NPF bycatch. However, there are many other factors that will also play an important role in restricting which method should be used.

(v) Other things to consider when setting up a monitoring program

Although in Section 9.7 we describe the most important factors that should be assessed when designing on a monitoring program for the NPF, there is a wide range of other factors that should be considered for such a program. These are listed in Appendix 3E and provide information that may help the fishery manager in setting up a high quality, monitoring program in the NPF.

Table 9.7.12. Description of one standard effort unit of field data for each method of monitoring small bycatch species.

Monitoring method	Average effort unit	Number of nights sampling	Number of trawls sampled	Total number of 10 kg subsamples
Scientific collections (charter or research ship)	3 x 10 kg subsamples from each of 10 x 30 min trawls per night	30	300	900
Trained observer collections	3 x 10 kg subsamples from each of 4 commercial trawls per night	30	120	360
Crew-member observer collections	3 x 10 kg subsamples from each of 4 commercial trawls per night	30	120	360

Table 9.7.13(a) Summary costs of monitoring conspicuous bycatch species (collected individually and not collected in subsamples) for two levels of abundance for each monitoring method. Each cost is also presented as the percentage of an estimate of the total profit of the fishery. The effort data are based on measuring a 50% decline in catch rate and are taken from the study at North Mornington (Table 9.5.4). The number of trawls required to detect a decline using scientific surveys are estimated as 80% of the fishery dependent surveys for trawler charters where catches are subsampled, and 50% of the fishery dependent surveys for charter of a research vessel where whole catches can be sorted. NB. These levels of sampling effort and costs are for monitoring one bycatch community or region only.

Species abundance	Method of data collection	No. of trawls to detect a 50% decline	Avg No of sampling units required	Total cost	% of NPF profit (98/99) ($30.7 million[1])
Rare 0.01 - 0.1 per hectare	Crew-member observer	100	0.83	$2,500	0.008%
	Trained observer	100	0.83	$11,000	0.04%
	Scientific – trawler charter	80	0.27	$47,100	0.15%
	Scientific - research vessel	50	0.17	$91,500	0.30%
Very rare 0.001 - 0.01 per hectare	Crew-member observer	2365	19.7	$59,100	0.19%
	Trained observer	2365	19.7	$260,100	0.85%
	Scientific – trawler charter	1892	6.3	$1,098,700	3.57%
	Scientific - research vessel	1182	3.94	$2,119,800	6.90%

1. Taken from a draft *Australian Fisheries Surveys Report for the Northern Prawn Fishery*, ABARE, 1999)

Table 9.7.13(b) Summary costs of monitoring conspicuous bycatch species (collected individually and not collected in subsamples) for two levels of abundance for each monitoring method. Each cost is also presented as the percentage of an estimate of the total profit of the fishery. The effort data are based on measuring a 99.9% decline in catch rate and are taken from the study at North Mornington (Table 9.5.4). The number of trawls required to detect a decline using scientific surveys are estimated as 80% of the fishery dependent surveys for trawler charters where catches are subsampled, and 50% of the fishery dependent surveys for charter of a research vessel where whole catches can be sorted. NB. These levels of sampling effort and costs are for monitoring one bycatch community or region only.

Species abundance	Method of data collection	No. of trawls to detect a 99.9% decline	Avg No of sampling units required	Total cost	% of NPF profit (98/99) ($30.7 million[1])
Rare 0.01 - 0.1 per hectare	Crew-member observer	17	0.14	$420	0.001%
	Trained observer	17	0.14	$1,850	0.006%
	Scientific – trawler charter	14	0.047	$8,200	0.03%
	Scientific - research vessel	9	0.030	$16,100	0.05%
Very rare 0.001 - 0.01 per hectare	Crew-member observer	402	3.35	$10,100	0.03%
	Trained observer	402	3.35	$44,223	0.14%
	Scientific – trawler charter	321	1.07	$186,600	0.61%
	Scientific - research vessel	201	0.67	$360,500	1.17%

1. Taken from a draft *Australian Fisheries Surveys Report for the Northern Prawn Fishery*, ABARE, 1999)

Table 9.7.13(c) Summary costs of monitoring small bycatch species (collected in subsamples) for different levels of abundance for each monitoring method. Each cost is also presented as the percentage of an estimate of the total profit of the fishery. The effort data are based on measuring a 50% decline in catch rate and are taken from the study at North Mornington (Table 9.5.4). The number of trawls required to detect a decline using scientific surveys are estimated as 80% of the fishery dependent surveys for trawler charters where catches are subsampled, and 50% of the fishery dependent surveys for charter of a research vessel where whole catches can be sorted. NB. These levels of sampling effort and costs are for monitoring one bycatch community or region only.

Species abundance	Method of data collection	No. of trawls (and subsamples) to detect a 50% decline	Avg No of sampling units required	Total cost	% of NPF profit (98/99) ($30.7 million[1])
Very abundant (>10 per hectare)	Crew-member observer	77 (231)	0.64	$18,900	0.06%
	Trained observer	77 (231)	0.64	$22,600	0.07%
	Scientific – trawler charter	62 (186)	0.21	$52,400	0.17%
	Scientific - research vessel	40 (-)	0.13	$70,200	0.23%
Abundant (1-10 per hectare)	Crew-member observer	124 (372)	1.03	$30,511	0.10%
	Trained observer	124 (372)	1.03	$36,368	0.12%
	Scientific – trawler charter	99 (297)	0.33	$82,300	0.27%
	Scientific - research vessel	62 (-)	0.21	$111,600	0.36%
Common 0.1 - 1 per hectare	Crew-member observer	290 (870)	2.42	$71,357	0.23%
	Trained observer	290 (870)	2.42	$85,330	0.28%
	Scientific – trawler charter	232 (696)	0.77	$192,800	0.63%
	Scientific - research vessel	145 (-)	0.48	$260,900	0.85%
Rare 0.01 - 0.1 per hectare	Crew-member observer	1116 (3348)	9.3	$274,601	0.89%
	Trained observer	1116 (3348)	9.3	$328,373	1.07%
	Scientific – trawler charter	893 (2679)	2.98	$742,000	2.42%
	Scientific - research vessel	558 (-)	1.86	$1,004,000	3.27%
Very rare 0.001 - 0.01 per hectare	Crew-member observer	3276 (9828)	27.3	$806,087	2.63%
	Trained observer	3276 (9828)	27.3	$963,935	3.14%
	Scientific – trawler charter	2621 (7863)	8.74	$2,179,000	7.10%
	Scientific - research vessel	1638 (-)	5.46	$2,947,000	9.60%

1. Taken from a draft *Australian Fisheries Surveys Report for the Northern Prawn Fishery*, ABARE, 1999)

Table 9.7.13(d) Summary costings of monitoring small bycatch species (collected in subsamples) for different levels of abundance for each monitoring method. Each cost is also presented as the percentage of an estimate of the total profit of the fishery. The effort data are based on measuring a 99.9% decline in catch rate and are taken from the study at North Mornington (Table 9.5.4). The number of trawls required to detect a decline using scientific surveys are estimated as 80% of the fishery dependent surveys for trawler charters where catches are subsampled, and 50% of the fishery dependent surveys for charter of a research vessel where whole catches can be sorted. NB. These levels of sampling effort and costs are for monitoring one bycatch community or region only.

Species abundance	Method of data collection	No. of trawls (and subsamples) to detect a 99.9% decline	Avg No of sampling units required	Total cost	% of NPF profit (98/99) ($30.7 million[1])
Very abundant (>10 per hectare)	Crew-member observer	15 (45)	0.125	$3,700	0.01%
	Trained observer	15 (45)	0.125	$4,400	0.01%
	Scientific – trawler charter	12 (36)	0.05	$12,500	0.04%
	Scientific - research vessel	8 (-)	0.03	$16,200	0.05%
Abundant (1-10 per hectare)	Crew-member observer	24 (72)	0.2	$5,900	0.02%
	Trained observer	24 (72)	0.2	$7,100	0.02%
	Scientific – trawler charter	19 (57)	0.06	$15,000	0.05%
	Scientific - research vessel	12 (-)	0.04	$21,600	0.07%
Common 0.1 - 1 per hectare	Crew-member observer	53 (159)	0.44	$13,000	0.04%
	Trained observer	53 (159)	0.44	$15,500	0.05%
	Scientific – trawler charter	42 (126)	0.14	$34,900	0.11%
	Scientific - research vessel	27 (-)	0.09	$48,600	0.16%
Rare 0.01 - 0.1 per hectare	Crew-member observer	194 (582)	1.62	$47,800	0.16%
	Trained observer	194 (582)	1.62	$57,200	0.19%
	Scientific – trawler charter	155 (465)	0.52	$129,700	0.42%
	Scientific - research vessel	97 (-)	0.32	$172,700	0.56%
Very rare 0.001 - 0.01 per hectare	Crew-member observer	548 (1644)	4.57	$134,900	0.44%
	Trained observer	548 (1644)	4.57	$161,400	0.53%
	Scientific – trawler charter	438 1314)	1.46	$364,100	1.19%
	Scientific - research vessel	274 (-)	0.91	$491,200	1.60%

1. Taken from a draft *Australian Fisheries Surveys Report for the Northern Prawn Fishery*, ABARE, 1999)

In Section 7 we describe how more information about some abiotic parameters could improve our ability to assess the vulnerability of species to trawling. This highlights the need to carefully plan and implement the collection of abiotic data (e.g. fishing depth, time of day, fishing position etc) in any bycatch monitoring program.

(vi) Overall comparison of methods

A summary of the parameters and their rankings used to compare the monitoring methods is presented in Table 9.7.14. The costs presented are for the rarest species groups, and as such, are the most expensive scenarios. An assessment of each method is described below addressing the parameters that may have most bearing on which method to use.

Crew-member observer collections are the cheapest, but may have a major limitation in the types of bycatch data that can be reliably collected. For example, collecting information for each of the different bycatch groups would require a person dedicated to this task. However, if data were required for only one bycatch group (e.g. sea turtles or subsamples of small fish), then collection by this method may be reliable and accurate.

Trained observer collections are also relatively cheap (although more expensive than crew-member observer collections) but have the advantage over crew-member observer collections of having a person dedicated to the bycatch data collection. Trained observers would be able to collect information on each of the bycatch groups, although with some imposition to the fishing crew. The data are also likely to be reliable, accurate and trusted by most stakeholders. An observer on board can also facilitate a very useful transfer of information between the industry and other stakeholder groups.

Research surveys would be able to collect reliable and accurate data on the full suite of bycatch species that is acceptable to most stakeholders and with virtually no imposition on the industry. However, the costs are more than double that of other methods, and depending on the sampling effort required, there may be a major impediment in the number of vessels that are available to collect these data. If the rarer groups are required to be monitored then multiple numbers of either scientific research vessels or trawlers available for charter would be required. Both of these scenarios are unlikely. Australia has an extremely limited research survey capacity, having few research vessels with trawling capability, or trawlers that are available for charter at reasonable cost. There is a range of other advantages in using research surveys that may be critical to the success of any NPF bycatch monitoring program:

<u>Speed of knowledge</u>: The methods that rely on large amounts of sample processing in the laboratory also will incur large delays (> one year) in the output of information, which may be critical to conserving species of bycatch. However, research surveys can process most or all catch information on board, including entry of the data into computer data bases. This system should be able to produce the necessary status reports on species population levels in a far shorter period than either crew-member observer or trained observer methods. The speed of output of this knowledge may be an important factor in the process of ensuring the sustainability of species included in the monitoring program.

Table 9.7.14 Comparisons of methods for monitoring Northern Prawn Fishery bycatch for five bycatch groups: Summaries of each parameter and their ranking for each method are taken from earlier tables. Scientific surveys are described in two forms: 1 = chartering a commercial trawler, and 2 = chartering a research vessel.

Bycatch group	Method	Data reliability and accuracy	Data feasibility	Industry acceptance	Other Stakeholder acceptance	Cost x 10^6 (one region) (50% decline)	Cost x 10^6 (one region) (99.9% decline)
Sea turtles (includes rare species)	Crew-member observer	Medium	High	High/Med	Medium	$0.08	$0.001
	Trained observer	High	High	Med/High	High	$0.36	$0.06
	Scientific surveys [1]	High	Low	Medium	High	$1.45	$0.25
	Scientific surveys [2]	High	Low	Medium	High	$2.95	$0.49
Sea snakes (includes rare species)	Crew-member observer	Low	High	Medium	Medium	$0.08	$0.001
	Trained observer	High	High	Med/High	High	$0.36	$0.06
	Scientific surveys [1]	High	Low	Medium	High	$1.45	$0.25
	Scientific surveys [2]	High	Low	Medium	High	$2.95	$0.49
Sharks, sawfish, stingrays and large fish (includes rare species	Crew-member observer	Low	High	Medium	Medium	$0.08	$0.001
	Trained observer	High	High	Med/High	High	$0.36	$0.06
	Scientific surveys [1]	High	Low	Medium	High	$1.45	$0.25
	Scientific surveys [2]	High	Low	Medium	High	$2.95	$0.49
Large invertebrates (includes rare species)	Crew-member observer	Low	High	Medium	Medium	$0.08	$0.001
	Trained observer	High	High	Med/High	High	$0.36	$0.06
	Scientific surveys [1]	High	Low	Medium	High	$1.45	$0.25
	Scientific surveys [2]	High	Low	Medium	High	$2.95	$0.49
Small bycatch (includes rare species)	Crew-member observer	High	High	Medium	Medium	$0.81	$0.13
	Trained observer	High	High	Med/High	High	$0.96	$0.16
	Scientific surveys [1]	High	Low	Medium	High	$2.18	$0.36
	Scientific surveys [2]	High	Low	Medium	High	$2.95	$0.49

Monitoring outside the fishing season: There are some advantages of sampling bycatch populations outside the months of the fishing season. For example, some species may be either attracted to or repelled from trawling grounds by the activities of prawn trawling. This would result in an unnatural species mix and misleading population data. However, sampling in the "closed season" would minimise these affects. This is only possible in the form of a research survey.

Consistency of sampling: One of the most important aspects of a long-term monitoring program is the consistency of the sampling method between years. This includes a consistency in fishing gear used, sampling the same lunar period in the same time of year and sampling the same fishing grounds. A high level of consistency in these sampling methods can greatly reduce the variability in the data, resulting in a greater reliability in its predictive value. However, controlling this consistency is very difficult with fishery-dependent methods. For example, managing a scenario whereby a subset of vessels must all use exactly the same trawls for one month (ideally a standard net without a TED or BRD) may be difficult. Vessel movements are also unpredictable. This will create a difficulty in designing a sampling program that can collect enough data from two or more designated regions within a restricted time. However, the sampling method of research surveys can be fully controlled which greatly decreases the risk of failure of a monitoring program. These may be important factors for deciding which method to use for monitoring bycatch in the NPF.

Sampling outside high effort areas: There are some potential advantages in a bycatch monitoring program having part of its sampling program in the low or no-effort areas of the NPF. For example, it would provide important data to assess whether changes in catches of species in high effort areas are due to fishing pressure (Figure 9.7.3 (a) and (b)). It will also probably be important to sample these areas to determine biomass estimates for bycatch species, as the high effort areas can only sample the most heavily impacted parts of their populations and in an untargeted way. These sampling strategies can greatly enhance the interpretive ability of a monitoring program and are best conducted as research surveys.

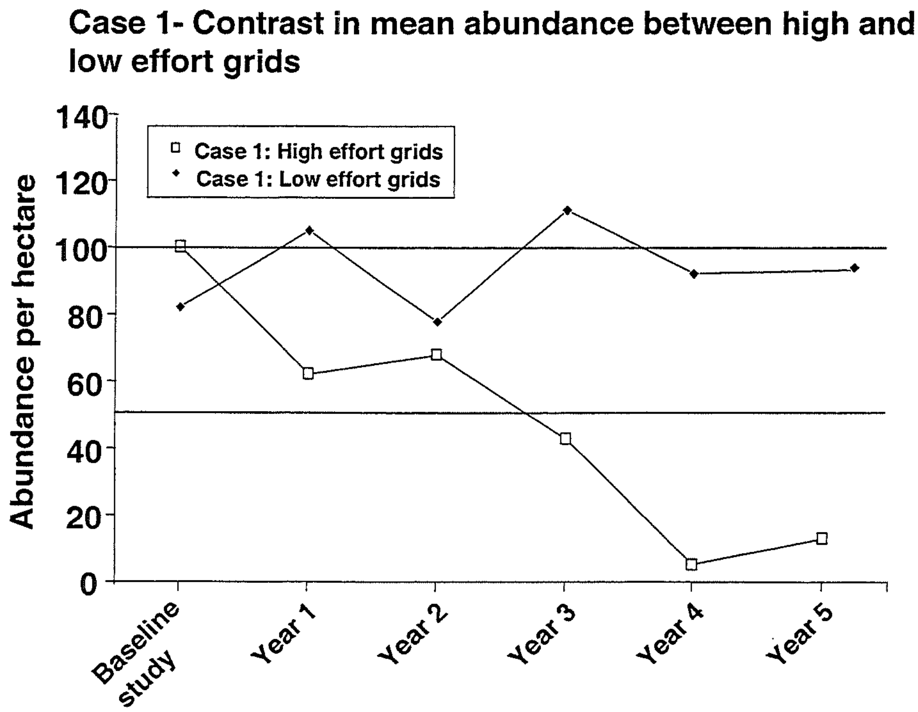
Responding to population declines: In the event of a concerning decline in the population of a species, some form of research sampling may ensue as part of a triggered response strategy. This would probably take the form of a specifically targeted sampling program, including data collection from low or no-effort areas. Research surveys are probably the only feasible way to successfully collect this type of data.

9.7.5 Other important issues for monitoring NPF bycatch

(i) How to decide which monitoring strategy to use

Before choosing a monitoring strategy the fishery manager must first choose which species should be targeted and decide on the objectives of the monitoring program. There is no overall best strategy for all monitoring objectives. However, a feasible monitoring program can be tailored to suit a specific set of management objectives.

(a)



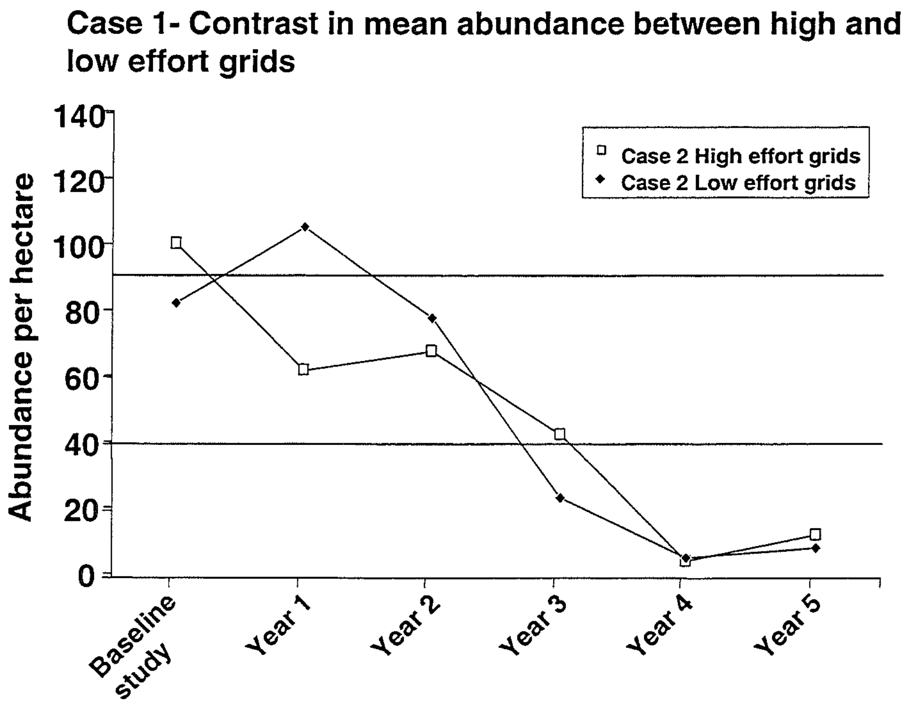


Figure 9.7.3(a) A graphical example of how monitoring catches in low effort areas may provide a contrast to demonstrate the impacts of high fishing effort on bycatch populations.

(b)

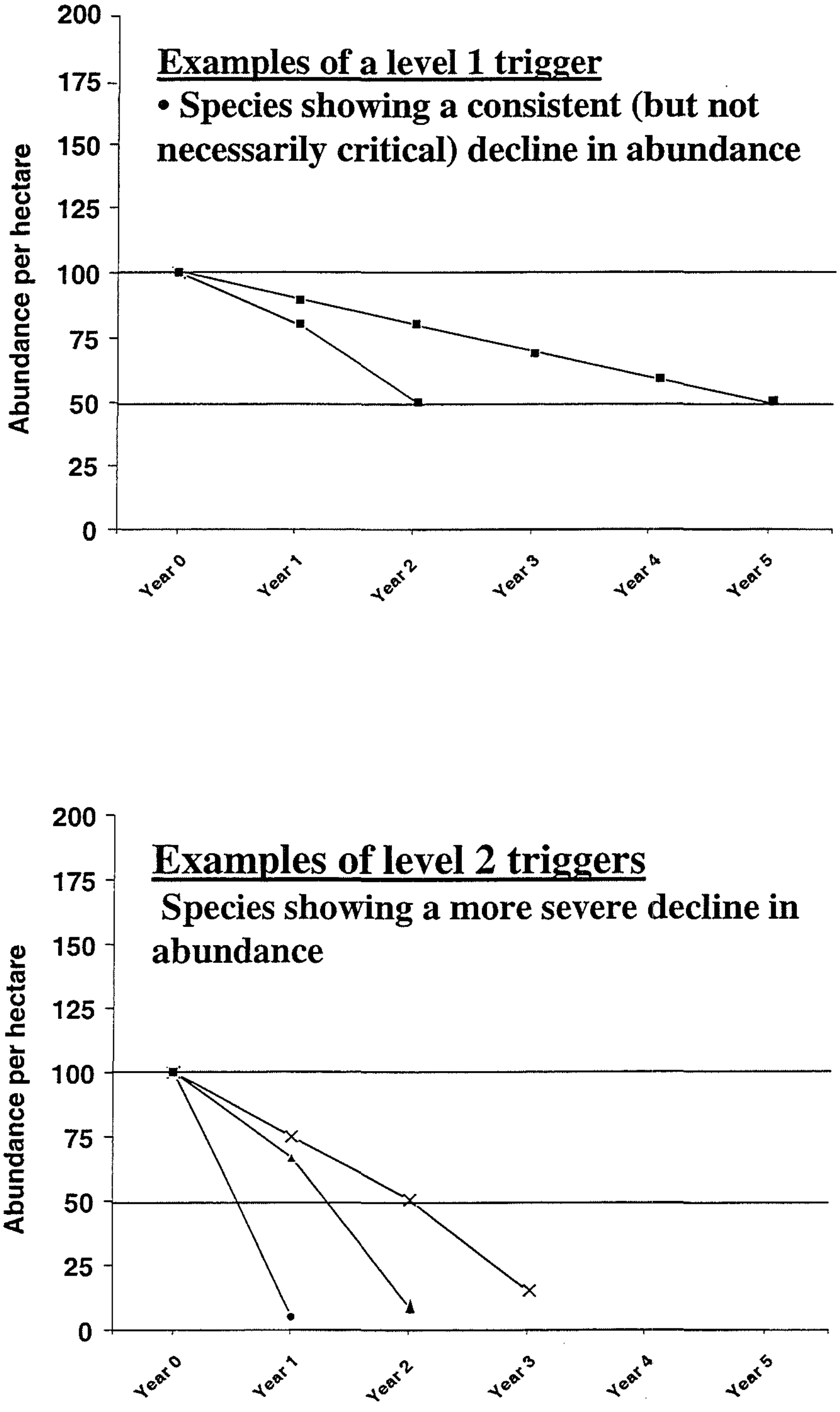


Figure 9.7.3(b) A graphical example of how monitoring catches in low effort areas may demonstrate the influence of factors other than fishing effort on bycatch populations.

It may be that the best monitoring strategy is a combination of approaches. For example, crew-member observer collections may be a suitable method for collecting catch data for two or three of the conspicuous species groups, but the reliability of the data will be greatly enhanced if a small number of trained observers are also used to validate these data. Scientific surveys also may be the only way to collect some types of data that are necessary for monitoring prawn trawl bycatch (see Section 9.7.4 (vi)).

It is important that the data reliability, accuracy and repeatability of any monitoring strategy are not compromised and are set at an appropriate level from the beginning. Although other factors such as the cost or stakeholder acceptance may change over time these factors will have less impact on the outcomes of the monitoring program.

A monitoring strategy is likely to have a higher stakeholder acceptance if the stakeholders are included in the selection process.

(ii) Developing a method to weigh total catches

Most of the scenarios for monitoring small animals in the bycatch will require a measure of the total bycatch weight from each trawl (probably obtained from total catch weight minus commercially valuable catch weight). Total bycatch weight may be used as an indicator or is necessary for calculating catch information from subsamples. However, a reliable method for obtaining this data has not been developed for NPF trawlers (ie. trained observer collections, crew-member observer collections or scientific survey using trawler charter). Scientific surveys on research vessels will usually have the ability to obtain this data.

If a program for monitoring bycatch is proposed to use NPF trawlers (e.g. crew-member observer or trained observer), then a feasible and accurate method for weighing the total weight of bycatch will need to be developed.

(iii) Choosing a level of detectable change

Deciding what level of change in species abundance is to be detected has important implications, and is an important issue for the fishery manager assessing the monitoring options. Setting sampling effort at levels to detect large scale changes (e.g. 99.9% drop in abundance in one year) requires lower numbers of trawls and is cheaper, but provides little time to respond. With this scenario smaller scale changes are not detected, yet the detectable changes equate to a near disappearance of the species from catches.

Selecting a smaller detectable change (e.g. 50% drop in abundance in one year) requires more sampling effort and is more expensive, but there is probably more time before a further, more serious drop in abundance occurs. In this report we have not presented the levels of effort required to detect smaller scale changes (e.g. 25% drop in abundance in one year), because the levels of effort required to detect this change are not feasible in the NPF for most of the bycatch species.

(iv) What spatial effort distribution should be used for monitoring NPF bycatch?

As described earlier there are two main bycatch species groupings; one associated with *P. semisulcatus* grounds and another on *P. esculentus* grounds. One can not be used as a surrogate for the other and so a minimum of two separate targeted sampling programs should be used. The sampling effort for each should be restricted to a single fishing region to minimise variability in catches due to spatial factors. The higher effort areas are preferable because they are more likely to reflect any impacts of fishing, and if fishery-dependent methods are used for data collection, these areas may be the only places that are fished by enough trawlers to provide an adequate level of sampling effort.

There should also be a sampling program that covers a broader spatial scale for species that (i) range over larger areas of the NPF and TSPF and (ii) require a larger coverage to sample enough individuals to detect statistically meaningful declines in populations. The most obvious of these are sea turtles and elasmobranchs, but there are likely to be others that also require a broader spatial scale sampling program.

(v) Important protocols to include in a monitoring program

Like any ecological sampling program, a bycatch monitoring program should maintain a consistency of sampling for the following factors.

Time of year: monitoring should be done at the same time of year, each year, to minimise any differences in catches due to this factor.

Lunar phase: monitoring should be done during the same lunar phase each year, and preferable over an entire lunar phase to minimise any differences in catches due to this factor.

Time of Day: any monitoring program should be aware that catch rates are different between night and day for most fish species, and any advantages of the inclusion of data from both times may be negated by the increased variability in the data (see Section 9.7.2. (v)).

Area of sample collection: monitoring should be done in the same fishing regions each year to minimise any differences in catches due to this factor.

Size of sampling effort: The same or greater level of sampling effort should be applied each year to maintain the power of the long-term data sets that are critical for interpreting changes to species that may occur in future years.

Regularity of sampling: Sampling effort should be maintained each year to ensure the collection of the long-term data sets that are critical for interpreting changes to species that may occur in future years.

Consistency of sampling gear: Valid year-to-year comparisons of catch data may require that the same, standardised trawl gear be used each year during the time that samples for bycatch monitoring are collected. This standard gear (e.g. Florida Flyer trawls with no TEDs or BRDs and standard mesh size) may be different from that required for normal fishing operations.

(vi) Determining if changes in catches are due to fishing pressure

Any high quality monitoring program should have a built-in contingency to determine whether any changes that are detected in species populations are due to the impact of fishing or some other factor (e.g. environmental changes, poor recruitment, disease). This may be done by assessing the population of species in adjacent low or no effort areas, either as part of the monitoring program, or as a management response to unacceptable levels of change. If the same level of change can be shown outside the trawl ground, then it is less likely to be the result of fishing impact (Fig 9.7.3(a)). However, if the change is not reflected outside the fishing grounds, it may be further evidence that the species is in decline due to the impact of trawling, at least within the trawl grounds (Fig 9.7.3(b)). These strategies will incur considerable additional cost, but should be assessed and considered as part of the planning process for any bycatch monitoring program.

(vii) Collecting data on sea snakes

Like sea turtles, sea snakes are protected and there is some concern for their long term ability to withstand the impacts of trawling. However, unlike sea turtles, there is an aversion within the industry to returning them to the sea alive. Monitoring sea snakes may have a similar effect on their populations because many species are very difficult to identify to species on board the trawler and an untrained crew-member observer or trained observer may need to keep all sea snake specimens for processing in the laboratory. This source of mortality may have a significant impact on some species and some other method of collecting this data should be used. It may simply require any crew-member observers or trained observers that are responsible for collecting these data be trained in sea snake identification so that, for some species at least, live animals can be returned to the sea. This may also be an important issue for other conspicuous bycatch groups and should be specifically considered during the planning of any monitoring program.

(viii) Other advantages of having a monitoring program in the fishery

A bycatch monitoring program has other benefits to the industry besides allowing it to meet criteria required by legislation. It would be a major step towards removing any threat to the fishery from conservation and political groups over the environmental impacts of the fishery.

In ecological terms, a healthy ecosystem should not be slowly degrading over time. It is a healthy ecosystem that has supported a significant prawn trawl fishery for the past three decades. A bycatch monitoring program may detect changes to this ecosystem that may otherwise go unnoticed for longer periods of time. Changes due to fishing pressure and other man-made impacts or environmental influences may be signalled by a monitoring program. Collecting these data on bycatch will also provide information for other management issues (e.g. allocation of Marine Protected Areas).

9.7.6 Conclusions

- A monitoring strategy should use a sustainability indicator(s) established during the first year of monitoring as a reference point (or baseline). Future monitoring years should use established performance measures (set levels of change in catch rates) that lead to established management actions or triggers.
- Choosing a monitoring strategy for the NPF is partly dependent on which species will be targeted by the monitoring program
- Monitoring changes in the rarest species requires more sampling effort (participating trawlers, trained observers, or research vessels) than the more common species. Fishery-dependent strategies (crew-member

observers or trained observers in the fishing fleet) have the highest capability to monitor the rarest species, but this may be at the limits of the fleet's feasibility.

- Crew-member observers could not collect reliable and accurate data on all bycatch groups (sea turtles, sharks, stingrays, sawfish, sea snakes, large invertebrates, and small bycatch that can be subsampled) without a significant imposition on their fishing operations. However, collecting information on one or two groups is probably feasible.
- Trained observers in the fleet should be able to collect acceptable, reliable and accurate data for all bycatch groups with limited imposition to fishing operations.
- Scientific surveys may be required to collect fishery-independent data on the unfished population status of bycatch species, and specific information on species of particular concern. They are also capable of providing the most accurate, reliable and immediately available data of all the methods.
- Monitoring should be conducted in at least two regions of the NPF. These are based on having different suites of prawns and bycatch species, and as such, they may respond differently to fishing pressure. A broader spatial scale sampling program should also be used for wider ranging, rare species such as sea turtles and some elasmobranchs.
- Monitoring should be conducted on a long-term basis in the same way as the target species.
- It is critical that there be a consistency of sampling for a range of factors in any monitoring program. These factors include the time of year, lunar phase, area of sample collection, size of sampling effort, standard fishing gear and regularity of sampling.
- There should be some contingency for assessing whether any changes measured in populations of bycatch species are due to fishing pressure of some other influence.

References

ABARE, 1999. Australian Fisheries Surveys Report 1999. Draft report.

Azarovitz, T.R. 1981.A brief historical review of the Woods Hole trawl survey time series. *In* Bottom trawl surveys. *Edited by* W.G. Doubleday and D.Rivard. Can. Spec. Publ. Fish. Aquat. Sci. No 58, pp. 62-67.

Eayrs, S., Buxton, C., McDonald, B., 1997. A guide to bycatch reduction in Australian prawn trawl fisheries. Australian Maritime College. 54 pp.

Halliday, R. G. and P. A. Koeller, 1981. A history of Canadian groundfish trawling surveys and data useage in ICNAF divisions 4TVWX. *In* Bottom trawl surveys. *Edited by* W.G. Doubleday and D.Rivard. Can. Spec. Publ. Fish. Aquat. Sci. No 58, pp. 27-42.

Heinemann, D., Farley, J., Clear, N., Gunn, J., Klaer, N., Whitelaw, W., 1999. Pilot Seabird Bycatch Observer Program for Australian Domestic Longline Fisheries: Design Guidelines, Options and Recommendations. CSIRO Marine Research Report. May 1999.

International Institute for Sustainable Development. Global green standards : ISO 14000 [fourteen thousand] and sustainable development. Winnipeg: IISD , 1996. 100 p.

Kennelly, S. J. , Liggins, G. W., Broadhurst, M. K., 1998. Retained and discarded by-catch from oceanic prawn trawling in New South Wales, Australia. Fish. Res. 36: 217-236.

Knuckey, I. A., Liggins, G. W., 1999. Focussing on bycatch issues in Australia's South East Trawl Fishery. In Buxton, C. D. and Eayrs, S. E. (eds) 1999. Establishing meaningful targets for bycatch reduction in Australian fisheries. Australian Society for Fish Biology Workshop Proceedings, Hobart, September 1998. Australian Society for Fish Biology, Sydney.

NORMAC (Northern Prawn Fishery Management Advisory Committee), 1998. Northern Prawn Fishery bycatch action plan. (Northern Prawn Fishery Management Advisory Committee, Australia), 21 pp.

Pitt, T. K., R. Wells and W. D. McKone, 1981. A critique of research vessel otter trawl surveys by the St. John's Research and Resource Services. *In* Bottom trawl surveys. *Edited by* W.G. Doubleday and D.Rivard. Can. Spec. Publ. Fish. Aquat. Sci. No 58, pp. 42-61.

Poiner, I. R., Buckworth, R. C., Harris, A. N. M., 1990. The incidental capture and mortality or sea turtles in Australia's Northern Prawn Fishery. Australian Journal of Marine and Freshwater Research. 41: 97-110.

Poiner, I. R., Harris, A. N. M., 1996. The incidental capture, direct mortality and delayed mortality of sea turtles in Australia's Northern Prawn Fishery. Mar. Biol. 125: 813-825.

Sainsbury, K. J., 1987. Assessment and management of the demersal fishery on the continental shelf of northwestern Australia. In 'Tropical Snappers and Groupers; Biology and Fishery Management'. (Eds J J Polovina and S Ralston) pp. 465-503 (Westview Press: Boulder CO)

Sainsbury, K., Smith, A., Webb, H., 1999. Current use and recommendations for future development of sustainability indicators to measure performance of Australian fisheries against ESD objectives. FRDC report to FRDC. Project No. 98/168.

10. BENEFITS

The outcomes of this project will benefit prawn trawl fisheries, fisheries managers, other stakeholders and the general public.

Bycatch Description

The description of the bycatch of the NPF, TSPF and Queensland Banana Prawn Fishery will directly benefit these fisheries. The data from this project provide the fisheries with knowledge of the composition of their bycatch and the factors that influence its variation. This is a critical first step towards sustainable management of this bycatch. Without this description it would not be possible for the industry and managers to identify potential problems. The identification of the major factors contributing to the variation in bycatch is important for the design of monitoring programs. If monitoring is stratified with respect to these factors it will reduce the variation around catch rates, providing a more powerful design for detecting changes.

The description of the bycatch in the Queensland Banana Prawn Fishery also benefits the commercial and recreational fisheries in this region. This work quantifies the amount of commercial and recreational fisheries' target species that are taken as bycatch by the prawn trawlers. This information is now available to be factored into the management of these other fisheries, increasing the likelihood of their sustainable management.

Sustainability of vertebrate bycatch species

The assessment of the sustainability of the bycatch species in the NPF will directly benefit this fishery and other prawn trawl fisheries. The results of this assessment highlight bycatch species that are potential problems. This provides a focus for future research and management to ensure the sustainability of these species. This assessment also demonstrates that the NPF is actively addressing the issue of the sustainability of its bycatch. This is a fundamental aspect of the new *Environment Protection and Biodiversity Conservation Act* that will come into force in July 2000. The results of this project will assist the NPF in addressing the guidelines of this Act. The results will also benefit the NPF by assisting in their development of bycatch sustainability indicators.

Other prawn trawl fisheries will benefit from the development of this process to assess the sustainability of bycatch species. Previously there has been no process available to address this issue at this scale. The one developed here can be applied to other prawn trawl fisheries and will assist in management of their bycatch.

Monitoring methods for bycatch

The evaluation of monitoring methods in the NPF will have direct benefit to the managers of the NPF and also other fisheries. The guidelines produced will increase the likelihood that a monitoring program for NPF bycatch will be effective. An effective monitoring program is essential to ensure that bycatch species are not impacted beyond sustainable levels.

Overall

The results of this research represent a large increase in our understanding and knowledge of bycatch in tropical prawn trawl fisheries. This will benefit all stakeholders in these fisheries by ensuring their ongoing ecolocially sustainable management. The sustainable management of the marine environment will benefit all Australians.

11. FURTHER DEVELOPMENT

The results of this project will be discussed with NORMAC and the NPF FAG in order to assist in the development of bycatch sustainability indicators and any future bycatch monitoring projects. The introduction of TEDs and BRDs into the NPF in 2000 will result in significant changes to the bycatch. It is important that these changes are monitored. This will enable them to be taken into account in the assessment of the sustainability of the bycatch species.

This project represents a large advance in our knowledge of the bycatch of prawn trawl fisheries. However, it has highlighted important gaps that should be addressed. There is a need for a greater understanding of the biology and distribution of bycatch species, particularly those that ranked high priority, i.e. the ones least likely to be sustainable. It is important that these species are studied and management issues addressed to ensure their sustainability. There is also a need in these fisheries for a greater understanding of the role of unfished areas for bycatch species. These areas provide a potential refuge for bycatch species that may be important in ensuring their sustainability.

This project examined the direct impact of trawling on bycatch species, but indirect impacts may be equally important. However, there is no information available on the indirect impacts of trawling for these fisheries. This should be the focus of future research.

12. CONCLUSION

This project has greatly increased our understanding of the bycatch in Australia's tropical prawn trawl fisheries. This is vital to ensuring the sustainability of these bycatch species. The project provides a detailed description of the bycatch of the NPF, TSPF and the Queensland Banana Prawn Fishery, a list of the vertebrate bycatch taxa that are least likely to be sustainable in the NPF bycatch, examined the impact of trawling on vertebrate biodiversity and evaluated the different monitoring options in the NPF. The objectives and our achievement with respect to them is detailed below:

1) To describe the bycatch of the NPF, TSPF and Queensland East Coast banana prawn fisheries

Detailed descriptions of the bycatch of these fisheries was complied. These descriptions cover the range of the fisheries and describe the high diversity, dominance of fish, predominance of rare species and the significant spatial and temporal variation. They quantify the scale of the bycatch issue for managers and hence, provide a first step towards sustainable management. We also provided an analysis of the factors that contribute most to the variation in bycatch. Identification of these factors is critical for our understanding of bycatch and also for the design of monitoring programs. Monitoring programs must be stratified with respect to these factors in order to account for this variation and maximise the power of monitoring to detect changes in catch rates.

2) To assess the impact of trawling on the sustainability of vertebrate bycatch species

We developed and applied a process that assesses the sustainability of vertebrate bycatch species. This was a significant challenge given the high diversity, the rarity of most species and the lack of historical and biological information. This is the first time an assessment of this type and scale has been undertaken. The output of this assessment is a list of species that are least likely to be sustainable in NPF bycatch, this will the NPF in the management of their bycatch. This process also highlighted important gaps in our knowledge that should be addressed to ensure the sustainability of bycatch species. The outputs from this section have been presented to the NPF FAG and will be used in addressing legislative requirements and in developing bycatch sustainability indicators.

This process can also be applied to other prawn trawl fisheries in order to examine the sustainability of the bycatch of these fisheries.

3) To assess the effects of prawn trawling on the biodiversity of vertebrate bycatch communities

The effect of prawn trawling on the biodiversity of the vertebrate bycatch community was examined by comparing areas open and closed to trawling. While some differences were detected between the areas, the results were equivocal with respect to the impact of trawling on biodiversity. This does not imply that trawling has no impact on these fauna. Any differences between open and closed areas may be reduced by the low and aggregated commercial effort in the open, possible illegal trawling in the closure, and the mobility of species. Combined with high natural variation these factors may obscure any impacts of trawling. The results of this section highlight the complexity of addressing the question of impacts on biodiversity in highly diverse and variable marine ecosystems.

4) To develop cost-effective, accurate and feasible methods of describing and monitoring bycatch.

The complex and unique nature of the NPF bycatch necessitated studies of sampling and monitoring methods to guide management. The outputs from these studies provide the first assessment of sampling procedures and monitoring methods for prawn trawl bycatch. The results provide valuable provide guidelines for future monitoring of bycatch in the NPF. These guidelines will also assist other prawn trawl fisheries in developing monitoring programs.

ACKNOWLEDGMENTS

We thank the commercial fishers in the NPF, TSPF and Queensland Banana Prawn fishery, who provided bycatch samples, allowed and assisted observers on their vessels, and who provide invaluable data in their logbooks; the fisheries management advisory committees for their support of this project; C. Rose for collecting the invaluable elasmobranch data; J. Bishop and M. Haywood and F. Manson for preparing the commercial effort data; Q. Dell and D. Vance for cleaning the RoxAnn data; Dr Gerry Geen for reviewing the comparison of the costs of the monitoring methods; the NPF FAG for their constructive contribution to the process for assessing the sustainability of bycatch species; the crew of the *R.V. Southern Surveyor* for their assistance in the research surveys; D. Barton, J. Bishop, S. Cook, E. Coronado, Q. Dell, D. Die, N. Elliott, N. Ellis, E. Gillespie, H. Greif, J. Kennedy, J. Lancaster, J. Langstreth, S. Leys, C. Liron, J. Loughlin, L. MacDonald, D. Mason-Posner, D. McKenzie, A. Moore, N. Mykytowych, C. Noell, F. Oliver, Y. Park, M. Piasente, S. Round, M. Ryba, M. Sherlock, J. Staunton-Smith, D. Vance, K. Yoemans, for their assistance at sea and in the lab and Dr Burke Hill for his invaluable comments on this report.

APPENDICES

Appendix 1: Intellectual property

No commercial intellectual property arose from this work.

Appendix 2: Staff

CSIRO Marine Research

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Appendix 3: Data tables

Appendix 3A Number of individuals within each taxa and their relative contribution to the total bycatch, based on raw sub-sample data from 184 standard net trawls (ie., no BRDs or grids) from the Queensland banana prawn otter-board trawl fishery.

Numbers of large individuals (ie., sharks, rays, turtles and sea snakes) are included but biased upwards because unlike most bycatch, these species were not sub-sampled but rather recorded and returned to the water.

	Species	Total	%	Cum. %
1	*Leiognathus splendens*	15,026	9.140	9.140
2	*Johnius borneensis*	12,532	7.623	16.763
3	*Charybdis callianassa*	11,769	7.159	23.921
4	*Leiognathus bindus*	11,557	7.030	30.951
5	*Pomadasys maculatus*	8,263	5.026	35.977
6	*Metapenaeus sp.*	8,091	4.922	40.899
7	*Caranx para*	7,907	4.810	45.708
8	*Terapon theraps*	7,192	4.375	50.083
9	*Gazza minuta*	5,319	3.235	53.318
10	*Trachypenaeus sp.*	4,969	3.022	56.341
11	*Pomadasys trifasciatus*	4,680	2.847	59.188
12	*Trichiurus lepturus*	4,344	2.642	61.830
13	*Pellona ditchela*	4,012	2.440	64.270
14	*Parapenaeopsis sp.*	3,837	2.334	66.604
15	*Polydactylus multiradiatus*	2,612	1.589	68.193
16	*Secutor ruconius*	2,604	1.584	69.777
17	*Secutor insidiator*	2,467	1.501	71.278
18	*Apogon poecilopterus*	2,221	1.351	72.629
19	*Caranx bucculentus*	2,158	1.313	73.941
20	*Thryssa hamiltonii*	2,154	1.310	75.251
21	*Metapenaeopsis sp.*	2,103	1.279	76.531
22	*Arius macrocephalus*	2,031	1.235	77.766
23	*Stolephorus indicus*	1,423	0.866	78.632
24	*Harpadon translucens*	1,332	0.810	79.442
25	*Leiognathus moretoniensis*	1,270	0.773	80.214
26	*Thryssa setirostris*	1,223	0.744	80.958
27	*Saurida micropectoralis*	1,202	0.731	81.689
28	*Upeneus sulphureus*	1,147	0.698	82.387
29	*Oratosquilla interupta*	1,101	0.670	83.057
30	*Teuthoidea*	1,056	0.642	83.699
31	*Oratosquilla inornata*	1,005	0.611	84.310
32	*Sillago sihama*	976	0.594	84.904
33	*Sardinella albella*	957	0.582	85.486
34	*Amusium pleuronectes*	929	0.565	86.051
35	*Herklotsichthys lippa*	927	0.564	86.615
36	*Apogon fasciatus*	882	0.536	87.152
37	*Atypopenaeus sp.*	879	0.535	87.686
38	*Otolithes ruber*	876	0.533	88.219
39	*Austronibea oedogenys*	807	0.491	88.710
40	*Portunus sanguinolentus*	801	0.487	89.197
41	*Archamia fucata*	800	0.487	89.684
42	*Terapon puta*	783	0.476	90.160
43	*Leiognathus equulus*	780	0.474	90.634
44	*Johnius amblycephalus*	756	0.460	91.094
45	*Leiognathus decorus*	715	0.435	91.529
46	*Siphamia roseigaster*	664	0.404	91.933
47	*Portunus acerbiterminalis*	657	0.400	92.333
48	*Lactarius lactarius*	606	0.369	92.701
49	*Portunus pelagicus*	603	0.367	93.068
50	*Pelates quadrilineatus*	493	0.300	93.368
51	*Sardinella gibbosa*	484	0.294	93.662
52	*Oratosquilla nepa*	474	0.288	93.951
53	*Alepes sp.*	449	0.273	94.224
54	*Parastromateus niger*	383	0.233	94.457
55	*Gerres filamentosus*	357	0.217	94.674
56	*Escualosa thoracata*	355	0.216	94.890
57	*Arius bilineatus*	337	0.205	95.095
58	*Arius graeffei*	324	0.197	95.292
59	*Mimachlamys sp.*	283	0.172	95.464
60	*Portunus gracilimanus*	282	0.172	95.636
61	*Drepane punctata*	275	0.167	95.803
62	*Herklotsichthys koningsbergeri*	258	0.157	95.960
63	*Oratosquilla woodmasoni*	240	0.146	96.106
64	*Nematalosa come*	198	0.120	96.226
65	*Netuma thalassinus*	185	0.113	96.339
66	*Torquigener whitleyi*	174	0.106	96.445
67	*Ilisha sp.*	168	0.102	96.547
68	*Matuta granulosa*	167	0.102	96.648
69	*Priacanthus macracanthus*	157	0.095	96.744
70	*Lapemis hardwickii*	141	0.086	96.830
71	*Apistus carinatus*	134	0.082	96.911
72	*Triacanthus nieuhofi*	128	0.078	96.989
73	Spatangoidea	118	0.072	97.061
74	Bivalvia	108	0.066	97.127
75	*Terapon jarbua*	106	0.064	97.191
76	*Trixiphichthys weberi*	106	0.064	97.255
77	*Chelonodon patoca*	105	0.064	97.319
78	*Arius armiger*	102	0.062	97.381
79	*Megalaspis cordyla*	99	0.060	97.442
80	*Rastrelliger kanagurta*	94	0.057	97.499
81	*Penaeus esculentus*	93	0.057	97.555
82	*Paraplagusia bilineata*	90	0.055	97.610

	Species	Total	%	Cum. %
83	*Sphyrna lewini*	90	0.055	97.665
84	*Lagocephalus inermis*	88	0.054	97.718
85	*Cynoglossus bilineatus*	86	0.052	97.771
86	*Carangoides malabaricus*	85	0.052	97.822
87	*Euristhmus lepturus*	85	0.052	97.874
88	*Charybdis truncata*	83	0.050	97.925
89	*Pomadasys argenteus*	83	0.050	97.975
90	*Anodontostoma chacunda*	81	0.049	98.024
91	*Lutjanus malabaricus*	81	0.049	98.074
92	*Charybdis yaldwyn*	80	0.049	98.122
93	*Paramonacanthus filicauda*	79	0.048	98.170
94	*Rhizoprionodon taylori*	71	0.043	98.214
95	*Charybdis feriatus*	66	0.040	98.254
96	*Pseudorhombus arsius*	66	0.040	98.294
97	*Selaroides leptolepis*	66	0.040	98.334
98	*Penaeus indicus*	65	0.040	98.373
99	*Scatophagus multifasciatus*	64	0.039	98.412
100	*Siganus fuscescens*	61	0.037	98.450
101	*Engyprosopon grandisquamum*	54	0.033	98.482
102	*Scomberoides tol*	54	0.033	98.515
103	*Rhizoprionodon acutus*	53	0.032	98.547
104	*Saurida undosquamis*	51	0.031	98.578
105	*Sillago maculata*	51	0.031	98.609
106	*Eleutheronema tetradactylum*	49	0.030	98.639
107	*Pelates sexlineatus*	48	0.029	98.668
108	*Apogon trimaculatus*	47	0.029	98.697
109	*Inegocia japonica*	45	0.027	98.724
110	*Alectis indicus*	43	0.026	98.751
111	*Hydrophis elegans*	43	0.026	98.777
112	*Carangoides hedlandensis*	42	0.026	98.802
113	*Carangoides humerosus*	42	0.026	98.828
114	*Dussumieria elopsoides*	42	0.026	98.853
115	*Centriscus scutatus*	41	0.025	98.878
116	*Carcharhinus limbatus*	38	0.023	98.901
117	*Scomberomorus queenslandicus*	38	0.023	98.925
118	*Scomberomorus semifasciatus*	38	0.023	98.948
119	*Terebellum terebellum*	38	0.023	98.971
120	*Himantura toshi*	36	0.022	98.993
121	*Arius sp.*	35	0.021	99.014
122	*Arnoglossus waitei*	33	0.020	99.034
123	*Charybdis helleri*	33	0.020	99.054
124	*Gerres subfasciatus*	33	0.020	99.074
125	*Nemipterus hexodon*	32	0.019	99.094
126	*Leiognathus leuciscus*	31	0.019	99.113
127	*Suggrundus rodericensis*	31	0.019	99.131
128	*Upeneus asymmetricus*	31	0.019	99.150
129	*Valamugil cunnesius*	31	0.019	99.169
130	*Callionymus goodladi*	30	0.018	99.187
131	*Oratosquilla perpensa*	30	0.018	99.206
132	Sergestidae	30	0.018	99.224
133	*Upeneus sundaicus*	29	0.018	99.241
134	*Zabidius novaemaculatus*	29	0.018	99.259
135	*Nemipterus peronii*	28	0.017	99.276
136	*Pentaprion longimanus*	28	0.017	99.293
137	*Chironex fleckeri*	27	0.016	99.310
138	*Minous versicolor*	27	0.016	99.326
139	Sepiidae	27	0.016	99.342
140	*Inegocia harrisii*	27	0.016	99.359
141	*Callionymus meridionalis*	26	0.016	99.375
142	*Harpiosquilla harpax*	26	0.016	99.391
143	*Suggrundus macracanthus*	26	0.016	99.406
144	*Carangoides talamparoides*	25	0.015	99.422
145	*Epinephelus sexfasciatus*	25	0.015	99.437
146	*Euristhmus nudiceps*	25	0.015	99.452
147	*Plotosus lineatus*	25	0.015	99.467
148	*Paramonacanthus japonicus*	24	0.015	99.482
149	*Carcharhinus macloti*	22	0.013	99.495
150	*Chirocentrus dorab*	22	0.013	99.509
151	*Dexillus muelleri*	22	0.013	99.522
152	*Leptobrama mulleri*	22	0.013	99.535
153	*Alcyonarian sp. 4*	21	0.013	99.548
154	*Centrogenys vaigiensis*	20	0.012	99.560
155	*Cottapistus praepositus*	20	0.012	99.572
156	*Carcharhinus brevipinna*	18	0.011	99.583
157	*Lutjanus russelli*	18	0.011	99.594
158	*Scyllarus sp. 2*	18	0.011	99.605
159	*Sphyraena putnamiae*	18	0.011	99.616
160	*Thenus indicus*	18	0.011	99.627
161	*Dictyosquilla foveolata*	17	0.010	99.637
162	*Platycephalus indicus*	16	0.010	99.647
163	*Podopthalmus vigil*	16	0.010	99.657
164	Alpheid sp. 16	15	0.009	99.666
165	*Ilisha striatula*	15	0.009	99.675
166	*Gymnura australis*	14	0.009	99.684
167	*Selar boops*	14	0.009	99.692
168	*Psettodes erumei*	13	0.008	99.700
169	*Sphyraena obtusata*	13	0.008	99.708
170	*Adventor elongatus*	12	0.007	99.715
171	*Lagocephalus lunaris*	12	0.007	99.723
172	*Phalangipes longipes*	12	0.007	99.730
173	*Hyastenus cambelli*	11	0.007	99.737
174	*Notesthes robusta*	11	0.007	99.743
175	*Upeneus luzonius*	11	0.007	99.750
176	*Penaeus latisulcatus*	10	0.006	99.756
177	*Sphaenopus*	10	0.006	99.762

Appendix 3 Data tables

	Species	Total	%	Cum. %
	marsupialis			
178	*Pseudorhombus elevatus*	9	0.005	99.768
179	*Tetrabrachium ocellatum*	9	0.005	99.773
180	*Centriscus cristatus*	8	0.005	99.778
181	*Gnathanodon speciosus*	8	0.005	99.783
182	*Nemipterus isacanthus*	8	0.005	99.788
183	*Paradorippe australiensis*	8	0.005	99.793
184	*Pomadasys kaakan*	8	0.005	99.797
185	*Scomberoides tala*	8	0.005	99.802
186	*Atule mate*	7	0.004	99.807
187	*Carcharhinus dussumieri*	7	0.004	99.811
188	*Charybdis jaubertensis*	7	0.004	99.815
189	*Cypraeidae*	7	0.004	99.819
190	*Platycephalus endrachtensis*	7	0.004	99.824
191	*Pterois russelli*	7	0.004	99.828
192	*Scomberoides commersonnianus*	7	0.004	99.832
193	*Apogon brevicaudata*	6	0.004	99.836
194	*Disteira major*	6	0.004	99.839
195	*Harpiosquilla melanoura*	6	0.004	99.843
196	*Oratosquilla quinquedentata*	6	0.004	99.847
197	*Parapenaeopsis cornuta*	6	0.004	99.850
198	*Rhynchobatus djiddensis*	6	0.004	99.854
199	*Ostracion nasus*	6	0.004	99.858
200	*Thenus orientalis*	6	0.004	99.861
201	*Apogon nigripinnis*	5	0.003	99.864
202	*Carcharhinus sorrah*	5	0.003	99.867
203	*Tragulichthys jaculiferus*	5	0.003	99.870
204	*Dorippe quadridens*	5	0.003	99.873
205	*Elates ransonettiii*	5	0.003	99.877
206	*Hyastenus sp.1*	5	0.003	99.880
207	*Lethrinus genivittatus*	5	0.003	99.883
208	*Sphyraena flavicauda*	5	0.003	99.886
209	*Apogon albimaculosus*	4	0.002	99.888
210	*Apogon cavitiensis*	4	0.002	99.891
211	*Aseraggodes melanostictus*	4	0.002	99.893
212	*Dasyatis leylandi*	4	0.002	99.895
213	*Disteira kingii*	4	0.002	99.898
214	*Lagocephalus spadiceus*	4	0.002	99.900
215	*Mene maculata*	4	0.002	99.903
216	*Muraenesox cinereus*	4	0.002	99.905
217	*Spiropagurus sp. 1*	4	0.002	99.908
218	*Torquigener pallimaculatus*	4	0.002	99.910
219	*Yongeichthys nebulosus*	4	0.002	99.912
220	*Anacanthus barbatus*	3	0.002	99.914
221	*Arius proximus*	3	0.002	99.916
222	*Arothron manilensis*	3	0.002	99.918
223	*Callionymus grossi*	3	0.002	99.920
224	*Carangoides caeruleopinnatus*	3	0.002	99.922
225	*Choerodon cephalotes*	3	0.002	99.923
226	*Parachaeturichthys polynema*	3	0.002	99.925
227	*Platycephalus arenarius*	3	0.002	99.927
228	*Protonibea diacanthus*	3	0.002	99.929
229	*Sillago robusta*	3	0.002	99.931
230	*Stolephorus waitei*	3	0.002	99.932
231	*Trachinocephalus myops*	3	0.002	99.934
232	Alcyonarian sp. 7	2	0.001	99.936
233	Annelida	2	0.001	99.937
234	*Arothron reticularis*	2	0.001	99.938
235	Asteroidea	2	0.001	99.939
236	*Bregmaceros japonicus*	2	0.001	99.940
237	*Callionymus japonicus*	2	0.001	99.942
238	*Carangoides chrysophrys*	2	0.001	99.943
239	*Chelonia mydas*	2	0.001	99.944
240	*Dactyloptena papilio*	2	0.001	99.945
241	*Diagramma pictum*	2	0.001	99.946
242	*Ebalia sp. 1*	2	0.001	99.948
243	*Ebalia sp. 2*	2	0.001	99.949
244	*Echeneis naucrates*	2	0.001	99.950
245	*Fistularia commersonii*	2	0.001	99.951
246	*Himantura uarnak*	2	0.001	99.953
247	*Inimicus didactylus*	2	0.001	99.954
248	*Ixa inermis*	2	0.001	99.955
249	*Leiognathus smithursti*	2	0.001	99.956
250	*Pegasus volitans*	2	0.001	99.957
251	*Portunus rubromarginatus*	2	0.001	99.959
252	*Scomberoides lysan*	2	0.001	99.960
253	*Scomberomorus munroi*	2	0.001	99.961
254	*Synodus variegatus*	2	0.001	99.962
255	*Abalistes stellaris*	1	0.001	99.963
256	*Abudefduf septemfasciatus*	1	0.001	99.964
257	Alcyonarian sp. 11	1	0.001	99.964
258	Alcyonarian sp. 13	1	0.001	99.965
259	*Apistops caloundra*	1	0.001	99.965
260	*Apogon ellioti*	1	0.001	99.966
261	Ascidiacea	1	0.001	99.967
262	Asteroid sp. 14	1	0.001	99.967
263	*Batrachomoeus occidentalis*	1	0.001	99.968
264	Brittle star sp. 41	1	0.001	99.968
265	Bryozoan sp. 3	1	0.001	99.969
266	*Caesio cuning*	1	0.001	99.970

	Species	Total	%	Cum. %
267	*Carcharhinus altimus*	1	0.001	99.970
268	*Carcharhinus leucas*	1	0.001	99.971
269	*Carinosquilla multicarinata*	1	0.001	99.971
270	*Charybdis anisodon*	1	0.001	99.972
271	*Charybdis natator*	1	0.001	99.973
272	*Chelmon muelleri*	1	0.001	99.973
273	*Clorida depressa*	1	0.001	99.974
274	Crinoid sp. 15	1	0.001	99.974
275	*Cryptopodia sp. 3*	1	0.001	99.975
276	*Paraplagusia longirostris*	1	0.001	99.976
277	*Dardanus hessii*	1	0.001	99.976
278	*Dasyatis fluviorum*	1	0.001	99.977
279	*Eucrate sp. 3*	1	0.001	99.977
280	*Galene bispinosa*	1	0.001	99.978
281	Gastropoda	1	0.001	99.979
282	*Gerres macracanthus*	1	0.001	99.979
283	Gorgonian sp. 20	1	0.001	99.980
284	*Harpiosquilla annandalei*	1	0.001	99.981
285	*Himantura uarnak*	1	0.001	99.981
286	*Himantura undulata*	1	0.001	99.982
287	*Inimicus sinensis*	1	0.001	99.982
288	*Lagocephalus sceleratus*	1	0.001	99.983
289	*Leiognathus sp.*	1	0.001	99.984
290	*Leucosia ocellata*	1	0.001	99.984
291	*Manningia notalis*	1	0.001	99.985
292	*Marilyna pleurosticta*	1	0.001	99.985

	Species	Total	%	Cum. %
293	*Mimachlamys sp. 2*	1	0.001	99.986
294	*Monacanthus chinensis*	1	0.001	99.987
295	*Parapercis diplospilus*	1	0.001	99.987
296	*Parthenope longispinus*	1	0.001	99.988
297	*Penaeus canaliculatus*	1	0.001	99.988
298	*Pentapodus porosus*	1	0.001	99.989
299	*Phalangipes australiensis*	1	0.001	99.990
300	*Platax teira*	1	0.001	99.990
301	*Priacanthus tayenus*	1	0.001	99.991
302	*Pristis zijsron*	1	0.001	99.991
303	*Psammoperca waigiensis*	1	0.001	99.992
304	*Pseudorhombus argus*	1	0.001	99.993
305	*Rhinoptera sp.*	1	0.001	99.993
306	*Schizophrys dama*	1	0.001	99.994
307	*Eusphyra blochii*	1	0.001	99.995
308	Porifera sp. 47	1	0.001	99.995
309	Porifera sp. 58	1	0.001	99.996
310	Porifera sp. 69	1	0.001	99.996
311	*Stellaster equestris*	1	0.001	99.997
312	*Stellaster sp*	1	0.001	99.998
313	*Inegocia japonica*	1	0.001	99.998
314	*Cociella hutchinsi*	1	0.001	99.999
315	*Tathicarpus butleri*	1	0.001	99.999
316	*Upeneus vittatus*	1	0.001	100.000

Appendix 3B For the 'North Mornington' region, the number of standard trawls required to detect declines of 50, 75 and 99.9% in catch rates from a future baseline trawl survey.

Appendix is ordered by (a) decreasing numbers of trawls for the 50% decline and (b) alphabetically within groups of taxa needing the same numbers of trawls (for 50% decline). No pres = number of trawls that taxa was recorded in; p = Poisson distribution and n = negative binomial used; Mean = mean number per trawl and Std dev = standard deviation based on raw count data; Abund = mean catch rates after scaling factor applied.

Obs. no	Taxa	No pres	Distrib^{n} used	Mean	Std dev.	Abund (no. ha^{-1})	Decline of 50%	Decline of 75%	Decline of 99.9%
1	Soleidae	1	p	0.019	0.139	0.010	3276	1213	548
2	*Acanthocepola abbreviata*	1	p	0.019	0.139	0.010	3276	1213	548
3	*Alectis indicus*	1	p	0.019	0.139	0.010	3276	1213	548
4	*Antennarius hispidus*	1	p	0.019	0.139	0.010	3276	1213	548
5	*Antennarius nummifer*	1	p	0.019	0.139	0.010	3276	1213	548
6	*Apogon cavitiensis*	1	p	0.019	0.139	0.010	3276	1213	548
7	*Argyrops spinifer*	1	p	0.019	0.139	0.010	3276	1213	548
8	Ascidiacea	1	p	0.019	0.139	0.010	3276	1213	548
9	*Astropecten* sp. 3	1	p	0.019	0.139	0.010	3276	1213	548
10	*Atypopenaeus spp*	1	p	0.019	0.139	0.010	3276	1213	548
11	*Bathypilumnus nigrispinifer*	1	p	0.019	0.139	0.010	3276	1213	548
12	*Bohadschia marmorata*	1	p	0.019	0.139	0.010	3276	1213	548
13	Gobiidae	1	p	0.019	0.139	0.010	3276	1213	548
14	Ophiuroidea 41	1	p	0.019	0.139	0.010	3276	1213	548
15	Bryozoa 3	2	p	0.019	0.139	0.010	3276	1213	548
16	*Carinosquilla carinata*	1	p	0.019	0.139	0.010	3276	1213	548
17	*Carcharhinus dussumieri*	1	p	0.019	0.139	0.010	3276	1213	548
18	*Calappa terraereginae*	1	p	0.019	0.139	0.010	3276	1213	548
19	*Cephalopholis boenack*	1	p	0.019	0.139	0.010	3276	1213	548
20	*Ceratoplax* sp. 2	1	p	0.019	0.139	0.010	3276	1213	548
21	*Ceratoplax* sp. 3	1	p	0.019	0.139	0.010	3276	1213	548
22	*Chirocentrus dorab*	1	p	0.019	0.139	0.010	3276	1213	548
23	*Charybdis miles*	1	p	0.019	0.139	0.010	3276	1213	548
24	*Charybdis natator*	1	p	0.019	0.139	0.010	3276	1213	548
25	*Chiloscyllium punctatum*	1	p	0.019	0.139	0.010	3276	1213	548
26	*Clypeaster* sp. 1	1	p	0.019	0.139	0.010	3276	1213	548

Obs. no	Taxa	No pres	Distrib[n] used	Mean	Std dev.	Abund (no. ha^{-1})	Decline of 50%	Decline of 75%	Decline of 99.9%
27	*Cottapistus praepositus*	1	p	0.019	0.139	0.010	3276	1213	548
28	*Dardanus hessii*	1	p	0.019	0.139	0.010	3276	1213	548
29	*Demania cultripes*	1	p	0.019	0.139	0.010	3276	1213	548
30	*Decapterus macrosoma*	1	p	0.019	0.139	0.010	3276	1213	548
31	*Erosa erosa*	1	p	0.019	0.139	0.010	3276	1213	548
32	*Gerres oyena*	1	p	0.019	0.139	0.010	3276	1213	548
33	*Gymnura australis*	1	p	0.019	0.139	0.010	3276	1213	548
34	Muraenidae	1	p	0.019	0.139	0.010	3276	1213	548
35	*Herklotsichthys lippa*	1	p	0.019	0.139	0.010	3276	1213	548
36	*Himantura toshi*	1	p	0.019	0.139	0.010	3276	1213	548
37	*Hydrophis elegans*	1	p	0.019	0.139	0.010	3276	1213	548
38	Hydrozoa	1	p	0.019	0.139	0.010	3276	1213	548
39	*Lagocephalus lunaris*	1	p	0.019	0.139	0.010	3276	1213	548
40	*Leiognathus equulus*	1	p	0.019	0.139	0.010	3276	1213	548
41	*Lethrinus laticaudis*	1	p	0.019	0.139	0.010	3276	1213	548
42	*Lophopilumnus globosus*	1	p	0.019	0.139	0.010	3276	1213	548
43	*Lutjanus russelli*	1	p	0.019	0.139	0.010	3276	1213	548
44	*Lupocyclus tugelae*	1	p	0.019	0.139	0.010	3276	1213	548
45	*Metapenaeus ensis*	1	p	0.019	0.139	0.010	3276	1213	548
46	*Odontodactylus cultrifer*	1	p	0.019	0.139	0.010	3276	1213	548
47	*Opistognathus latitabundus*	1	p	0.019	0.139	0.010	3276	1213	548
48	*Oxyurichthys* sp.	1	p	0.019	0.139	0.010	3276	1213	548
49	*Parachaeturichthys polynema*	1	p	0.019	0.139	0.010	3276	1213	548
50	*Cercodemes anceps*	1	p	0.019	0.139	0.010	3276	1213	548
51	*Pilumnus semilanatus*	1	p	0.019	0.139	0.010	3276	1213	548
52	*Platax teira*	1	p	0.019	0.139	0.010	3276	1213	548
53	Porcellanidae	1	p	0.019	0.139	0.010	3276	1213	548
54	*Rhopalaea crassa*	1	p	0.019	0.139	0.010	3276	1213	548
55	*Samaris cristatus*	1	p	0.019	0.139	0.010	3276	1213	548
56	*Scorpaenopsis diabolus*	1	p	0.019	0.139	0.010	3276	1213	548
57	*Scyllarus hannii*	1	p	0.019	0.139	0.010	3276	1213	548
58	Scyphozoa	1	p	0.019	0.139	0.010	3276	1213	548
59	*Secutor insidiator*	1	p	0.019	0.139	0.010	3276	1213	548
60	Pennatulacea 1	1	p	0.019	0.139	0.010	3276	1213	548
61	Pennatulacea 8	1	p	0.019	0.139	0.010	3276	1213	548

Obs. no	Taxa	No pres	Distrib^{n} used	Mean	Std dev.	Abund (no. ha^{-1})	Decline of 50%	Decline of 75%	Decline of 99.9%
62	*Terapon jarbua*	1	p	0.019	0.139	0.010	3276	1213	548
63	*Thalassinia sp. 2*	1	p	0.019	0.139	0.010	3276	1213	548
64	*Trachyrhamphus longirostris*	1	p	0.019	0.139	0.010	3276	1213	548
65	*Velifer hypselopterus*	1	p	0.019	0.139	0.010	3276	1213	548
66	Gorgonocephalidae 1	1	n	0.038	0.277	0.019	3003	1122	547
67	Pilumnidae	1	n	0.038	0.277	0.019	3003	1122	547
68	*Siphamia guttulatus*	1	n	0.058	0.416	0.029	2912	1092	547
69	*Microcosmus exasperatus*	1	n	0.212	1.525	0.105	2780	1048	547
70	*Thryssa setirostris*	2	n	0.154	0.978	0.077	2189	824	425
71	*Solenocera pectinata*	2	n	0.154	0.872	0.077	1754	660	338
72	Alpheidae	2	n	0.058	0.308	0.029	1675	625	299
73	Bivalvia	2	n	0.058	0.308	0.029	1675	625	299
74	*Aluterus monoceros*	2	p	0.038	0.194	0.019	1638	607	274
75	Alcyonarian 7	2	p	0.038	0.194	0.019	1638	607	274
76	*Carangoides hedlandensis*	2	p	0.038	0.194	0.019	1638	607	274
77	*Dussumieria elopsoides*	2	p	0.038	0.194	0.019	1638	607	274
78	*Engyprosopon grandisquamum*	2	p	0.038	0.194	0.019	1638	607	274
79	*Hyastenus sp. 1*	2	p	0.038	0.194	0.019	1638	607	274
80	*Johnius borneensis*	2	p	0.038	0.194	0.019	1638	607	274
81	*Lumiconger arafura*	2	p	0.038	0.194	0.019	1638	607	274
82	*Murex* sp.	2	p	0.038	0.194	0.019	1638	607	274
83	*Oratosquilla quinquendentata*	2	p	0.038	0.194	0.019	1638	607	274
84	*Parachaetodon ocellatus*	2	p	0.038	0.194	0.019	1638	607	274
85	*Penaeus esculentus*	2	p	0.038	0.194	0.019	1638	607	274
86	Pennatulacea 7	2	p	0.038	0.194	0.019	1638	607	274
87	*Stolephorus indicus*	2	p	0.038	0.194	0.019	1638	607	274
88	*Synchiropus rameus*	2	p	0.038	0.194	0.019	1638	607	274
89	*Portunus rugosus*	2	n	0.173	0.923	0.086	1554	584	299
90	*Lethrinus lentjan*	2	n	0.115	0.583	0.057	1429	536	268
91	*Sphyraena obtusata*	3	n	0.115	0.583	0.057	1429	536	268
92	*Portunus spinipes*	3	n	0.096	0.454	0.048	1280	479	235
93	*Leiognathus bindus*	27	n	6.865	32.845	3.412	1203	454	241
94	*Atule mate*	3	n	0.077	0.334	0.038	1127	420	199
95	*Bathypilumnus pugilator*	3	n	0.077	0.334	0.038	1127	420	199
96	*Lutjanus lutjanus*	3	n	0.077	0.334	0.038	1127	420	199

Obs. no	Taxa	No pres	Distrib^n used	Mean	Std dev.	Abund (no. ha^{-1})	Decline of 50%	Decline of 75%	Decline of 99.9%
97	*Onigocia macrolepis*	3	n	0.077	0.334	0.038	1127	420	199
98	*Choerodon cephalotes*	3	p	0.058	0.235	0.029	1092	404	183
99	*Charybdis yaldwin*	3	p	0.058	0.235	0.029	1092	404	183
100	*Congrogadus amplimaculatus*	3	p	0.058	0.235	0.029	1092	404	183
101	*Gerres macracanthus*	3	p	0.058	0.235	0.029	1092	404	183
102	*Hemigaleus microstoma*	3	p	0.058	0.235	0.029	1092	404	183
103	*Holothurioidea*	3	p	0.058	0.235	0.029	1092	404	183
104	*Myra biconica*	3	p	0.058	0.235	0.029	1092	404	183
105	*Neomerinthe megalepis*	3	p	0.058	0.235	0.029	1092	404	183
106	*Parupeneus heptacanthus*	3	p	0.058	0.235	0.029	1092	404	183
107	Polychaeta	3	p	0.058	0.235	0.029	1092	404	183
108	*Portunus* sp. 1	3	p	0.058	0.235	0.029	1092	404	183
109	*Pseudocolochirus axiologus*	3	p	0.058	0.235	0.029	1092	404	183
110	*Sphyraena flavicauda*	3	p	0.058	0.235	0.029	1092	404	183
111	*Sphyraena forsteri*	4	n	0.250	1.118	0.124	1092	411	210
112	*Torquigener tuberculiferus*	3	p	0.058	0.235	0.029	1092	404	183
113	*Pseudomonacanthus peroni*	3	n	0.096	0.409	0.048	1058	395	190
114	*Carangoides malabaricus*	4	n	0.115	0.471	0.057	965	361	175
115	*Thenus orientalis*	4	n	0.115	0.471	0.057	965	361	175
116	*Upeneus sulphureus*	22	n	14.500	60.499	7.207	915	346	183
117	*Lethrinus genivittatus*	4	n	0.096	0.358	0.048	835	311	146
118	*Rachycentron canadum*	4	n	0.096	0.358	0.048	835	311	146
119	*Sillago maculata*	4	n	0.096	0.358	0.048	835	311	146
120	*Inimicus sinensis*	4	p	0.077	0.269	0.038	819	303	137
121	*Lupocyclus rotundatus*	4	p	0.077	0.269	0.038	819	303	137
122	*Minous versicolor*	4	p	0.077	0.269	0.038	819	303	137
123	*Rastrelliger brachysoma*	4	p	0.077	0.269	0.038	819	303	137
124	*Xiphocheilus typus*	4	p	0.077	0.269	0.038	819	303	137
125	*Tathicarpus butleri*	4	n	0.115	0.427	0.057	811	302	144
126	*Plotosus lineatus*	4	n	0.173	0.648	0.086	798	299	148
127	*Trixiphichthys weberi*	9	n	0.596	2.277	0.296	784	295	154
128	*Drepane punctata*	6	n	0.173	0.617	0.086	729	273	134
129	*Paramonacanthus japonicus*	5	n	0.154	0.538	0.077	711	265	129
130	*Spiropagurus* sp. 1	5	n	0.154	0.538	0.077	711	265	129
131	*Echeneis naucrates*	5	n	0.115	0.379	0.057	656	244	113

Obs. no	Taxa	No pres	Distrib^n used	Mean	Std dev.	Abund (no. ha^{-1})	Decline of 50%	Decline of 75%	Decline of 99.9%
132	*Sicyonia cristata*	5	n	0.115	0.379	0.057	656	244	113
133	*Netuma thalassinus*	5	p	0.096	0.298	0.048	655	243	110
134	*Callionymus grossi*	5	p	0.096	0.298	0.048	655	243	110
135	*Lepidotrigla argus*	5	p	0.096	0.298	0.048	655	243	110
136	Scorpaenidae	5	p	0.096	0.298	0.048	655	243	110
137	*Upeneus tragula*	5	p	0.096	0.298	0.048	655	243	110
138	*Gerres filamentosus*	7	n	0.231	0.783	0.115	649	243	121
139	*Pelates quadrilineatus*	12	n	0.462	1.590	0.229	646	243	125
140	*Mene maculata*	6	n	0.212	0.667	0.105	571	214	105
141	*Apogon nigripinnis*	6	p	0.115	0.323	0.057	546	202	91
142	*Charybdis jaubertensis*	6	p	0.115	0.323	0.057	546	202	91
143	*Lagocephalus spadiceus*	6	p	0.115	0.323	0.057	546	202	91
144	*Zabidius novaemaculatus*	6	p	0.115	0.323	0.057	546	202	91
145	*Selar boops*	6	n	0.154	0.460	0.077	537	200	94
146	*Scomberomorus queenslandicus*	6	n	0.135	0.397	0.067	536	199	92
147	*Choerodon monostigma*	6	n	0.173	0.513	0.086	523	195	93
148	Loveniidae	24	n	45.154	142.201	22.443	521	197	104
149	*Anacanthus barbatus*	7	p	0.135	0.345	0.067	468	173	78
150	*Euristhmus lepturus*	7	n	0.269	0.770	0.134	468	175	86
151	*Lutjanus sebae*	7	p	0.135	0.345	0.067	468	173	78
152	*Rhynchobatus djiddensis*	7	p	0.135	0.345	0.067	468	173	78
153	*Seriolina nigrofasciata*	7	p	0.135	0.345	0.067	468	173	78
154	*Trichiurus lepturus*	7	n	0.250	0.711	0.124	466	174	85
155	*Scyllarus demani*	8	n	0.231	0.645	0.115	456	170	82
156	Pectinidae	7	n	0.173	0.474	0.086	454	169	79
157	*Choerodon sugillatum*	7	n	0.154	0.415	0.077	450	167	77
158	*Sorsogona tuberculata*	7	n	0.154	0.415	0.077	450	167	77
159	*Selar crumenophthalmus*	7	n	0.192	0.525	0.096	446	166	79
160	*Leiognathus* sp.	13	n	0.519	1.462	0.258	436	164	83
161	*Tetrabrachium ocellatum*	8	n	0.212	0.572	0.105	433	161	77
162	*Synodus sageneus*	8	n	0.250	0.653	0.124	400	149	72
163	*Charybdis feriatus*	8	n	0.212	0.536	0.105	387	144	68
164	*Abalistes stellaris*	8	n	0.173	0.430	0.086	385	143	65
165	*Carangoides chrysophrys*	9	n	0.327	0.834	0.163	373	140	68
166	*Dexillus muelleri*	10	n	0.327	0.810	0.163	354	132	65

Obs. no	Taxa	No pres	Distrib^n used	Mean	Std dev.	Abund (no. ha^{-1})	Decline of 50%	Decline of 75%	Decline of 99.9%
167	*Zebrias quagga*	9	n	0.212	0.498	0.105	341	127	58
168	*Amphotistius leylandi*	9	n	0.250	0.590	0.124	334	124	59
169	*Pseudochromis quinquedentatus*	9	n	0.250	0.590	0.124	334	124	59
170	*Alepes* sp.	9	n	0.308	0.729	0.153	329	123	59
171	*Terapon theraps*	10	n	0.231	0.509	0.115	301	112	51
172	*Apogon albimaculosus*	10	p	0.212	0.457	0.105	298	110	50
173	*Tragulichthys jaculiferus*	10	p	0.212	0.457	0.105	298	110	50
174	*Selaroides leptolepis*	30	n	2.000	4.589	0.994	282	106	55
175	*Nettastoma parviceps*	11	p	0.231	0.469	0.115	273	101	46
176	*Diagramma pictum*	12	n	0.288	0.605	0.143	267	99	46
177	*Caranx bucculentus*	17	n	1.038	2.214	0.516	249	93	48
178	*Carangoides caeruleopinnatus*	13	p	0.269	0.490	0.134	234	87	39
179	*Lutjanus vitta*	13	p	0.269	0.490	0.134	234	87	39
180	*Paraplagusia longirostris*	15	n	0.481	0.960	0.239	231	86	42
181	*Cottapistus cottoides*	13	n	0.462	0.917	0.229	230	86	42
182	*Decapterus russelli*	17	n	0.519	1.019	0.258	223	83	41
183	*Pterois russelli*	14	p	0.288	0.498	0.143	218	81	37
184	*Thalamita sima*	13	p	0.288	0.536	0.143	218	81	37
185	*Nemipterus furcosus*	26	n	2.731	5.358	1.357	206	78	41
186	*Apogon septemstriatus*	25	n	1.231	2.357	0.612	201	76	39
187	*Podopthalmus vigil*	15	n	0.365	0.658	0.182	199	74	34
188	*Dactylopus dactylopus*	15	n	0.481	0.874	0.239	195	73	35
189	*Leiognathus moretoniensis*	34	n	14.346	27.155	7.131	189	71	38
190	*Lepidotrigla* sp. 2	18	n	1.596	2.899	0.793	180	68	35
191	*Brachypleura novaezeelandiae*	16	n	0.692	1.213	0.344	176	66	32
192	*Pentaprion longimanus*	50	n	31.442	57.022	15.628	173	65	35
193	*Uranoscopus cognatus*	22	n	1.077	1.877	0.535	169	64	32
194	*Apistus carinatus*	26	n	2.981	5.241	1.482	166	62	33
195	*Pristotis jerdoni*	17	n	0.654	1.101	0.325	165	62	30
196	*Minous trachycephalus*	20	n	0.750	1.250	0.373	160	60	29
197	*Jonas luteanus*	23	n	0.942	1.577	0.468	158	59	29
198	*Stolephorus waitei*	21	n	1.308	2.192	0.650	156	58	30
199	Cynoglossidae	17	n	0.423	0.667	0.210	155	58	26
200	*Apistus carinatus*	27	n	3.173	5.368	1.577	154	58	30
201	*Siphamia majimai*	22	n	1.192	1.981	0.593	154	58	29

Obs. no	Taxa	No pres	Distrib^n used	Mean	Std dev.	Abund (no. ha^{-1})	Decline of 50%	Decline of 75%	Decline of 99.9%
202	Octopoda	18	p	0.423	0.637	0.210	149	55	25
203	Teuthoidea	28	n	1.346	2.186	0.669	146	55	28
204	*Oratosquilla woodmasoni*	20	n	0.692	1.076	0.344	142	53	25
205	*Carangoides talamparoides*	23	n	0.769	1.182	0.382	138	51	25
206	*Paramonacanthus choirocephalus*	22	n	0.692	1.058	0.344	138	51	25
207	*Synodus hoshinonis*	26	n	1.269	1.962	0.631	134	50	25
208	*Adventor elongatus*	20	n	0.481	0.700	0.239	133	49	22
209	*Brachypterois serrulatus*	32	n	1.904	2.966	0.946	133	50	26
210	*Arnoglossus waitei*	22	n	0.692	1.020	0.344	129	48	23
211	*Muraenesox cinereus*	22	n	0.615	0.889	0.306	127	47	22
212	*Suggrundus rodericensis*	23	n	0.769	1.113	0.382	124	46	22
213	*Upeneus asymmetricus*	34	n	2.942	4.394	1.462	121	45	23
214	*Carangoides humerosus*	27	n	1.231	1.789	0.612	119	45	22
215	*Yongeichthys nebulosus*	22	n	1.288	1.861	0.640	118	44	22
216	*Thenus indicus*	28	n	1.058	1.434	0.526	106	40	19
217	*Nemipterus peronii*	43	n	7.692	10.356	3.823	97	36	19
218	Alcyonarian 4	26	n	0.808	1.011	0.402	95	35	16
219	*Oratosquilla inornata*	39	n	5.173	6.802	2.571	93	35	18
220	*Dactyloptena papilio*	40	n	4.808	5.990	2.390	84	32	16
221	*Portunus tenuipes*	31	n	3.269	4.064	1.625	84	32	16
222	Caridea	32	n	3.154	3.862	1.568	82	31	16
223	*Portunus sanguinolentus*	33	n	1.500	1.732	0.746	77	29	14
224	*Saurida* sp. 2	27	n	29.096	35.146	14.462	77	29	15
225	*Callionymus japonicus*	36	n	2.115	2.431	1.051	74	28	14
226	*Psettodes erumei*	30	n	1.077	1.186	0.535	73	27	13
227	*Pseudorhombus spinosus*	37	n	1.481	1.663	0.736	73	27	13
228	*Ostracion nasus*	40	n	2.846	3.189	1.415	70	26	13
229	*Priacanthus tayenus*	47	n	5.712	6.467	2.839	69	26	13
230	*Lutjanus malabaricus*	32	n	1.096	1.159	0.545	68	25	12
231	*Sirembo imberbis*	34	p	0.981	0.939	0.488	64	24	11
232	*Trachinocephalus myops*	35	n	1.288	1.333	0.640	64	24	11
233	*Metapenaeus endeavouri*	51	n	13.173	14.126	6.548	61	23	12
234	*Portunus acerbiterminalis*	47	n	25.346	27.311	12.598	61	23	12
235	*Pseudorhombus diplospilus*	34	n	1.635	1.657	0.813	60	23	11
236	*Amusium pleuronectes*	52	n	64.712	68.672	32.164	59	22	12

Obs. no	Taxa	No pres	Distrib^n used	Mean	Std dev.	Abund (no. ha^{-1})	Decline of 50%	Decline of 75%	Decline of 99.9%
237	*Saurida undosquamis*	36	n	63.231	66.749	31.428	59	22	12
238	*Charybdis truncata*	52	n	21.212	22.295	10.543	58	22	12
239	*Centriscus scutatus*	45	n	3.423	3.466	1.701	57	21	11
240	*Upeneus* sp. 1	42	n	2.865	2.715	1.424	51	19	9
241	*Portunus gracilimanus*	48	n	33.077	30.263	16.441	44	17	9
242	*Rogadius asper*	46	n	4.154	3.664	2.065	43	16	8
243	*Chaetodiadema granulatum*	48	n	5.019	4.318	2.495	41	15	8
244	*Inegocia japonica*	47	n	4.231	3.595	2.103	40	15	8
245	*Trachypenaeus* spp	52	n	123.654	105.722	61.461	38	15	8
246	*Portunus pelagicus*	44	n	3.154	2.523	1.568	37	14	7
247	*Epinephelus sexfasciatus*	45	p	1.923	1.311	0.956	33	12	5
248	*Scolopsis taeniopterus*	48	n	4.462	3.410	2.218	33	12	6
249	*Apogon poecilopterus*	52	n	13.154	10.185	6.538	32	12	6
250	*Apogon fasciatus*	50	n	11.327	8.508	5.630	31	11	6
251	*Elates ransonnetii*	52	n	28.923	21.421	14.376	29	11	6
252	*Lagocephalus sceleratus*	49	n	5.135	3.710	2.552	29	11	5
253	*Callionymus goodladi*	46	n	19.519	14.108	9.702	28	11	5
254	*Saurida micropectoralis*	52	n	20.712	14.896	10.295	28	10	5
255	*Apogon ellioti*	52	n	27.135	18.453	13.487	25	9	5
256	*Fistularia petimba*	52	n	19.788	13.118	9.836	24	9	5
257	*Grammatobothus polyophthalmus*	51	n	6.173	4.057	3.068	24	9	5
258	*Pseudorhombus elevatus*	52	n	9.250	6.003	4.598	23	9	4
259	*Metapenaeopsis* spp	52	n	100.981	64.787	50.192	22	8	4
260	*Paramonacanthus filicauda*	50	n	12.981	8.216	6.452	22	8	4
261	*Portunus rubromarginatus*	52	n	46.154	24.691	22.940	15	6	3
262	*Euristhmus nudiceps*	52	n	18.731	9.594	9.310	14	5	3
263	Sepiidae	51	n	11.192	5.667	5.563	14	5	3
264	*Nemipterus nematopus*	52	n	70.423	31.766	35.003	11	4	2
265	*Suggrundus macracanthus*	51	n	12.327	5.090	6.127	10	4	2
266	*Nemipterus hexodon*	52	n	45.404	17.657	22.568	8	3	2

Appendix 3C For the 'North Groote' region, the number of standard trawls required to detect declines of 50, 75 and 99.9% in catch rates from a future baseline trawl survey.

Appendix is ordered by (a) decreasing numbers of trawls for the 50% decline and (b) alphabetically within groups of taxa needing the same numbers of trawls (for 50% decline). No. pres = number of trawls that taxon was recorded in; p = Poisson distribution and n = negative binomial used; Mean = mean number per trawl and Std dev = standard deviation based on raw count data; Abund = mean catch rates after scaling factor applied.

Obs. no	Taxa	No. pres.	Distrib[n] used	Mean	Std dev.	Abund (no. ha^{-1})	Decline of 50%	Decline of 75%	Decline of 99.9%
1	Apogonidae	1	p	0.023	0.153	0.006	2709	1003	453
2	Blenniidae	1	p	0.023	0.153	0.006	2709	1003	453
3	Engraulididae	1	p	0.023	0.153	0.006	2709	1003	453
4	*Abalistes stellaris*	1	p	0.023	0.153	0.006	2709	1003	453
5	*Acentrogobius caninus*	1	p	0.023	0.153	0.006	2709	1003	453
6	Alpheid sp. *3*	1	p	0.023	0.153	0.006	2709	1003	453
7	*Feroxodon multistriatus*	1	p	0.023	0.153	0.006	2709	1003	453
8	*Apogon notatus*	1	p	0.023	0.153	0.006	2709	1003	453
9	*Aplisia* spp	1	p	0.023	0.153	0.006	2709	1003	453
10	*Argyrops spinifer*	1	p	0.023	0.153	0.006	2709	1003	453
11	*Astropecten* sp. 3	1	p	0.023	0.153	0.006	2709	1003	453
12	*Atelomycterus fasciatus*	1	p	0.023	0.153	0.006	2709	1003	453
13	*Batrachomoeus trispinosus*	1	p	0.023	0.153	0.006	2709	1003	453
14	*Melo amphora*	1	p	0.023	0.153	0.006	2709	1003	453
15	Gobiidae	1	p	0.023	0.153	0.006	2709	1003	453
16	Ophiuroidea	1	p	0.023	0.153	0.006	2709	1003	453
17	*Carcharhinus dussumieri*	1	p	0.023	0.153	0.006	2709	1003	453
18	*Caranx kleinii*	1	p	0.023	0.153	0.006	2709	1003	453
19	*Charybdis callianassa*	1	p	0.023	0.153	0.006	2709	1003	453
20	*Charybdis yaldwin*	1	p	0.023	0.153	0.006	2709	1003	453
21	*Clorida chlorida*	1	p	0.023	0.153	0.006	2709	1003	453
22	Cnidaria	1	p	0.023	0.153	0.006	2709	1003	453
23	*Cottapistus cottoides*	1	p	0.023	0.153	0.006	2709	1003	453
24	Conidae	1	p	0.023	0.153	0.006	2709	1003	453
25	*Culcita* spp	1	p	0.023	0.153	0.006	2709	1003	453

Obs. no	Taxa	No. pres.	Distrib^{n} used	Mean	Std dev.	Abund (no. ha^{-1})	Decline of 50%	Decline of 75%	Decline of 99.9%
26	*Dardanus imbricata*	1	p	0.023	0.153	0.006	2709	1003	453
27	Didemnid 8	4	p	0.023	0.153	0.006	2709	1003	453
28	Echinodermata	1	p	0.023	0.153	0.006	2709	1003	453
29	*Epinephelus quoyanus*	1	p	0.023	0.153	0.006	2709	1003	453
30	Gorgonian 20	1	p	0.023	0.153	0.006	2709	1003	453
31	*Gymnura australis*	1	p	0.023	0.153	0.006	2709	1003	453
32	*Himantura jenkinsii*	1	p	0.023	0.153	0.006	2709	1003	453
33	*Ixa inermis*	1	p	0.023	0.153	0.006	2709	1003	453
34	*Johnius borneensis*	1	p	0.023	0.153	0.006	2709	1003	453
35	*Lagocephalus lunaris*	1	p	0.023	0.153	0.006	2709	1003	453
36	*Leiognathus decorus*	1	p	0.023	0.153	0.006	2709	1003	453
37	*Lutjanus carponotatus*	1	p	0.023	0.153	0.006	2709	1003	453
38	*Lutjanus quinquelineatus*	1	p	0.023	0.153	0.006	2709	1003	453
39	*Lutjanus russelli*	1	p	0.023	0.153	0.006	2709	1003	453
40	Majidae (82)	1	p	0.023	0.153	0.006	2709	1003	453
41	*Mene maculata*	1	p	0.023	0.153	0.006	2709	1003	453
42	*Myripristis murdjan*	1	p	0.023	0.153	0.006	2709	1003	453
43	*Bohadschia* spp	1	p	0.023	0.153	0.006	2709	1003	453
44	*Pelates quadrilineatus*	1	p	0.023	0.153	0.006	2709	1003	453
45	*Pilumnus sp. 4*	1	p	0.023	0.153	0.006	2709	1003	453
46	*Polydactylus multiradiatus*	1	p	0.023	0.153	0.006	2709	1003	453
47	Polychaeta	1	p	0.023	0.153	0.006	2709	1003	453
48	*Protonibea diacanthus*	1	p	0.023	0.153	0.006	2709	1003	453
49	*Pseudamia amblyuroptera*	1	p	0.023	0.153	0.006	2709	1003	453
50	*Rachycentron canadum*	1	p	0.023	0.153	0.006	2709	1003	453
51	*Scyllarus demani*	1	p	0.023	0.153	0.006	2709	1003	453
52	*Scyllarus hannii*	1	p	0.023	0.153	0.006	2709	1003	453
53	*Scomberoides tol*	1	p	0.023	0.153	0.006	2709	1003	453
54	*Seriolina nigrofasciata*	1	p	0.023	0.153	0.006	2709	1003	453
55	Pennatulacea 1	1	p	0.023	0.153	0.006	2709	1003	453
56	Pennatulacea 8	1	p	0.023	0.153	0.006	2709	1003	453
57	*Siphamia argyrogaster*	1	p	0.023	0.153	0.006	2709	1003	453
58	*Solenocera pectinata*	1	p	0.023	0.153	0.006	2709	1003	453
59	*Sorsogona tuberculata*	1	p	0.023	0.153	0.006	2709	1003	453
60	*Cociella hutchinsi*	1	p	0.023	0.153	0.006	2709	1003	453

Obs. no	Taxa	No. pres.	Distrib^n used	Mean	Std dev.	Abund (no. ha^{-1})	Decline of 50%	Decline of 75%	Decline of 99.9%
61	*Thryssa hamiltonii*	1	p	0.023	0.153	0.006	2709	1003	453
62	*Trachyrhamphus longirostris*	1	p	0.023	0.153	0.006	2709	1003	453
63	*Ctenotrypauchen microcephalus*	1	p	0.023	0.153	0.006	2709	1003	453
64	*Upeneus* sp. 1	1	p	0.023	0.153	0.006	2709	1003	453
65	*Upogebia* sp. 2	1	p	0.023	0.153	0.006	2709	1003	453
66	*Uraspis uraspis*	1	p	0.023	0.153	0.006	2709	1003	453
67	*Xiphocheilus typus*	1	p	0.023	0.153	0.006	2709	1003	453
68	*Amblygaster sirm*	1	n	0.047	0.305	0.011	2483	928	453
69	Crangonidae	1	n	0.047	0.305	0.011	2483	928	453
70	*Leiognathus aureus*	1	n	0.047	0.305	0.011	2483	928	453
71	*Bathypilumnus pugilator*	1	n	0.070	0.458	0.017	2408	903	453
72	*Plotosus lineatus*	2	n	0.256	1.529	0.061	1917	722	376
73	Porcellanidae	2	n	0.116	0.625	0.028	1608	604	304
74	*Valamugil cunnesius*	2	n	0.093	0.479	0.022	1504	563	279
75	*Carangoides chrysophrys*	2	n	0.070	0.338	0.017	1381	515	247
76	*Lethrinus lentjan*	2	n	0.070	0.338	0.017	1381	515	247
77	*Tragulichthys jaculiferus*	2	n	0.070	0.338	0.017	1381	515	247
78	*Dussumieria elopsoides*	3	n	0.186	0.932	0.044	1375	517	264
79	*Netuma thalassinus*	3	n	0.279	1.403	0.067	1364	514	266
80	*Alectis indicus*	2	p	0.047	0.213	0.011	1355	502	226
81	Alcyonarian 3	2	p	0.047	0.213	0.011	1355	502	226
82	*Apogon albimaculosus*	2	p	0.047	0.213	0.011	1355	502	226
83	*Apogon nigripinnis*	2	p	0.047	0.213	0.011	1355	502	226
84	*Arcania novemspinosa*	2	p	0.047	0.213	0.011	1355	502	226
85	*Atelomycterus fasciatus*	2	p	0.047	0.213	0.011	1355	502	226
86	*Bohadschia marmorata*	2	p	0.047	0.213	0.011	1355	502	226
87	*Clorida latreillei*	2	p	0.047	0.213	0.011	1355	502	226
88	*Cottapistus praepositus*	2	p	0.047	0.213	0.011	1355	502	226
89	Crinoidea	2	p	0.047	0.213	0.011	1355	502	226
90	*Engyprosopon grandisquamum*	2	p	0.047	0.213	0.011	1355	502	226
91	*Epinephelus areolatus*	2	p	0.047	0.213	0.011	1355	502	226
92	Exocoetidae	2	p	0.047	0.213	0.011	1355	502	226
93	*Hyastenus* sp. 1	2	p	0.047	0.213	0.011	1355	502	226
94	Hydrozoa	2	p	0.047	0.213	0.011	1355	502	226
95	Muricidae	2	p	0.047	0.213	0.011	1355	502	226

Obs. no	Taxa	No. pres.	Distrib^n used	Mean	Std dev.	Abund (no. ha^{-1})	Decline of 50%	Decline of 75%	Decline of 99.9%
96	*Onigocia spinosa*	2	p	0.047	0.213	0.011	1355	502	226
97	Ostreidae	2	p	0.047	0.213	0.011	1355	502	226
98	*Oxyurichthys sp.*	2	p	0.047	0.213	0.011	1355	502	226
99	*Paramonacanthus choirocephalus*	2	p	0.047	0.213	0.011	1355	502	226
100	*Platycephalus endrachtensis*	2	p	0.047	0.213	0.011	1355	502	226
101	*Polycarpa papilleta*	2	p	0.047	0.213	0.011	1355	502	226
102	*Nettastoma parviceps*	2	p	0.047	0.213	0.011	1355	502	226
103	*Scorpaenopsis diabolus*	2	p	0.047	0.213	0.011	1355	502	226
104	Echinoid 11	2	p	0.047	0.213	0.011	1355	502	226
105	*Pomadasys maculatus*	5	n	0.349	1.689	0.083	1260	475	247
106	*Pentapodus paradiseus*	3	n	0.116	0.498	0.028	1054	394	193
107	*Pomadasys trifasciatus*	4	n	0.256	1.115	0.061	1038	390	200
108	*Charybdis jaubertensis*	3	n	0.093	0.366	0.022	926	345	163
109	Gastropoda	3	n	0.093	0.366	0.022	926	345	163
110	*Minous trachycephalus*	3	n	0.093	0.366	0.022	926	345	163
111	*Pseudorhombus diplospilus*	3	n	0.093	0.366	0.022	926	345	163
112	*Sphyraena flavicauda*	3	n	0.093	0.366	0.022	926	345	163
113	*Saurida longimanus*	3	n	0.140	0.560	0.033	920	344	169
114	*Choerodon monostigma*	4	n	0.163	0.652	0.039	907	340	169
115	*Clorida decorata*	3	p	0.070	0.258	0.017	903	334	151
116	*Gerres oyena*	3	p	0.070	0.258	0.017	903	334	151
117	*Jonas luteanus*	3	p	0.070	0.258	0.017	903	334	151
118	*Lethrinus genivittatus*	3	p	0.070	0.258	0.017	903	334	151
119	*Opistognathus latitabundus*	3	p	0.070	0.258	0.017	903	334	151
120	*Ostracion nasus*	3	p	0.070	0.258	0.017	903	334	151
121	Pennataculea 7	3	p	0.070	0.258	0.017	903	334	151
122	*Siganus canaliculatus*	3	p	0.070	0.258	0.017	903	334	151
123	*Sicyonia cristata*	3	p	0.070	0.258	0.017	903	334	151
124	*Thalassinia* sp. 1	3	p	0.070	0.258	0.017	903	334	151
125	*Trachinocephalus myops*	3	p	0.070	0.258	0.017	903	334	151
126	Veneridae	3	p	0.070	0.258	0.017	903	334	151
127	*Fistularia petimba*	3	n	0.116	0.448	0.028	869	324	156
128	Pilumnidae	3	n	0.116	0.448	0.028	869	324	156
129	Ophiuroidea 11	4	n	0.233	0.895	0.056	823	309	156
130	*Lepidotrigla* sp. 2	3	n	0.233	0.895	0.056	823	309	156

Obs. no	Taxa	No. pres.	Distribⁿ used	Mean	Std dev.	Abund (no. ha^{-1})	Decline of 50%	Decline of 75%	Decline of 99.9%
131	Alpheidae	4	n	0.140	0.516	0.033	792	296	144
132	*Psenopsis humerosa*	11	n	0.628	2.310	0.150	727	274	142
133	*Torquigener whitleyi*	4	n	0.163	0.575	0.039	718	268	131
134	*Gerres macrosoma*	7	n	0.442	1.593	0.105	706	266	137
135	Bivalvia	4	n	0.116	0.391	0.028	684	254	119
136	*Dorippe quadridens*	4	n	0.116	0.391	0.028	684	254	119
137	Eucrate sp. 2	4	n	0.116	0.391	0.028	684	254	119
138	*Thalamita sexlobata*	4	n	0.116	0.391	0.028	684	254	119
139	*Selar crumenophthalmus*	6	n	0.372	1.310	0.089	679	255	130
140	Ascidiacea	4	p	0.093	0.294	0.022	677	251	113
141	*Diagramma pictum*	4	p	0.093	0.294	0.022	677	251	113
142	*Leucosia ocellata*	4	p	0.093	0.294	0.022	677	251	113
143	Octopoda	4	p	0.093	0.294	0.022	677	251	113
144	*Parachaeturichthys polynema*	4	p	0.093	0.294	0.022	677	251	113
145	*Penaeus latisulcatus*	4	p	0.093	0.294	0.022	677	251	113
146	*Portunus gladiator*	4	p	0.093	0.294	0.022	677	251	113
147	*Pterois russelli*	4	p	0.093	0.294	0.022	677	251	113
148	Scyphozoa	4	p	0.093	0.294	0.022	677	251	113
149	*Velifer hypselopterus*	4	p	0.093	0.294	0.022	677	251	113
150	Soleidae	4	n	0.140	0.467	0.033	664	247	118
151	*Scomberomorus munroi*	5	n	0.395	1.312	0.094	605	227	116
152	*Paraplagusia longirostris*	5	n	0.326	1.063	0.078	592	222	112
153	*Crangon sp. 1*	5	n	0.186	0.588	0.044	581	217	105
154	*Solenocera australiana*	15	n	2.512	8.116	0.599	552	209	110
155	*Himantura toshi*	5	p	0.116	0.324	0.028	542	201	91
156	*Pseudorhombus arsius*	5	p	0.116	0.324	0.028	542	201	91
157	*Nemipterus nematopus*	5	n	0.209	0.638	0.050	539	201	98
158	*Calappa terraereginae*	5	n	0.140	0.413	0.033	535	199	92
159	*Parthenope longimanus*	5	n	0.140	0.413	0.033	535	199	92
160	*Megalops cyprinoides*	5	n	0.163	0.485	0.039	530	197	93
161	*Nemipterus furcosus*	5	n	0.163	0.485	0.039	530	197	93
162	*Lutjanus vitta*	6	n	0.186	0.546	0.044	508	190	91
163	*Leiognathus ruconius*	6	n	1.209	3.700	0.288	500	189	99
164	*Pseudorhombus spinosus*	6	n	0.349	0.997	0.083	459	172	86
165	*Sillago lutea*	6	n	0.465	1.334	0.111	454	171	87

Obs. no	Taxa	No. pres.	Distrib^n used	Mean	Std dev.	Abund (no. ha^{-1})	Decline of 50%	Decline of 75%	Decline of 99.9%
166	*Alepes* sp.	6	p	0.140	0.351	0.033	452	167	75
167	Alcyonarian 4	6	p	0.140	0.351	0.033	452	167	75
168	Congridae	6	p	0.140	0.351	0.033	452	167	75
169	*Eucrate dorsalis*	6	p	0.140	0.351	0.033	452	167	75
170	*Grammatobothus polyophthalmus*	6	p	0.140	0.351	0.033	452	167	75
171	*Inimicus sinensis*	6	p	0.140	0.351	0.033	452	167	75
172	*Pterocaesio digramma*	6	p	0.140	0.351	0.033	452	167	75
173	*Trixiphichthys weberi*	6	p	0.140	0.351	0.033	452	167	75
174	*Scomberomorus queenslandicus*	6	n	0.186	0.500	0.044	436	162	76
175	*Zebrias quagga*	6	n	0.186	0.500	0.044	436	162	76
176	*Paradorippe australiensis*	6	n	0.163	0.433	0.039	435	162	74
177	Asteroidea	6	n	0.163	0.433	0.039	435	162	74
178	*Acanthocepola abbreviata*	8	n	0.256	0.693	0.061	427	159	77
179	*Portunus spinipes*	7	n	0.209	0.559	0.050	424	158	75
180	*Callionymus goodladi*	8	n	0.419	1.139	0.100	414	155	78
181	*Lutjanus malabaricus*	8	n	0.279	0.734	0.067	401	150	73
182	*Champsodon nudivittis*	7	p	0.163	0.374	0.039	387	143	65
183	*Dardanus hessii*	7	p	0.163	0.374	0.039	387	143	65
184	*Sillago burrus*	8	n	0.279	0.701	0.067	369	138	66
185	*Thryssa setirostris*	7	n	0.209	0.515	0.050	367	137	64
186	*Sirembo imberbis*	8	n	0.233	0.571	0.056	361	134	63
187	*Lutjanus lutjanus*	8	n	0.256	0.621	0.061	350	130	62
188	*Sphyraena putnamiae*	15	n	1.326	3.322	0.316	338	127	66
189	*Leiognathus fasciatus*	17	n	1.395	3.451	0.333	329	124	64
190	*Stolephorus waitei*	8	n	0.302	0.708	0.072	323	120	58
191	*Brachypleura novaezeelandiae*	16	n	1.465	3.581	0.349	321	121	63
192	*Ulua aurochs*	8	n	0.372	0.874	0.089	318	119	58
193	*Amphotistius leylandi*	8	n	0.209	0.466	0.050	310	115	52
194	Holothuroidea	8	n	0.2093	0.4659	0.050	310	115	52
195	*Penaeus semisulcatus*	8	n	0.209	0.466	0.050	310	115	52
196	*Solenocera* spp.	13	n	0.930	2.208	0.222	307	116	59
197	*Rastrelliger brachysoma*	25	n	5.512	12.820	1.315	286	108	57
198	*Lagocephalus sceleratus*	9	n	0.419	0.932	0.100	285	107	52
199	*Gerres macracanthus*	10	n	3.302	7.642	0.788	284	107	56
200	*Parastromateus niger*	10	n	0.442	0.983	0.105	284	106	52

Obs. no	Taxa	No. pres.	Distrib^{n} used	Mean	Std dev.	Abund (no. ha^{-1})	Decline of 50%	Decline of 75%	Decline of 99.9%
201	*Centriscus scutatus*	9	n	0.279	0.591	0.067	273	101	47
202	*Scolopsis taeniopterus*	24	n	3.140	7.100	0.749	272	103	54
203	*Galene bispinosa*	9	p	0.233	0.480	0.056	271	100	45
204	*Liagore rubromaculata*	9	p	0.233	0.480	0.056	271	100	45
205	*Phalangipes longipes*	9	p	0.233	0.480	0.056	271	100	45
206	Caridea	28	n	9.302	20.804	2.219	264	100	53
207	*Myra biconica*	11	n	0.419	0.879	0.100	257	96	46
208	*Leiognathus equulus*	20	n	5.070	11.085	1.209	253	96	50
209	*Chelonodon patoca*	14	n	0.419	0.852	0.100	242	90	44
210	*Oratosquilla woodmasoni*	10	n	0.279	0.549	0.067	241	89	41
211	*Upeneus sundaicus*	15	n	1.977	4.166	0.472	239	90	47
212	*Thalamita sima*	11	n	0.326	0.644	0.078	238	88	41
213	*Sphyraena forsteri*	12	n	0.861	1.767	0.205	234	88	44
214	*Chaetodiadema granulatum*	12	p	0.279	0.454	0.067	226	84	38
215	*Atypopenaeus* spp.	20	n	4.861	9.894	1.159	220	83	44
216	*Yongeichthys nebulosus*	12	n	0.395	0.728	0.094	205	76	36
217	*Chirocentrus dorab*	13	n	0.628	1.176	0.150	201	75	37
218	*Pseudocolochirus axiologus*	13	n	0.419	0.763	0.100	200	74	35
219	*Epinephelus sexfasciatus*	13	n	0.488	0.883	0.117	193	72	34
220	*Bregmaceros mcclellandi*	18	n	1.023	1.883	0.244	188	71	36
221	*Brachypterois serrulatus*	15	n	0.488	0.856	0.117	183	68	32
222	*Anodontostoma chacunda*	21	n	2.767	5.023	0.660	177	67	35
223	*Herklotsichthys lippa*	25	n	8.326	15.084	1.986	174	66	35
224	*Sphyraena obtusata*	17	n	0.930	1.609	0.222	168	63	32
225	*Caranx bucculentus*	26	n	2.581	4.473	0.616	162	61	32
226	Cynoglossidae	16	n	0.581	0.957	0.139	160	60	29
227	Spiropagurus *sp. 1*	16	n	0.605	0.979	0.144	155	58	28
228	*Torquigener tuberculiferus*	18	n	0.744	1.217	0.178	154	58	28
229	*Apistus carinatus*	22	n	1.814	3.034	0.433	153	57	29
230	*Pellona ditchela*	36	n	18.767	31.607	4.476	149	56	30
231	*Terapon jarbua*	29	n	2.419	3.990	0.577	147	55	29
232	*Portunus sanguinolentus*	16	n	0.535	0.827	0.128	145	54	25
233	*Tetrabrachium ocellatum*	23	n	1.093	1.743	0.261	143	54	27
234	*Harpiosquilla harpax*	18	n	0.930	1.470	0.222	142	53	26
235	*Muraenesox cinereus*	19	n	0.698	1.081	0.166	141	53	25

Obs. no	Taxa	No. pres.	Distrib^{n} used	Mean	Std dev.	Abund (no. ha^{-1})	Decline of 50%	Decline of 75%	Decline of 99.9%
236	*Selar boops*	20	n	1.186	1.880	0.283	141	53	26
237	*Oratosquilla quinquendentata*	18	n	0.907	1.411	0.216	139	52	25
238	*Minous versicolor*	17	n	0.721	1.098	0.172	136	51	24
239	*Bregmaceros japonicus*	26	n	2.698	4.195	0.643	131	49	25
240	*Lagocephalus spadiceus*	16	n	0.488	0.703	0.117	130	48	22
241	*Portunus rubromarginatus*	20	n	1.209	1.712	0.288	114	43	21
242	*Carangoides caeruleopinnatus*	20	n	1.209	1.698	0.288	112	42	21
243	*Secutor insidiator*	38	n	55.558	80.884	13.251	111	42	22
244	*Gazza minuta*	34	n	13.861	19.955	3.306	110	41	22
245	*Suggrundus rodericensis*	26	n	1.605	2.248	0.383	110	41	21
246	*Nemipterus peronii*	25	n	2.907	4.076	0.693	107	40	21
247	*Uranoscopus cognatus*	26	n	2.116	2.921	0.505	105	39	20
248	*Amusium pleuronectes*	42	n	27.954	39.297	6.667	104	39	21
249	*Apogon fasciatus*	36	n	5.186	7.169	1.237	102	39	20
250	*Leiognathus leuciscus*	33	n	4.395	6.052	1.048	102	38	20
251	*Podopthalmus vigil*	22	n	1.186	1.578	0.283	102	38	19
252	*Leiognathus bindus*	36	n	14.395	19.712	3.433	99	37	20
253	*Metapenaeus endeavouri*	24	n	1.000	1.291	0.239	98	37	18
254	*Dactyloptena papilio*	30	n	2.256	2.985	0.538	97	36	18
255	*Leiognathus* sp.	29	n	7.140	9.606	1.703	97	36	19
256	*Dexillus muelleri*	25	n	1.349	1.744	0.322	96	36	18
257	*Sardinella albella*	33	n	12.233	16.174	2.918	93	35	18
258	*Euristhmus nudiceps*	40	n	11.372	14.831	2.712	90	34	18
259	*Portunus tenuipes*	28	n	1.884	2.363	0.449	88	33	17
260	*Trichiurus lepturus*	36	n	10.070	12.981	2.402	88	33	17
261	*Dictyosquilla foveolata*	27	n	1.395	1.650	0.333	81	30	15
262	*Gerres filamentosus*	33	n	10.488	12.759	2.502	79	30	16
263	*Carangoides malabaricus*	28	n	2.326	2.714	0.555	76	29	14
264	*Carangoides humerosus*	35	n	3.023	3.515	0.721	74	28	14
265	*Thenus indicus*	32	n	2.535	2.898	0.605	73	27	14
266	*Carcinoplax purpurea*	27	n	1.465	1.594	0.349	69	26	12
267	*Paramonacanthus filicauda*	35	n	3.395	3.818	0.810	69	26	13
268	*Selaroides leptolepis*	32	n	3.395	3.768	0.810	68	25	13
269	*Priacanthus tayenus*	42	n	12.488	14.014	2.979	67	25	13
270	*Terapon theraps*	31	n	1.581	1.680	0.377	66	25	12

Obs. no	Taxa	No. pres.	Distrib^n used	Mean	Std dev.	Abund (no. ha^{-1})	Decline of 50%	Decline of 75%	Decline of 99.9%
271	*Arnoglossus waitei*	29	n	1.744	1.853	0.416	65	24	12
272	*Charybdis feriatus*	28	n	1.116	1.117	0.266	62	23	11
273	*Upeneus sulphureus*	39	n	15.581	16.138	3.716	57	22	11
274	Sepiidae	34	n	2.698	2.677	0.643	56	21	10
275	*Portunus acerbiterminalis*	35	n	5.814	5.848	1.387	55	21	11
276	*Inegocia japonica*	33	n	2.605	2.546	0.621	54	20	10
277	*Leiognathus splendens*	41	n	69.326	67.475	16.535	50	19	10
278	*Oratosquilla inornata*	43	n	30.163	28.992	7.194	49	18	10
279	*Pseudorhombus elevatus*	40	n	3.837	3.565	0.915	48	18	9
280	*Carangoides talamparoides*	41	n	6.140	5.668	1.464	46	17	9
281	*Charybdis truncata*	43	n	92.837	82.692	22.143	42	16	8
282	*Portunus pelagicus*	39	n	6.465	5.654	1.542	42	16	8
283	*Metapenaeopsis* spp.	43	n	56.721	50.307	13.529	41	16	8
284	*Suggrundus macracanthus*	41	n	6.256	5.215	1.492	38	14	7
285	*Nemipterus hexodon*	42	n	14.302	11.793	3.411	36	14	7
286	*Psettodes erumei*	38	n	3.442	2.728	0.821	36	13	7
287	*Saurida micropectoralis*	42	n	5.116	4.060	1.220	35	13	7
288	*Elates ransonnetii*	39	n	5.023	3.820	1.198	32	12	6
289	*Portunus gracilimanus*	43	n	38.744	30.018	9.241	32	12	6
290	*Apogon ellioti*	42	n	6.349	4.659	1.514	30	11	6
291	*Leiognathus moretoniensis*	43	n	24.349	18.303	5.807	30	11	6
292	*Pentaprion longimanus*	43	n	31.605	23.380	7.538	29	11	6
293	Teuthoidea	43	n	12.070	8.908	2.879	29	11	6
294	*Trachypenaeus* spp.	42	n	30.767	22.344	7.338	28	11	6
295	*Apogon poecilopterus*	42	n	39.837	25.673	9.502	22	8	4
296	*Saurida undosquamis*	43	n	30.977	14.748	7.388	12	5	2

Appendix 3D Collection of bycatch samples by crew-member observers

This section describes the method used to collect information on the logistics and costs of obtaining samples of small bycatch taxa using crew-member observers (fishers). We requested 17 Northern Prawn Fishery (NPF) fishers and one Torres Strait Prawn Fishery (TSPF) fisher to each collect up to 20 samples (approx 10kg each) from the tiger prawn fishery in the second season 1996. Some fishers were approached directly by the CSIRO observer while on NPF vessels. Others were contacted via their NPF fleet managers who requested the collection of these samples. Participating skippers were issued with sampling kits containing 20 waxed fish cartons, plastic carton liners, marking pens and labels, and background information explaining the collection procedure and need for the sampling. Sampling kits were either given directly to NPF crews by the CSIRO observer, or were frieghted to participating vessels via the supply barges.

Data were recorded on the number of samples returned by this method, fishing areas that samples were returned from, and the capital costs of all aspects of the process. These data have been used in Section 9.7 - the comparison of methods for monitoring bycatch.

A total of 12 NPF skippers provided 172 bycatch samples and one TSPF skipper provided 20 samples. These samples were frozen on board, consigned and transferred by these fishers to motherships for transportation back to the Cleveland laboratories for sorting.

All animals in the bycatch samples were sorted to the lowest taxonomic level, mostly species, but occasionally genus or family. The total number and total weight of all species, and the length-frequency measurements from a random selection of up to 20 individuals from each fish species were entered directly into Oracle databases.

Appendix 3E A list of protocols, policies and ideas that should be considered for incorporation into a bycatch-monitoring program.

This information was collated from a range of sources including (a) papers and presentations at the Integrated Fisheries Monitoring Conference, Sydney, February 1999, (b) discussions with scientists and fishery managers and (c) reports on bycatch monitoring programs (Heinemann *et al.* 1999, Knuckey and Liggins 1999).

1. Data issues
Data forms and manuals
Collection of relevant ecological data
Collection of relevant trawl log data
Collection of social economic and cultural data
Careful and thorough data transmission, entry, checking and storage
System for data formats and management
Appropriate security and confidentiality
Identified levels of data access
Data reporting to stakeholders
2. Training and protocols
Selection of high quality observers (experience, knowledge, integrity, motivation)*
Evaluation of observer performance*
Observer training program
Use of international training standards (e.g. ISO9001, ISO14001)*
Manuals for all aspects of work*
Safety protocols *
Contingency plans for a range of conditions*
Fair compensation for observers*
Detailed trip reporting and formal debriefs
Protocols to address changes in the fishery operation or behaviour
3. Policies
Program design based on clear objectives
Sanctions policy
Harassment policy and response guidelines*
3rd party authorisation policy to protect observers, fishers etc;*
3rd party ratification of objectives, methods, etc

* Particularly refers to use of observers for monitoring

Appendix 4: Publications

Heales, D., Brewer, D., Wang Y-G. 2000. Subsampling multi-species trawl catches from tropical northern Australia: Does it matter which part of the catch is sampled? Fisheries Research, in press.

AFMA News April 1998. CSIRO seeks fishers' help with bycatch research.

Johnson, K., 1998. Bycatch studies continue. Queensland Fisherman, April 1998.

Papers Presented at Conferences

Brewer, D., 1999. Monitoring bycatch. NORMAC Pre-season Workshop, 1999, Cairns.

Salini, J., Brewer, D., Farmer, M., Jones P., 1999. Lunar phase and trawl bycatch abundance off Weipa, Gulf of Carpentaria. AMSA 1999, Melbourne.

Stobutzki, I., 1999. Sustainability of bycatch. NORMAC Pre-season Workshop, 1999, Cairns.

Heales, D., Brewer, D., Wang Y-G., 1998. Pitfalls of subsampling and implications for monitoring. ASFB, 1998 Hobart.

Robins, J., Courtney, T. 1998. Status report on bycatch within the Queensland east coast trawl fishery.

Stobutzki, I., Pitcher, R. 1998. How does bycatch impact on biodiversity and the ecosystem? ASFB Workshop: Establishing meaningful targets for bycatch reduction in Australian fisheries.

Blaber, S., 1997 Sustainability of Bycatch. NPF Bycatch Conference 1997, Cairns.

Farmer, M., Blaber, S., Brewer, D., Milton, D., Salini, J., Wassenberg, T., 1997. Ecological Sustainability of Vertebrate Prawn Trawl Bycatch. AMSA 1997, Auckland.

Heales, D., 1997 Designing a program for monitoring bycatch. NPF Bycatch Conference 1997, Cairns.

Heales, D., Brewer, D., Wang Y-G., 1997. Monitoring NPF trawl bycatch: estimating the abundance of rare species. ASFB 1997, Darwin.