Environmental Conservation 28 (2): 167–181 © 2001 Foundation for Environmental Conservation

Sustainability of fishery bycatch: a process for assessing highly diverse and numerous bycatch

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Date submitted: 6 September 2000 Date accepted: 26 January 2001

Summary

In tropical prawn (shrimp) trawl fisheries it is daunting to assess the sustainability of bycatch species because they are diverse and there is little historical and biological information for quantitative stock assessments. We developed a process to examine the likely impact of prawn trawling on the sustainability of bycatch species and applied this to fish bycatch in the Australian Northern Prawn Fishery. The 411 fish bycatch species were ranked with respect to biological and ecological criteria that contributed to two overriding characteristics, namely first, their susceptibility to capture and mortality due to prawn trawling, and second the population's capacity to recover after depletion. The rank of each species on these two characteristics determined its relative capacity to sustain trawling, and therefore its priority for research and management. Species that were the least likely to be sustainable came from the families Apogonidae, Ariidae, Bathysauridae, Callionymidae, Congridae, Diodontidae, Labridae, Opisthognathidae, Plotosidae, Synodontidae and Tetraodontidae. These species are highly susceptible to capture by trawls, they are benthic or demersal, their primary habitat is soft sediments, and their diet may include prawns. The recovery capacity of these species is also low, with the estimated removal rate by trawling high. The species that were the most likely to be sustainable came from the families Carangidae, Clupeidae, Ephippidae, Scombridae, Sphyraenidae and Terapontidae. They are less susceptible to capture by trawls, they are generally pelagic, their primary habitat is not in trawl grounds, and they have a broad depth distribution and range in the fishery. These species also have a greater capacity to recover, as most individuals have bred before capture, and a low estimated removal rate by trawling. The final ranking of the species must be used with caution because of the assumptions made in the process. However, the process is a valuable first step towards ensuring the sustainability of the bycatch species. Because of the simplicity of the process, it can be readily used in fisheries, particularly those with diverse bycatch, to manage the sustainability of their bycatch.

Keywords: bycatch, sustainability, fish, prawn trawling, recovery

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Introduction

Continental-shelf sea floors are among the richest regions of the marine environment. They support a diversity of animals in, on or immediately above, the substratum. Many of these animals are valued as seafood (e.g. fish and prawns) and most of the world's fisheries exploit this zone; 95% of marine fish catches come from continental shelves (Pauly & Christensen 1995). However, modern fishing gear is not selective; it rarely catches only the target species. Some of the catch of non-target species, or bycatch, is retained for marketing (often termed 'byproduct'), but the extent of this varies among countries and with the relative values of the bycatch and target species. Alverson *et al.* (1994) estimated that 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 have resulted in bycatch becoming an issue of global importance. Consequently, there is increasing pressure to understand and manage the impacts of fishing on bycatch species.

Prawn (shrimp) 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 & Pepperell 1992). Worldwide, prawn trawling is thought to be responsible for a third of all fisheries discards (Alverson *et al.* 1994). In most prawn trawl fisheries, the bycatch research and management initiatives have been driven by external pressures that focus on particular species; commercial and recreational fisheries are concerned about the impacts of trawling on their target species (e.g. Broadhurst & Kennelly 1994; Graham 1995; Nance & Scott-Denton 1996), and conservation agencies focus attention on vulnerable or endangered species, such as turtles (CSTC 1990; Poiner *et al.* 1990; Nance & Scott-Denton 1996). However, such selectivity is dangerous; fisheries need to examine the sustainability of all bycatch species to identify potential problems and to meet legislative obligations.

International legislation reflects the concern about bycatch. Many international treaties and conventions contain obligations on the signatories to address bycatch problems. The FAO 'Code of conduct for responsible fisheries' and the United Nations' Agreement for conservation and management of straddling fish stocks and highly migratory fish stocks' contain obligations regarding the impact of fishing on bycatch species. The United Nations Convention on the Law of the Sea requires governments to manage responsibly the 'dependant and associated species' within their exclusive economic zones. This international legislation is reflected in the national legislation in many countries. In Australia, for example, Commonwealth and State legislation requires fisheries to be managed in a manner consistent with the principal of ecologically sustainable development and therefore, impacts on non-target species must be taken into account. There is clearly a need for fisheries to manage their impacts on non-target species but how this is to be done is unclear. This aspect of fisheries science and management is relatively new and there is limited information on which managers can base decisions.

The bycatch of most tropical prawn trawl fisheries is highly diverse, although it is dominated by teleosts (bony fishes) (Hall 1999). In Australia's Northern Prawn Fishery (NPF), over 400 teleost species contribute 73% of the bycatch weight (Stobutzki *et al.* 2001). This diversity and the lack of historical and biological information prevent the use of quantitative stock assessments to determine the population status of each species and so alternative methods are required.

The aim of our study was to develop a broad-brush method to examine the likely impact of trawling on the sustainability of teleost bycatch species, and the specific objective was to identify species least likely to be sustainable in the bycatch, so that these could be the focus of research and management. We applied it to the NPF, but it should also be applicable to other fisheries with bycatch issues. The method focuses on the teleost species that are currently captured as bycatch. The term sustainability of the bycatch species is used to mean that the impact of the fishery on these species will not exceed the ability of the species to renew themselves (modified from Garcia & Staples 2000).

Two overriding characteristics were deemed to determine the sustainability of bycatch species to trawling, namely their susceptibility to capture and fishing mortality, and the population's capacity to recover. These characteristics are organized into a matrix in Figure 1. By marking the position of each species on the two characteristics we can assess all of bycatch of a fishery. We consistently apply a systematic approach to all the teleost bycatch species, to examine their status and highlight potential problems.

The IUCN Red Lists for species are based on a similar approach; they categorize species with respect to threat of extinction worldwide, using the criteria of the extent of population decrease, area of occurrence, per cent of population that are mature, and the probability of extinction (IUCN 1996). Hawkins *et al.* (2000) applied the IUCN criteria to assess the status of coral reef fishes with restricted ranges in the context of human impacts. Smith *et al.* (1998) have also developed a process for assessing the recovery capacity of shark species, in order to evaluate their ability to withstand fishing pressure. Our motives are similar, namely the need to evaluate a large number of species to guide management and research. However, our process differs in that it examines this issue at the level of a fishery and, unlike Smith *et al.* (1998), examines both recovery capacity and the susceptibility of species to the fishery.

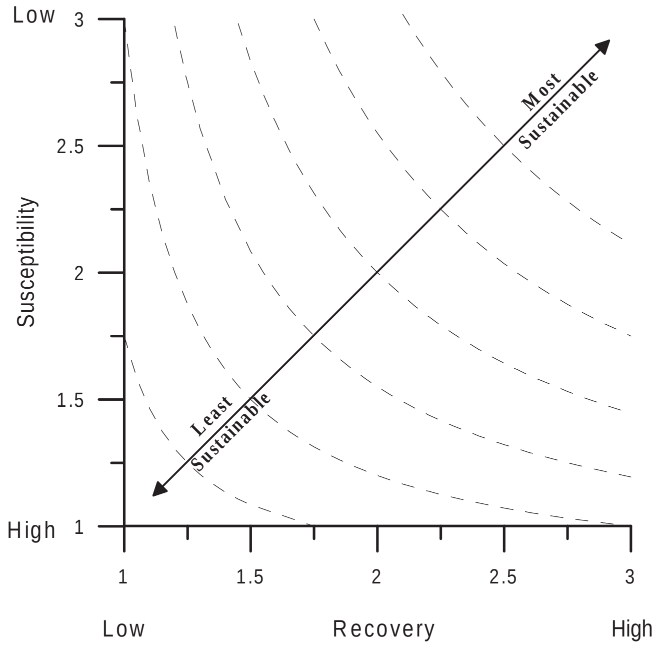

Figure 1 The axes on which species will be ranked to determine their relative sustainability in prawn trawl bycatch. The y axis includes criteria that influence the susceptibility of species to capture and mortality from prawn trawling. The x axis includes criteria that represent the capacity of species to recover after depletion. The contour lines represent a multiplicative relationship between the axes and are explained in the Methods. The minimum rank a species can get on each axis is 1 and the maximum rank is 3.

Description of the fishery

The 130 vessels of Australia's Northern Prawn Fishery (NPF) captured 6947 tonnes of prawns in 1999 (Sharp *et al.* 2000). The fishery's managed area covers over 6000 km of coastline and over 1 000 000 km^2 of ocean (Fig. 2). There are currently 18 314 effort days in the fishery (Sharp *et al.* 2000), and if each boat conducts four trawls per night (3–4 h duration), this is 73 256 trawls (with two nets) over a season. However this effort is highly aggregated, with only 25% of the managed area trawled (Stobutzki & Pitcher 1999).

The vessels tow a twin gear configuration, usually with Florida Flyer trawl nets. The fishery is currently open for about six months of the year, from April to June and then August to November. For most of the fishing season (approximately 25 weeks), the fishery is a night-time fishery

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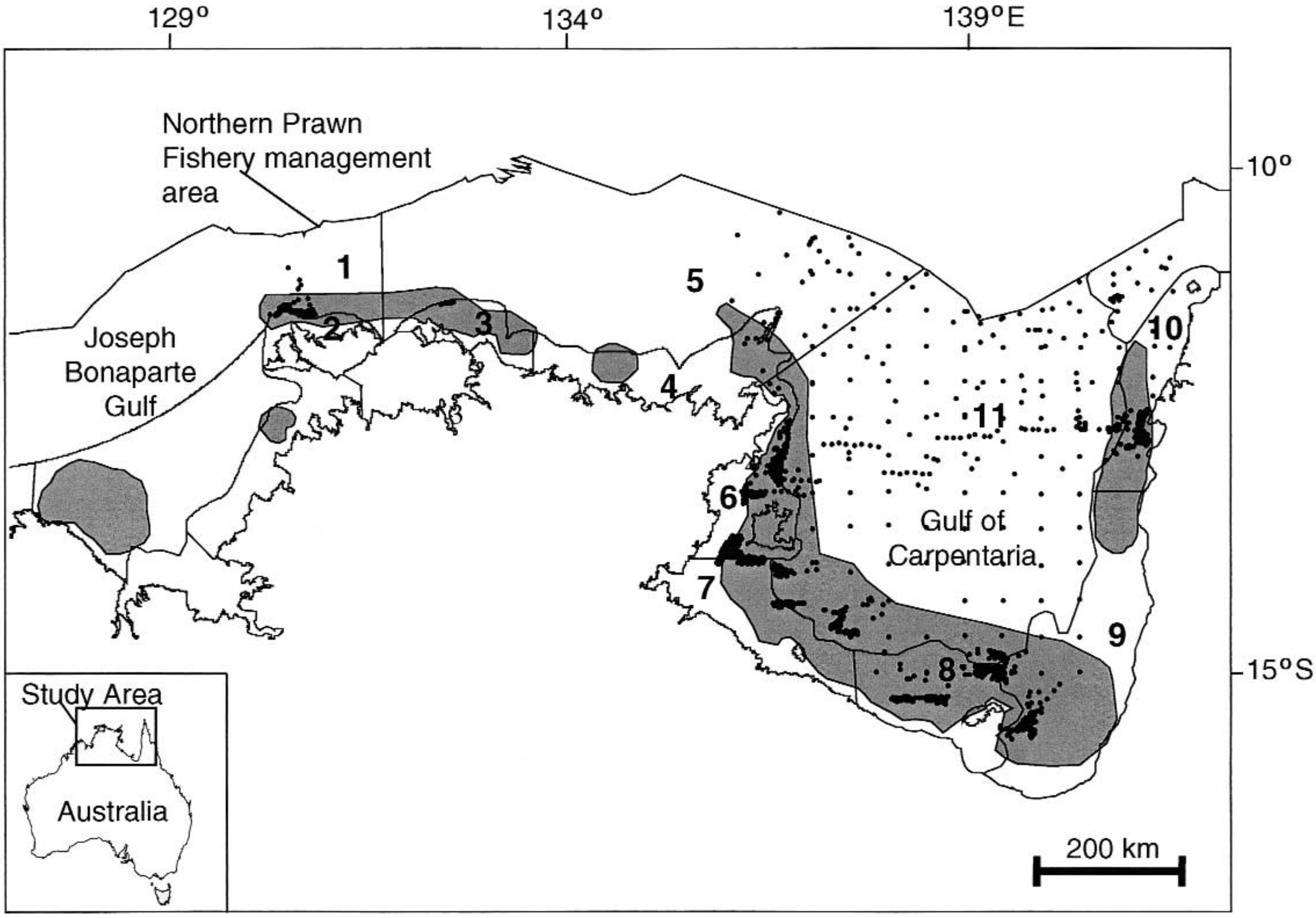

Figure 2 The management area of the Northern Prawn Fishery and the bioregions defined through the IMCRA process (Thackway & Cresswell 1998). The shaded areas represent the regions fished by commercial prawn trawlers. The dots mark the positions of the trawls sampled to estimate the removal rates and total biomass of bycatch species, detailed in Table 1. The numbers refer to the bioregions in Table 2.

(trawling after 8.30am is banned) targeting tiger (*Penaeus semisulcatus* and *P. esculentus*) and endeavour (*Metapenaeus endeavouri* and *M. ensis*) prawns (McLoughlin *et al.* 1997). Fishing in the Joseph Bonaparte Gulf region of the fishery differs from the other areas of the fishery, with vessels targeting red-legged banana prawns (*Peneaus longistylus*); this area of the fishery was excluded from the analysis.

Methods

Bycatch species in the NPF

We assessed the sustainability of all teleost bycatch species caught in prawn trawls in the NPF. A list of the bycatch species was compiled from two sources (Table 1). The first were research surveys of the NPF fishing grounds, undertaken either to describe the bycatch of this fishery (Stobutzki *et al.* 2000, 2001) or to collect prawns, with bycatch samples retained (Blaber *et al.* 1997; Crocos & Coman 1997; Crocos *et al.* 1997). The second were bycatch samples collected by scientific observers on commercial vessels (Pender *et al.* 1992; Stobutzki *et al.* 2001). These surveys targeted the areas of highest effort in the fishery.

Process for assessing the sustainability of bycatch species

Biological and ecological information was collated from the literature for each species which included the research surveys and observers' records referred to earlier. 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 indicating the susceptibility of a species to capture and mortality due to prawn trawling (Susceptibility), and axis 2 the capacity of a species to recover after the population is depleted (Recovery).

Each characteristic (or axis) was derived from several criteria that are listed below and summarized aspects of the biology and ecology of the species (seven criteria for axis 1 and

https://doi.org/10.1017/S0376892901000170 Published online by Cambridge University Press

Table 1 The surveys that contributed to the estimate of the total biomass and removal rate (*) for teleost species in the NPF,# indicates the surveys that contributed to the list of bycatch species, n = number.

Year	*Month*	*Type*	*Gear*	*Trawls (n)*	*Nets used (n)*	*Reference*
1998*#	September–October	Research survey	Florida Flyer	366	1	Stobutzki *et al.* 2000
1997*#	October	Research survey	Florida Flyer	424	1	Stobutzki *et al.* 2001
1997*#	September–October	Scientific observer	Florida Flyer	60	2	Stobutzki *et al.* 2001
1997*#	May–June	Scientific observer	Florida Flyer	76	2	Stobutzki *et al.* 2001
1997*#	February–March	Research survey	Florida Flyer, Engels	248	1	Stobutzki *et al.* 2001
1996*#	September	Scientific observer	Florida Flyer	83	2	Stobutzki *et al.* 2001
1995#	June	Research survey	Florida Flyer	38	1	Blaber *et al.* 1997
1995#	October–November	Research survey	Florida Flyer	39	1	Blaber *et al.* 1997
1995#	February–March	Research survey	Florida Flyer	39	1	Blaber *et al.* 1997
1994#	Novermber	Research survey	Florida Flyer	7	2	Crocos & Coman 1997; Crocos *et al.* 1997
1994#	July	Research survey	Florida Flyer	7	2	Crocos & Coman 1997; Crocos *et al.* 1997
1994#	May	Research survey	Florida Flyer	4	2	Crocos & Coman 1997; Crocos *et al.* 1997
1994#	March	Research survey	Florida Flyer	5	2	Crocos & Coman 1997; Crocos *et al.* 1997
1993#	November	Research survey	Florida Flyer	81	1	Crocos & Coman 1997; Crocos *et al.* 1997
1993#	October	Research survey	Florida Flyer	5	2	Blaber *et al.* 1997
1993#	August	Research survey	Florida Flyer	9	2	Crocos & Coman 1997; Crocos *et al.* 1997
1993	January–February	Research survey	Engels, Frank and Bryce	71	1	Milton *et al.* 1995
1991	November	Research survey	Frank and Bryce	62	1	Milton *et al.* 1995
1990	November–December	Research survey	Frank and Bryce	128	1	Blaber *et al.* 1994; Milton *et al.* 1995

six criteria for axis 2). Each species was given a rank from 1 to 3 for each criterion, the ranks for each criterion are defined in Table 2. A rank of 1 suggested the species is highly susceptible to capture or has a low capacity to recover; a rank of 3 suggested the species has a low susceptibility to capture or a high capacity to recover. Depending on the criterion these ranks were based on categorical or continuous data (Table 2). Where continuous data were used, as no information was available to assign the divisions between the ranks, the range of the data was divided into thirds to create the categories.

Where species-specific information was not available, a species was given the same rank as other species within its family for the criteria water column position, diet and day/night catchability. For other criteria where it was not logical that family members would be similar, or where family information was not available, the rank of 1 was given as a precautionary approach.

Axis 1: The susceptibility of species to capture and mortality due to a prawn trawl

There were seven criteria on this axis.

Water-column position

As prawn trawls operate close to the sea floor, demersal and benthic species are more likely to be captured than pelagic species.

Preferred habitat

This criterion reflects the likelihood of a species' habitat overlapping with the habitat where trawling occurs, which is generally soft and muddy sediments.

Survival

This criterion draws on studies of the survival of bycatch species captured in trawls (Wassenberg & Hill 1989; Hill & Wassenberg 1990). Data were given on 17 species; the values for the remaining species were either based on species within their family or, if no data were available given a rank of 1, as teleosts usually have a low survival (Wassenberg & Hill 1989; Hill & Wassenberg 1990). The possible survival range of 0%–100% was divided into thirds for the divisions between the ranks.

Range

This criterion reflects the geographic spread of species within the NPF. Commercial fishing is highly aggregated within the managed area of the fishery; regions of high effort produce most of the fishery catch. We assumed that species with a restricted range could be impacted more heavily by trawling than those with a broader range.

Day/night catchability

The tiger prawn fishery is predominantly a night-time fishery (trawling after 8.30am is banned for most of the season).

Table 2 The criteria used to assess the relative susceptibility of bycatch species to capture and mortality due to trawling and their recovery capacity. These were combined to provide the ranks for the axes in Figure 1. For each criterion the weighting score and the definition of the three ranks is given.

Criteria	*Weighting score*	*Rank* 1	2	3
Susceptibility				
Water column position	3	Demersal or benthic	Benthopelagic	Pelagic
Preferred habitat	3	Soft or muddy sediments or prawn trawl grounds	Soft or muddy sediments but also other habitats (e.g. reefs and estuaries)	Habitats outside prawn trawl grounds
Survival	3	Probability of survival ⩽ 33.3%	33.3% < probability of survival ⩽ 66.6%	Probability of survival > 66.6%
Range	2	Species range ⩽ 3 fishery regions	3 fishery regions < species range ⩽ 6 fishery regions	Species range > 6 fishery regions
Day/night catchability	2	Higher catch rate at night	No difference between night and day	Higher catch rate in the day
Diet	2	Known, or are able to feed on commercial prawns	Not known to feed on commercial prawns but feeds on other benthic or demersal organisms	Feeds on pelagic organisms
Depth range	1	Less than 40 m	Not applicable	Deeper than 40 m
Recovery				
Probability of breeding	3	Probability of breeding before capture < 50%	Probability of breeding before capture not significantly different from 50%	Probability of breeding before capture > 50%
Maximum size	3	Maximum size < 1066 mm	813 mm < maximum size ⩽ 1066 mm	Maximum size < 813 mm
Removal rate	3	Removal rate > 33.3%	33.3% < removal rate ⩽ 66.6%	66.6% ⩽ removal rate
Reproductive strategy	2	Bear live young or brood young	Guard eggs and/or young	Broadcast spawners
Hermaphroditism	1	Hermaphrodites	Not applicable	Dioecious
Mortality index	1	Mortality index > 3.44	1.88 < mortality index ⩽ 3.44	Mortality index ⩽ 1.88

Species with a higher catchability at night are therefore more susceptible to capture as bycatch. The relative catch rate of species during night and day-time trawls was compared during research surveys in October 1997 (Table 1).

Diet

This criterion reflects whether the diet of the species may attract them to trawl grounds and whether they feed within the area of the water column that is swept by a prawn trawl. Species that feed on commercial prawns may be attracted to the commercial fishing grounds, increasing their susceptibility to capture. Species that feed on benthic and demersal organisms are assumed to be more susceptible to prawn trawls than species that feed higher in the water column.

Depth range

Commercial trawls in the NPF are made mainly between 15 m and 40 m depth (Somers 1994). An overlap between the depth range of trawling and the preferred depth range of a species will influence its susceptibility to capture: a higher proportion of a species' population is likely to be taken if there is an overlap. Species with a broader depth range may have a spatial refuge from trawling, making them less susceptible.

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

There were six criteria on this axis.

Probability of breeding

A species is likely to have a greater capacity to recover from a decrease in population due to trawling if most individuals are captured after they have bred. The probability that individuals of a species had bred before capture was estimated from their mean lengths at capture compared to the species' recorded size at maturity. The mean lengths at capture were recorded in the 1997 and 1998 research surveys (Table 1); up to 20 randomly selected individuals of each species were measured in each trawl. These data were combined to estimate the mean length at capture for each species. As the size at maturity is not known for many species, we calculated the ratio of size at maturity to maximum size within families, and applied this ratio to estimate size at maturity. If a species came from a family about which there was no information on the size at maturity of any family members, the ratio between size at maturity and maximum size was estimated from species in the other families combined. A t-test (Sokal &

Rohlf 1996) was used to determine whether the mean length at capture was significantly different from the size at maturity for each species.

Maximum size

The maximum size of a species was used as an indicator of the species' relative recovery rate. In general, larger species tend to live longer and their populations recover more slowly (Roberts & Hawkins 1999). If no estimate of maximum size was available, the largest size captured in the present study was used as the estimate. The range of the maximum sizes of species (20 mm–240 mm) was divided into thirds to determine the division between the ranks.

Removal rate

We assumed that species that had a higher proportion of their population removed as bycatch would have a lower capacity to recover. The estimate of removal rate was based on the catch rates from research surveys and scientific observer collections made between 1996 and 1998 (Table 1). This assumes that these catch rates were representative of the catch rates in the commercial fishery. Although the research survey trawls were shorter in duration than commercial trawls, Wassenberg *et al.* (1998) demonstrated that short duration trawls accurately reflected the species composition and size frequency of longer duration trawls, but may overestimate the catch rates of some species (10% of the species examined). The inclusion of longer duration commercial trawls, recorded by the observer, would modify this effect.

The catch rates of species in each trawl were standardized for the trawl duration as the numbers of individuals per hour trawled and then converted into catch per swept area of the trawl as numbers of individuals per square kilometre swept. This assumed that the prawn trawls had a spread of 0.66 of the headrope length (Bishop & Sterling 1999). The catch rates of species showed significant spatial variation within the fishery (Stobutzki *et al.* 2001). Therefore, the fishery was stratified by the bioregions identified in the Interim Marine and Coastal Regionalization for Australia (IMCRA) process (Thackway & Cresswell 1998; Fig. 2). A mean catch rate for each species was calculated for each bioregion where commercial tiger prawn trawling occurs.

The amount removed by the commercial fishery in numbers of individuals per year was estimated by multiplying the mean catch rate calculated above by the 1997 commercial fishery effort in each bioregion (Table 3). Commercial fishing effort is recorded in log books in boat days (held by the Australian Fisheries Management Authority). One boat day was assumed to be the equivalent of 12 h trawling with two nets with 14 fathom (25.48 m) headropes at a speed of 3.2 knots (5.9 km h^{-1}) (Bishop & Sterling 1999).

The estimate of the total amount removed for a species within the whole fishery was calculated by summing the removal estimates for the bioregions. This removal was then converted to a proportion of the estimated total biomass of the species.

Table 3 The bioregions where commercial trawling for tiger prawns occurs in the NPF, their area and the amount of commercial fishing effort in 1997 (from the log-books held by the Australian Fisheries Management Authority). The labels refer to Figure 2.

Bioregion	*Label*	*Total area (km^2)*	*Effort (boat days)*
Oceanic Shoals	1	253 343	198
Tiwi	2	5134	45
Cobourg	3	8380	97
Arnhem Wessel	4	22 752	21
Arafura	5	155 114	92
Groote	6	16 717	2909
Pellew	7	21 494	558
Wellesley	8	26 771	2195
Karumba-Nassau	9	56 700	1524
West Cape York	10	22 269	2846
Carpentaria	11	229 974	2349

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 1990s (Fig. 2; Table 1). The gears used were prawn trawls (Florida Flyers) and two types of fish trawls (Frank and Bryce trawls, and Engel trawls). Both night- and day-time trawling were included. Both prawn and fish trawl surveys were included in order to cover the management area of the fishery.

The catch rates of species in each trawl were converted to the catch per swept area of the trawl as described previously, the fish trawls being assumed to have a spread of 0.6 of the headrope length (Blaber *et al.* 1994). A mean catch rate for each gear at each time (day or night) was calculated in each bioregion, resulting in up to six catch rate estimates for a species in a bioregion. The highest of these means was used for each species in that bioregion. This catch rate was then multiplied by the area of the bioregion to give an estimate of total numbers of individuals in the bioregion (n).

Currently there are no robust estimates of the catchability coefficients for these gears and these species and so we assumed a catchability coefficient of one for all species. Such a high catchability coefficient is unlikely to be valid for most species and results in an underestimate of the total biomass.

For two bioregions where commercial tiger prawn trawlers operate, there was no survey data from which to estimate catch rates (Arnhem Wessel and Arafura; Fig. 2) The mean catch rate across all other bioregions was therefore taken as the estimate of catch rate in these bioregions. The total biomass of each species in the managed area of the NPF was calculated by summing the estimates for the bioregions.

The removal rate should range between 0% and 100%; this range was divided into thirds for the divisions between the ranks.

Reproductive strategy
Species that are broadcast spawners generally have the capacity to produce more young than species that bear live young or brood their young. This means that broadcast spawners may have the capacity to recover faster if their population size is reduced. The reproductive strategies of each species provided a proxy for the relative fecundity (which was not available for most of species).

Hermaphroditism
Hermaphroditic species may have a lower capacity to recover, as hermaphroditism is often associated with other characteristics that produce a lower recovery rate (Roberts & Hawkins 1999). Hermaphroditic species were, therefore, given a rank of 1 and dioecious species a rank of 3.

Mortality index
The recovery capacity of a population is likely to be related to its fishing mortality rate (Sparre & Venema 1992). A measure of this rate can be derived from the length frequency of a species and the von Bertalanffy growth parameters (Sparre & Venema 1992). However, for most bycatch species, von Bertalanffy parameters are not available, so an a index of mortality was calculated as follows:

$$\text{Mortality index} = (L_{max} - L_{ave}) / (L_{ave} - L_{min}), \qquad (1)$$

where L_{max} is the maximum length a species attains, L_{ave} is the mean length at capture in the fishery, and L_{min} is the smallest length caught. The closer the average length of captured individuals (L_{ave}) is to the maximum length (L_{max}), the lower the fishing mortality of the population. As mortality due to fishing increases, the average length of species in a population approaches the smallest length (L_{min}). This index will be influenced by past and current fishing effort and assumes constant catchability and mortality across the whole length-range caught (Sparre & Venema 1992). The L_{ave} and L_{min} were calculated from the 1997 and 1998 research surveys. The range of the mortality estimates was calculated (0.32–4.99) and divided into thirds for the divisions between the ranks.

Analysis of criteria

Partial correlations (Sokal & Rohlf 1996) were used to determine whether there was any redundancy in the criteria. Strong correlations suggested that two or more criteria were explaining the same factors, which would lead to overemphazising their effect, and, one of the correlated criteria should, therefore, be removed.

The total susceptibility or removal ranks of a species were determined by the following equation:

$$S_i = \frac{\sum_{j=1}^{n} w_j R_i}{\sum_{j=1}^{n} w_j} \qquad (2)$$

where S_i is the total susceptibility or recovery ranks for species i, w_j is the weighting for criterion j, R_i is the rank of species i for criterion j, and n is the number of criteria on each axis.

The weighting score of the criterion (Table 2) was determined by the NPF Fishery Assessment Group, through consensus. The weighting scores were allocated to reflect the relative importance of each criterion in determining the overall characteristic and the robustness of the data. On the susceptibility axis, water column position, preferred habitat and survival had the highest weights (3), as these were seen as the major determinants of whether species were caught and killed by prawn trawls. Range, day/night catchability and diet had weights of 2, as these were assumed to be less important and depth range had a ranking of 1 because there was little fine-scale information available.

On the recovery axis, probability of breeding, maximum size and removal rate were weighted highest (3), as they were thought to have the largest impact on the recovery of a species. Reproductive strategy was weighted 2, and hermaphroditism and mortality index given a weighting of 1.

The total susceptibility and recovery ranks for the species were graphed to determine the relative sustainability of the species caught as bycatch by prawn trawlers. The species least likely to be sustainable were identified as the species with the lowest ranks on both axes.

Contour lines were drawn on the graph to group species that would be similar with respect to their sustainability. As neither susceptibility nor recovery alone provide a complete index to the sustainability of species, the overall index was 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 assumed that this relationship was symmetrical and, given this assumption, the contour lines followed the equation:

$$16(y - 0.75)(x - 0.75) = 4, 9, 16, 25, 36, 49 \qquad (3)$$

Results

At least 411 species, from 99 families, have been recorded in the bycatch from the NPF (Appendix 1). The number of species within families ranges up to 32 for the Carangidae, but over 40% of the families were represented in the bycatch by a single species. The 411 species were ranked with respect to each criterion for both the susceptibility and recovery axes (this information is available from the authors on request).

The proportion of species for which the ranking was based on species-specific information varied among the criteria (Table 4). For most species, the ranks in such criteria as preferred habitat, depth range and maximum size were based on species-specific information. Criteria such as survival relied mainly on family estimates.

The partial correlations between the criteria (Tables 5 and 6) indicate that there was little redundancy among the criteria. The low partial correlations, with most not statisti-

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Table 4 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
	Hermaphroditism	24
	Mortality index	69

cally significant, suggest that each criterion contributes unique information.

On the susceptibility to capture axis (Fig. 3), the species with the lowest ranks (⩽ 1.19) were: *Gnathophis* sp. (Congridae), S*aurida undosquamis* (Bathysauridae) and *Torquigener hicksi* (Tetraodontidae). These were the species most susceptible to capture and mortality. The least susceptible species were: *Caranx melampygus* (Carangidae), *Herklotsichthys lippa* (Clupeidae) and *Pellona ditchela* (Clupeidae) (ranks 2.44) (Fig. 3).

On the recovery axis, the species with the lowest recovery capacity were: *Arius bilineatus* (Ariidae), *Arius proximus* (Ariidae), *Euleptorhamphus viridis* (Hemiramphidae), *Euristhmus lepturus* (Plotosidae) and *Rhabdamia gracilis* (Apogonidae), with ranks ⩽ 1.53 (Fig. 3). The species with the highest recovery capacity were: *Leiognathus bindus* (Leiognathidae)and *Pomadasys maculatus* (Haemulidae), with ranks of 3 (Fig. 3).

The species that were the least likely to be sustainable, based on ranking, were *Arothron manilensis* (Tetraodontidae), *Arius bilineatus* (Ariidae), *Arius nella* (Ariidae), *Arius proximus* (Ariidae), *Callionymus belcheri* (Callionymidae), *Callionymus sublaevis* (Callionymidae), *Cyclichthys orbicularis* (Diodontidae), *Euristhmus lepturus* (Plotosidae), *Leptojulis cyanopleura* (Labridae), *Lumiconger arafura* (Congridae), *Opistognathus latitabundus* (Opisthognathidae) *Poeciloconger kapala* (Congridae), *Rhabdamia gracilis* (Apogonidae), *Saurida undosquamis* (Bathysauridae) and *Synodus macrops* (Synodontidae) (Fig. 3; Tables 7 and 8).

The species that were most likely to be sustainable were *Atule mate* (Carangidae), *Carangoides caeruleopinnatus* (Carangidae), *Carangoides malabaricus* (Carangidae), *Carangoides talamparoides* (Carangidae), *Zabidius novaemaculatus* (Ephippidae), *Megalaspis cordyla* (Carangidae), *Parastromateus niger* (Scombridae), *Pelates quadrilineatus* (Teraponidae), *Pellona ditchela* (Clupeidae), *Rastrelliger kanagurta* (Scombridae), *Sphyraena forsteri* (Sphyraenidae), *Terapon jarbua* (Teraponidae), *Terapon theraps* (Teraponidae) (Fig. 3; Tables 9 and 10).

Discussion

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 these species. This challenge is magnified by the lack of information about individual bycatch species, most of which are rarely captured. The approach applied in this study was designed to overcome both problems and highlights the species that are least likely to be sustainable in the prawn trawl fishery. This is the first assessment of such a diverse bycatch on this scale. The use of criteria maximizes what can be determined from the limited information available on individual species. The criteria include characteristics that are thought to influence the sensitivity of species to overfishing and the probability of extinction (Roberts & Hawkins 1999).

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 (Fig. 3; Tables 7 and 8). There is

Table 5 The correlations between susceptibility criteria, * = $p < 0.05$.

	Preferred habitat	*Survival*	*Range*	*Day/night catchability*	*Diet*	*Depth range*
Water column position	0.27*	−0.08	0.03	0.02	−0.05	0.04
Preferred habitat		−0.05	0.02	−0.06	0.07	−0.02
Survival			0.04	−0.03	−0.30*	−0.04
Range				−0.03	−0.07	0.13*
Day/night catchability					0.15*	−0.02
Diet						−0.05

Table 6 The correlations between recovery criteria, * = $p < 0.05$.

	Maximum size	*Removal rate*	*Reproductive strategy*	*Hermaphroditism*	*Mortality index*
Probability of breeding	−0.21*	0.09	0.03	−0.04	0.34
Maximum size		−0.05	−0.10	−0.07	0.19*
Removal rate			−0.02	−0.07	0.39*
Reproductive strategy				−0.09	0.12*
Hermaphroditism					0.08

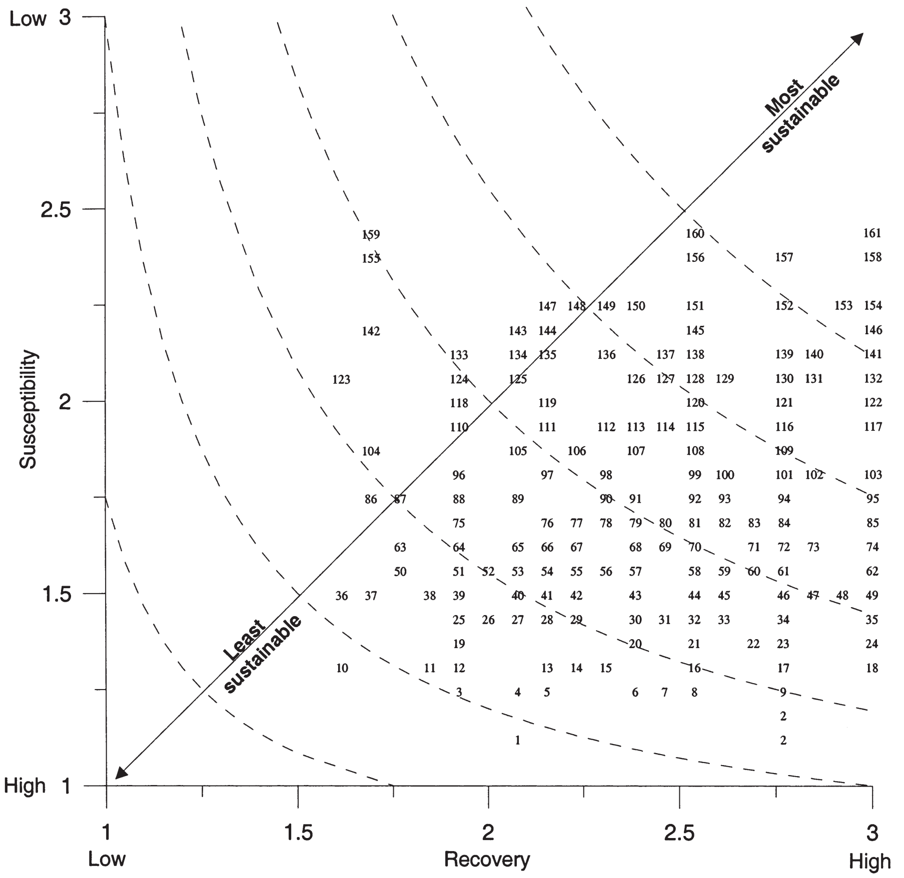

Figure 3 The ranking of teleost species with respect to criteria that reflect their susceptibility to capture and their capacity to recover. These combine to reflect their relative ability to sustain capture as prawn trawl bycatch in the NPF. The contour lines group species with a similar sustainablity. For an explanation of the number labels, see Appendix 1.

Table 7 The ranking of the species that are least likely to be sustainable on the criteria on the susceptibility axis. See Appendix 1 for labels; * = species-specific information not available.

Label	*Family*	*Species*	*Criterion*							*Susceptibility rank*
			Water column position (3)	*Preferred habitat (3)*	*Survival (3)*	*Range (2)*	*Day/night catchability (2)*	*Diet (2)*	*Depth range (1)*	
36	Apogonidae	*Rhabdamia gracilis*	1*	3	1*	1*	1*	2	1	1.50
10	Ariidae	*Arius bilineatus*	1*	2	1*	1*	1*	1	3	1.31
10	Ariidae	*Arius nella*	1*	2	1*	1*	1*	1	3	1.31
11	Ariidae	*Arius proximus*	1	2	1*	1*	1*	1	3	1.31
1	Bathysauridae	*Saurida undosquamis*	1	1	1*	1*	1*	1	3	1.13
12	Callionymidae	*Callionymus belcheri*	1	2	1*	1*	1*	2	1	1.31
12	Callionymidae	*Callionymus sublaevis*	1	2	1*	1*	1*	2	1	1.31
12	Congridae	*Poeciloconger kapala*	1*	2	1*	1*	1*	1	1	1.31
3	Diodontidae	*Cyclichthys orbicularis*	1*	1	1*	1*	1*	2	1*	1.25
12	Labridae	*Leptojulis cyanopleura*	1*	2	1*	1*	1*	2	1	1.31
4	Opisthognathidae	*Opistognathus latitabundus*	1	1	1*	1*	1*	1	3	1.25
10	Plotosidae	*Euristhmus lepturus*	1*	2	1*	1*	1*	1	3	1.31
12	Synodontidae	*Synodus macrops*	1	2	1*	1*	1*	1	3	1.31
12	Tetraodontidae	*Arothron manilensis*	1*	2	1*	1*	1*	1	3	1.31

little information available on the majority of these species, all of which have a high susceptibility to capture and mortality by prawn trawling. They are benthic or demersal and closely associated with the sea floor where prawn trawls fish. Their habitats are primarily soft or muddy sediments, although some species also utilize other habitats, such as estuaries. Their diets are either known to include prawns or are likely to do so. There is no information on the survival of

Table 8 The ranking of the species that are least likely to be sustainable on the criteria on the recovery axis. See Appendix 1 for labels; * = species-specific information not available.

Label	Family	Species	Criterion: Probability of breeding (3)	Maximum size (3)	Removal rate (3)	Reproductive strategy (2)	Hermaphroditism (1)	Mortality index (1)	Recovery rank
36	Apogonidae	*Rhabdamia gracilis*	1*	3	1*	1*	3*	1*	1.62
10	Ariidae	*Arius bilineatus*	1*	3	1*	1*	3	1*	1.62
10	Ariidae	*Arius nella*	1*	3	2	1*	3*	1*	1.85
11	Ariidae	*Arius proximus*	1*	3	1*	1*	3*	1*	1.62
1	Bathysauridae	*Saurida undosquamis*	1*	3	1*	3*	3*	3	2.08
12	Callionymidae	*Callionymus belcheri*	1*	3	1*	3*	3*	1*	1.92
12	Callionymidae	*Callionymus sublaevis*	1*	3	1*	3*	3*	1*	1.92
12	Congridae	*Poeciloconger kapala*	1*	3	1*	3*	3*	1*	1.92
3	Diodontidae	*Cyclichthys orbicularis*	1*	3	1	3*	3*	1*	1.92
12	Labridae	*Leptojulis cyanopleura*	1*	3	1*	3*	3*	1*	1.92
4	Opisthognathidae	*Opistognathus latitabundus*	1*	3	3	1*	3*	1*	2.08
10	Plotosidae	*Euristhmus lepturus*	1*	3	1*	1*	3*	1*	1.62
12	Synodontidae	*Synodus macrops*	1*	3	1*	3*	3*	1*	1.92
12	Tetraodontidae	*Arothron manilensis*	1*	3	1*	3*	3*	1*	1.92

Table 9 The ranking of the species that are most likely to be sustainable on the criteria on the susceptibility axis. See Appendix 1 for labels; * = species-specific information not available.

Label	Family	Species	Criterion: Water column position (3)	Preferred habitat (3)	Survival (3)	Range (2)	Day/night catchability (2)	Diet (2)	Depth range (1)	Susceptibility rank
154	Carangidae	*Atule mate*	3*	2	2*	3	2	1	3	2.25
154	Carangidae	*Carangoides caeruleopinnatus*	3*	2	2	3	2	1	3	2.25
154	Carangidae	*Carangoides malabaricus*	3*	2	2*	3	2	1	3	2.25
157	Carangidae	*Carangoides talamparoides*	3*	2	2*	3	3	1	3	2.38
153	Carangidae	*Megalaspis cordyla*	3*	2	2*	1*	2*	3	3	2.25
146	Carangidae	*Parastromateus niger*	2*	2	2*	3	3	1	3	2.19
161	Clupeidae	*Pellona ditchela*	3	2	1*	3	3	3	3	2.44
157	Ephippidae	*Zabidius novaemaculatus*	3*	3	1*	3	2*	3	1	2.38
146	Scombridae	*Rastrelliger kanagurta*	3*	2	1*	3	3	1	3	2.19
154	Sphyraenidae	*Sphyraena forsteri*	3*	3	1*	1*	3	2	3	2.25
158	Terapontidae	*Pelates quadrilineatus*	3	2	2	3	2	2	3	2.38
158	Terapontidae	*Terapon jarbua*	2*	2	3*	3	2	2	3	2.38
146	Terapontidae	*Terapon theraps*	1	2	3	3	2	2	3	2.19

Table 10 The ranking of the species that are most likely to be sustainable on the criteria on the recovery axis. See Appendix 1 for labels; * = species-specific information not available.

Label	Family	Species	Criterion: Probability of breeding (3)	Maximum size (3)	Removal rate (3)	Reproductive strategy (2)	Hermaphroditism (1)	Mortality index (1)	Recovery rank
154	Carangidae	*Atule mate*	3	3	3	3*	3*	3	3.00
154	Carangidae	*Carangoides caeruleopinnatus*	3	3	3	3*	3*	3	3.00
154	Carangidae	*Carangoides malabaricus*	3	3	3	3*	3*	3	3.00
157	Carangidae	*Carangoides talamparoides*	2	3	3	3*	3*	3	2.77
153	Carangidae	*Megalaspis cordyla*	3	3	3	3*	3*	2	2.92
146	Carangidae	*Parastromateus niger*	3	3	3	3	3	3	3.00
161	Clupeidae	*Pellona ditchela*	3	3	3	3	3	3	3.00
157	Ephippidae	*Zabidius novaemaculatus*	2	3	3	3*	3*	3	2.77
146	Scombridae	*Rastrelliger kanagurta*	3	3	3	3	3	3	3.00
154	Sphyraenidae	*Sphyraena forsteri*	3	3	3	3	3	3	3.00
158	Terapontidae	*Pelates quadrilineatus*	3	3	3	3*	3*	3	3.00
158	Terapontidae	*Terapon jarbua*	3	3	3	3	3	3	3.00
146	Terapontidae	*Terapon theraps*	3	3	3	3*	3*	3	3.00

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most of these species after capture or their geographical range within the fishery and so ranks of 1 were given for these criteria. These susceptible species were also considered to have little capacity to recover from depletion by 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, they were given ranks of 1 on these criteria. Some species had relatively high recovery ranks (Table 8), but they also had high susceptibility, so were less likely to be sustainable.

Four of the species that were the least likely to be sustainable, namely the ariid and plotosid catfish are mouth brooders (McDowall 1988). Their fecundity is therefore likely to be low, which reduces their recovery capacity in comparison to broadcast spawners, although, parental care may increase survival of the young. These species occur in large numbers in estuaries and fresh water in the Gulf of Carpentaria region (Blaber *et al.* 1989). These areas were not incorporated in the estimates of total biomass in the region of the fishery 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 be distinguished only by genetic analysis (Thresher *et al.* 1986), which has not been done for NPF specimens. It is possible only one species was present. We have taken the conservative approach by 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. For *S. undosquamis*, in contrast, there was little information available but its characteristics ranked it in the low sustainability group. Such taxonomic difficulties are also likely to occur in other genera, particularly within the Ariidae.

The species that ranked as most likely to be sustainable (Fig. 3; Tables 9 and 10) included many in the families Carangidae, Terapontidae and Sphyraenidae. 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 prawn trawls, and their primary habitat lies outside of prawn trawl grounds. They have a broader depth range than that exploited by trawlers and their distribution in the area of the fishery is broad. Also, most do not have higher catch rates at night, when commercial trawling occurs, than during the day. Some terapontid species 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 ranked high. There was more information on these species than on those that were least likely to be sustainable. For most of these species it was estimated that individuals were likely to have bred before capture and both the removal rate by trawling and the mortality index were low.

The process we have developed is designed to highlight bycatch species whose populations may not be sustainable at present bycatch levels. The ranking is aimed at assisting researchers and managers to focus on the species that are most likely to be unsustainable. It also aims to highlight the species that are likely to be sustainable and identify gaps in our knowledge that hinder this assessment. The use of ranks of 1 for species where information was not available results in lower overall ranks for these species, but was used as a precautionary approach. If this information were available, the ranks of these species may be higher. The low rankings may, therefore, be strongly influenced by the lack of information; this bias must be taken into account. It must also be remembered that the current rankings are relative and are influenced by the assumptions outlined in the methods. The uncertainty around the ranks does not allow discrimination between species that are ranked closely together.

The removal rate estimates are subject to the largest number of assumptions in the process, as outlined in the Methods. Some assumptions may have negatively biased these estimates (e.g. assuming the catchability coefficients were 1) while others may have positively biased the estimates (e.g. the use of the highest mean catch rate). However, the process is relative rather than absolute; problems will arise if not all species are biased in the same direction. It was, however, important that these estimates were attempted. Improving the data on which these were based would substantially increase the robustness of the process.

The weighting of the criteria on each axis also influences the final ranking of species. If the criteria were not weighted, there would be less spread among the species. However, the species at the extremes would still rank at the extremes. The weights were used to reflect the relative importance of the criteria in determining the overall characteristic and also the limitations of the data.

Future research should focus on species that are the least likely to be sustainable and to fill gaps in knowledge that affect the assessment of species' sustainability. This research should include:

- Examination of the fine-scale distribution of species, providing a greater understanding of the overlap between the distribution of the species and the distribution of commercial fishing. Only about 25% of the managed area of the NPF is trawled (Stobutzki & Pitcher 1999). The remaining areas that are not fished may provide a refuge for bycatch species.
- Improving estimates of the removal rate of species by the commercial fishery.
- Examining the indirect impacts of trawling on species. The current process assesses the species with respect to only the impact of capture by trawlers.

The criteria we have employed can be used to examine how management actions change the ranking of a species, and therefore its likely sustainability. The criteria on the recovery axis that can be influenced are the removal rate, the probability

https://doi.org/10.1017/S0376892901000170 Published online by Cambridge University Press

of breeding before capture and the mortality index. Turtle excluder devices (TEDs) and bycatch reduction devices (BRDs) will be compulsory in the NPF in 2000 and 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 are no species-specific data to enable us to determine which bycatch species will be affected and to what extent. Changes in the species and size composition of bycatch with the introduction of TEDs and BRDs should be monitored, for their impact on the sustainability of species.

The closure of areas to fishing or changes in fishing effort may have a similar impact on some criteria. In particular the removal rate, probability of breeding before capture and the mortality index may be influenced by closures within the fishery or changes in effort levels. The criteria on the susceptibility axis, in their current form, cannot be directly influenced by changes in management.

Managers can use the ranks for selecting bycatch sustainability indicators. Many Australian fisheries have such indicators for their target species, but indicators for ecosystems or environments are under development (Sainsbury *et al.* 1999). The selection of sustainability indicators for bycatch species is not straightforward and requires substantial knowledge about the species (Fausch *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 (Fausch *et al.* 1990). The process of identifying sustainability indicators for communities requires substantial knowledge of those communities and the interrelationships among species, which, for bycatch communities, is currently unavailable.

The species identified as the least sustainable here are potentially more sensitive to the impacts of trawling, but if these do not reflect changes in other bycatch species they may not be good indicators of the sustainability of the bycatch community as a whole. Furthermore, least sustainable species tended to be rare and therefore difficult to monitor, which reduces their value as indicators.

The process we developed for assessing the sustainability of bycatch is designed to be dynamic. It can be refined as more bycatch information is acquired, strengthening the robustness of the ranking. It can also be applied in other fisheries, however the criteria used may vary. The process provides an approach that can help fisheries, particularly those with highly diverse bycatch, to examine and manage the sustainability of their bycatch.

Acknowledgements

We thank the commercial fishers who took the time to record their catch in log-books and support this project; the Northern Prawn Fishery Management Advisory Committee for its support; the Fishery Assessment Group of the Northern Prawn Fishery for their participation; S. Blaber, D. Heales, B. Hill, D. Fluharty, V. Mawson, D. Milton, N. Polunin, A. Punt and an anonymous reviewer for constructive comments on the manuscript; F. Manson and J. Bishop for assistance with the bioregion data and commercial effort data; C. Burridge and W. Venables for assistance with the statistical analysis. We also thank the fishing, scientific and electronic crew of the R.V. *Southern Surveyor,* who made the research surveys possible. This project was funded by the Australian Fisheries Research and Development Corporation (FRDC 96/257) and CSIRO Marine Research.

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Appendix 1

1 = *Saurida undosquamis*; 2 = *Gnathophis* sp., *Torquigener hicksi*; 3 = *Cyclichthys orbicularis*; 4 = *Opistognathus latitabundus*; 5 = *Ariosoma anago*; 6 = *Callionymus meridionalis, Lumiconger arafura, Uroconger lepturus, Leiognathus elongatus, Nemipterus celebicus, Inegocia harrisii, Onigocia spinosa*; 7 = *Siphamia roseigaster*; 8 = *Synchiropus rameus, Cynoglossus maculipinnis, Sirembo imberbis, Sorsogona tuberculata*; 9 = *Nemipterus marginatus, Onigocia macrolepis, Pardachirus pavoninus, Synodus hoshinonis, Lepidotrigla argus, Lepidotrigla spiloptera*; 10 = *Arius bilineatus, Arius proximus, Euristhmus lepturus*; 11 = *Arius nella*; 12 = *Callionymus belcheri, Callionymus sublaevis, Poeciloconger kapala, Leptojulis cyanopleura, Synodus macrops, Arothron manilensis*; 13 = *Scolopsis vosmeri*; 14 = *Pseudamia amblyuroptera, Arius argyropleuron, Gymnothorax reticularis*; 14 = *Epinephelus heniochus*; 15 = *Lagocephalus inermis*; 16 = *Synodus sageneus*; 17 = *Platycephalus indicus, Feroxodon multistriatus*; 18 = *Choerodon sugillatum, Plotosus lineatus*; 19 = *Samaris cristatus,*

Richardsonichthys leucogaster; 20 = *Antennarius hispidus, Cynoglossus bilineatus, Strabozebrias cancellatus*; 21 = *Saurida micropectoralis, Callionymus grossi, Brachypleura novaezeelandiae, Rogadius asper, Polydactylus nigripinnis, Dendrochirus brachypterus, Sillago lutea, Lepidotrigla* sp. 2; 22 = *Cyclichthys hardenbergi*; 23 = *Tathicarpus butleri, Tetrabrachium ocellatum, Adventor elongatus, Callionymus japonicus*; 24 = *Callionymus goodladi, Pomadasys maculatus, Nemipterus nematopus*; 25 = *Psettina gigantea*, Chaunacidae, *Gerres erythrourus, Microdesmidae, Platycephalus arenarius, Ichthyscopus fasciatus*; 26 = *Parapercis xanthozona*; 27 = *Siphamia fuscolineata, Siphamia guttulatus*; 28 = *Apogon nigripinnis*; 29 = *Apogon albimaculosus, Apogon melanopus*; 30 = *Pseudorhombus dupliciocellatus, Dactyloptena macracanthus, Lophodiodon calori, Pentapodus porosus, Scolopsis affinis, Ophichthidae*; 31 = *Apogon septemstriatus, Apogon* sp. 2; 32 = *Saurida longimanus, Engyprosopon grandisquamum, Pseudorhombus jenynsii, Pomadasys argenteus, Pomadasys trifasciatus, Muraenesox cinereus, Cociella hutchinsi, Platycephalus endrachtensis, Suggrundus macracanthus, Torquigener pallimaculatus, Torquigener tuberculiferus, Torquigener whitleyi*; 33 = *Scolopsis monogramma*; 34 = *Harpadon translucens, Parupeneus heptacanthus, Cymbacephalus nematophthalmus, Sillago sihama, Sillago analis*; 35 = *Upeneus moluccensis, Upeneus tragula, Chelonodon patoca*; 36 = *Rhabdamia gracilis*; 37 = *Conger wilsoni, Epinephelus malabaricus*; 38 = *Apogn aureus*; 39 = *Trachinotus cf mookalee, Plectorhinchus gibbosus*; 40 = *Cheilodipterus artus*; 41 = *Otolithes ruber*; 42 = *Apogon poecilopterus*; 43 = *Batrachomoeus trispinosus*; 44 = *Centriscus scutatus, Inegocia japonica, Polydactylus multiradiatus, Cottapistus cottoides, Minous versicolor, Arothron stellatus*; 45 = *Nemipterus furcosus*; 46 = *Upeneus asymmetricus*, *Suggrundus rodericensis*; 47 = *Scolopsis taeniopterus*; 48 = *Velifer hypselopterus*; 49 = *Nemipterus hexodon, Nemipterus peronii, Sillago burrus, Trachinocephalus myops, Uranoscopus cognatus*; 50 = *Acentrogobius viridipunctatus, Ctenotrypauchen microcephalus, Drombus globiceps, Chaetodermis penicilligera*; 51 = *Encheliophis gracilis, Leiognathus blochii, Triacanthus biaculeatus, Paramonacanthus japonicus*; 52 = *Gerres filamentosus*; 53 = *Netuma thalassinus, Trachyrhamphus longirostris*; 54 = *Nettastoma parviceps*; 55 = *Acentrogobius caninus, Aluterus monoceros, Euristhmus nudiceps*; 56 = *Gerres oyena*; 57 = *Siphamia majimai, Parachaeturichthys polynema, Paramonacanthus choirocephalus, Congrogadus amplimaculatus, Cynoglossus macrophthalmus, Myripristis botche, Ogcocephalidae, Eurypegasus draconis*; 58 = *Saurida* sp. 2, *Pseudorhombus argus, Pseudorhombus spinosus, Cynoglossus arel, Gerres macrosoma, Gerres subfasciatus, Choerodon monostigma, Pegasus volitans, Rhinoprenes pentanemus, Sillago ingenuua, Dexillus muelleri, Zebrias quagga*; 59 = *Abalistes stellaris, Oxyurichthys papuanus, Oxyurichthys* sp., *Anacanthus barbatus, Pseudomonacanthus peroni*; 60 = *Leiognathus smithursti*; 61 = *Monacanthus chinensis, Acanthocepola abbreviata, Cynoglossus kopsii, Paraplagusia bilineata, Paraplagusia longirostris, Gerres baconensis, Epinephelus sexfasciatus, Lagocephalus lunaris, Uranoscopus* sp. 1; 62 = *Dactylopus dactylopus, Leiognathus fasciatus, Valamugil cunnesius, Pentapodus paradiseus, Psettodes erumei*; 63 = *Apogon brevicaudata*; 64 = *Parupeneus barberinoides*; 65 = *Apogon cavitiensis, Apogon nigrocincta*; 66 = *Conger cinereus, Papilloculiceps bosschei*; 67 = *Pseudochromis quinquedentatus*; 68 = *Apogon notatus, Parapercis nebulosa, Atrobucca brevis*; 69 = *Siphamia argyrogaster*; 70 = *Pentaprion longimanus, Sargocentron rubrum, Xiphocheilus typus, Argyrops spinifer*; 71 = *Tetrosomus gibbosus*; 72 = *Laeops parviceps, Chelmon marginalis, Myripristis hexagona, Chaetodontoplus duboulayi*; 73 = *Paramonacanthus filicauda*; 74 = *Ostracion nasus*; 75 = *Paracentropogon longispinus, Scorpaena neglecta*; 76 = *Plectropomus leopardus*; 77 = *Cephalopholis boenack*; 78 = *Epinephelus coioides, Plectropomus maculatus*; 79 = *Leiognathus aureus, Lutjanus quinquelineatus, Epinephelus quoyanus*; 80 = *Apogon fasciatus, Diagramma pictum*; 81 = *Grammatobothus polyophthalmus, Pseudorhombus diplospilus, Pseudorhombus elevatus, Gerres macracanthus, Leiognathus ruconius, Upeneus luzonius, Upeneus* sp. 1, *Upeneus sundaicus, Elates ransonnetii, Hypodytes carinatus, Minous trachycephalus, Neomerinthe megalepis, Lagocephalus spadiceus*; 82 = *Epinephelus areolatus*; 83 = *Apogon ellioti, Cottapistus praepositus*; 84 = *Pseudorhombus arsius, Tragulichthys jaculiferus, Leiognathus decorus, Inimicus sinensis, Neomerinthe amplisquamiceps*; 85 = *Glaucosoma magnificum, Pomadasys kaakan, Pristotis jerdoni*; 86 = *Psettina tosana, Mugil cephalus*; 87 = *Polyipnus tridentifer*; 88 = *Scatophagus multifasciatus*; 89 = *Scatophagus argus*; 90 = *Protonibea diacanthus*; 91 = *Antennarius pictus, Antennarius striatus, Onuxodon margaritiferae, Myripristis murdjan, Pomacanthus sexstriatus, Scarus ghobban, Johnius laevis, Erosa erosa, Scorpaenopsis diabolus, Scorpaenopsis venosa*; 92 = *Caranx kleinii, Pempheris analis, Austronibea oedogenys, Brachypterois serrulatus*; 93 = *Trimma taylori*; 94 = *Antennarius nummifer, Coradion chrysozonus, Choerodon cephalotes, Lagocephalus sceleratus*; 95 = *Parachaetodon ocellatus*; 96 = *Chaetodon flavirostris, Encrasicholina devisi*; 97 = *Escualosa thoracata, Rachycentron canadum*; 98 = *Champsodon nudivittis, Stolephorus waitei*; 99 = *Herklotsichthys koningsbergeri, Encrasicholina heteroloba, Fistularia petimba, Leiognathus moretoniensis, Lutjanus argentimaculatus, Upeneus sulphureus*; 100 = *Lutjanus sebae*; 101 = *Chirocentrus dorab, Dactyloptena papilio*; 102 = *Yongeichthys nebulosus*; 103 = *Leiognathus splendens, Lutjanus vitta, Trixiphichthys weberi*; 104 = *Atractoscion aequidens*; 105 = *Ulua mentalis*; 106 = *Polyipnus elongatus*; 107 = *Ariomma indica, Leptobrama mulleri*; 108 = *Arnoglossus waitei, Johnius amblycephalus, Johnius borneensis*; 109 = *Lutjanus carponotatus, Pterois russelli*; 110 = *Pterois volitans*; 111 = *Chelmonops truncatus*; 112 = *Sardinella albella, Fistularia commersonii, Scomberomorus semifasciatus*; 113 = *Malakichthys* sp. 1, *Myctophidae*; 114 = *Setipinna tenuifilis*; 115 = *Anodontostoma chacunda, Stolephorus indicus, Thryssa hamiltonii, Leiognathus equulus, Leiognathus leuciscus*; 116 = *Amblygaster sirm, Secutor insidiator, Lutjanus erythropterus, Lutjanus lutjanus, Siganus fuscescens*; 117 = *Chelmon muelleri, Lactarius lactarius, Gazza* *minuta, Leiognathus bindus, Mene maculata*; 118 = *Dendrochirus zebra*; 119 = *Siganus argenteus*; 120 = *Uraspis uraspis, Lutjanus johnii, Symphorus nematophorus*; 121 = *Gnathanodon speciosus, Seriolina nigrofasciata*; 122 = *Scomberoides tala, Siganus canaliculatus*; 123 = *Euleptorhamphus viridis*; 124 = *Pterocaesio chrysozona, Heniochus diphreutes, Sphyraena barracuda*; 125 = *Bregmaceros japonicus, Hemiramphus robustus, Scomberomorus commerson*; 126 = *Thryssa marasriae*; 127 = Exocoetidae, *Scomberomorus munroi*; 128 = *Selaroides leptolepis, Platax batavianus, Leiognathus* sp.; 129 = *Lethrinus genivittatus*; 130 = *Psenopsis humerosa, Priacanthus tayenus, Scomberomorus queenslandicus*; 131 = *Lethrinus lentjan*; 132 = *Drepane punctata*; 133 = *Stolephorus carpentariae*; 134 = *Hyporhamphus affinis*; 135 = *Siganus lineatus*; 136 = *Caesio teres*; 137 = *Sphyraena qenie*; 138 = *Carangoides hedlandensis, Selar boops, Terapon puta*; 139 = *Pantolabus radiatus, Platax teira, Pelates sexlineatus*; 140 = *Lethrinus laticaudis*; 141 = *Scomberoides tol, Selar crumenophthalmus, Ulua aurochs, Lutjanus russelli*; 142 = *Alectis ciliaris*; 143 = *Rastrelliger brachysoma*; 144 = *Carangoides gymnostethus*; 145 = *Bregmaceros mcclellandi, Alectis indicus, Dussumieria elopsoides, Sardinella gibbosa, Thryssa setirostris*; 146 = *Parastromateus niger, Rastrelliger kanagurta, Terapon theraps*; 147 = *Megalops cyprinoides*;148 = *Bathophilus nigerrimus, Eustomias multifilis*; 149 = *Carangoides fulvoguttatus*; 150 = *Caesio caerulaurea, Pterocaesio digramma, Decapterus macrosoma, Sphyraena putnamiae*; 151 = *Alepes* sp., *Carangoides humerosus, Caranx bucculentus, Scomberoides commersonnianus, Sphyraena flavicauda, Sphyraena obtusata, Trichiurus lepturus*; 152 = *Carangoides chrysophrys, Echeneis naucrates, Lutjanus malabaricus*; 153 = *Megalaspis cordyla*; 154 = *Atule mate, Carangoides caeruleopinnatus, Carangoides malabaricus, Sphyraena forsteri*; 155 = *Sphyraena jello*; 156 = *Decapterus russelli*; 157 = *Carangoides talamparoides, Zabidius novaemaculatus*; 158 = *Pelates quadrilineatus, Terapon jarbua*; 159 = *Caranx melampygus*; 160 = *Herklotsichthys lippa*; 161 = *Pellona ditchela*.