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Assessing the Sustainability of Elasmobranch By-catch in a Prawn Trawl Fishery: a Method for Dealing with High Diversity and Limited Information
(Elasmobranch Fisheries – Poster)

by

I. Stobutzki, M. Miller, D. Heales, D. Brewer

CSIRO Marine Research, PO Box 120 Cleveland QLD 4163, Australia. ilona.stobutzki@csiro.au, margaret.miller@csiro.au, donald.heales@csiro.au, david.brewer@csiro.au

Abstract

The issue of elasmobranch by-catch is of global concern and there are limited data available to assess the extent of the problem. In Australia's Northern Prawn Fishery (NPF) 56 elasmobranch species are caught in the by-catch, on average at least one individual per trawl. The sustainability of this elasmobranch by-catch is an important issue for this fishery, however there is little biological or historical information available to assess their sustainability through a traditional stock assessment approach. Hence, we have developed an approach to examine the likely impact of trawling on these species and applied this to the NPF. Two overriding characteristics determine the sustainability of by-catch species: the susceptibility of a species to capture and mortality in a prawn trawl (susceptibility) and the productivity of the species (productivity), which determines the population's ability to recover once depleted. Species were ranked on attributes that determine each characteristic. The overall ranking of species reflects their ability to sustain fishing pressure and therefore, their priority for management, monitoring and research. The highest priority species, those that were the least likely to be sustainable, included stingrays (Dasyatidae), sawfishes (Pristidae), angel sharks (Squatinidae), zebra sharks (Stegostomatidae), shovelnose rays (Rhinobatidae) and nurse sharks (Ginglymostomatidae). They are all bottom dwellers, which increases their susceptibility to capture. This approach can be extended to other fisheries or impacts and is particularly valuable where species diverse is high and little data are available.

Introduction

Evaluating the sustainability of by-catch species is often hampered by lack of information, this is particularly so for elasmobranchs. Elasmobranch by-catch is often not recorded (Bonfil, 1994), or where it is recorded, the species composition is unknown. There is also limited biological information for most species, such as age at maturity, growth rate and fecundity. This lack of information hampers the use of conventional stock assessment methods to determine the status of populations.

Australia has a highly diverse elasmobranch fauna, with almost half of the species endemic (Last and Stevens, 1994). In northern Australian waters, elasmobranchs are impacted by a range of fisheries, both target (including gillnet, longline and dropline fisheries) and by-catch fisheries (including dropline and gillnet fisheries that target teleosts and trawl fisheries that target teleosts or prawns). Levels of elasmobranch by-catch are unknown for most fisheries. The largest fishery in northern Australia is the Northern Prawn Fishery (NPF), with a management area covering over 1,000,000 km^2 of ocean (Fig. 1) (McLoughlin *et al.*, 1997). Elasmobranchs contribute 4% of the total by-catch weight of this fishery (Stobutzki *et al.,* 2001a). Prior to 2001, NPF trawlers were allowed to retain shark products, but were restricted with respect to the amount on board at any one time.

This study is one of several (Milton, 2001; Stobutzki *et al.*, 2001b) that broadly examine the sustainability of by-catch species groups in the NPF and is published in full in Stobutzki *et al.* (2002). The aim was to assess the relative sustainability of elasmobranch species taken as by-catch in the NPF. This study provides a demonstration of a broadbrush method developed by Stobutzki *et al*. (2001b) to deal with the high diversity and limited information. This semi-quantitative technique assesses the sustainability of species based on two overriding characteristics, 1) their susceptibility to capture and mortality due to trawling and 2) the population's productivity. Traditional population assessment methods attempt to measure/model these factors. Our process uses biological and ecological attributes of the species to provide an index of these two characteristics, maximising the use of the limited information available. The process identifies species that are the least likely to be sustainable in the by-catch, so that research and management can be focused on these species.

Methods

A list of the elasmobranchs species recorded in the area of the NPF was compiled (Last and Stevens, 1994). A list of species taken as NPF by-catch was collated from two sources:

1) fishery research surveys undertaken within the NPF fishing grounds (Blaber *et al*., 1997; Crocos *et al*., 1997; Crocos and Coman, 1997; Stobutzki *et al.,* 2001a) and
2) elasmobranch by-catch recorded at sea by observers on commercial vessels; these observers were either scientific staff or trained crew-members (Pender *et al*., 1992; Stobutzki *et al*., 2000; 2001a).

The assessment of the sustainability of the species is based on the method developed by Stobutzki *et al.* (2001b) and documented in detail in Stobutzki *et al*. (2002). The sustainability of the species was assumed to be dependant on two overriding characteristics, 1) their susceptibility to capture and mortality due to trawling and 2) the population's productivity or capacity to recover after depletion. Biological and ecological information was collated from the literature (Compagno, 1984a; 1984b; Last and Stevens, 1994; Froese and Pauly, 1999). This was used to rank species along two axes:

Axis 1: The susceptibility of a species to capture and mortality due to a prawn trawl (susceptibility),
Axis 2: The productivity of the species (productivity).

Each characteristic (or axis) was derived from several attributes that determine or provide an index of the characteristic (Table 1). Each species was given a rank from 1-3 for each attribute (the definitions of the ranks for the criteria are provided in Table 1). A rank of 3 suggested the species is highly susceptible to capture or has a low productivity; a rank of 1 suggested the species has a low susceptibility to capture or a high productivity. Depending on the criterion these ranks were based on categorical or continuous data (Table 1). 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 attribute: water column position, diet and day/night catchability. In the other attributes, where it is not necessarily logical that family members would be similar, or where family information was not available, a rank of 1 was used as a precautionary approach. Table 1 shows the proportion of species for which species-specific information was available for each attribute.

Analysis

Partial correlations (Sokal and Rohlf, 1996) were used to determine whether there was any redundancy in the rankings of the attributes. Strong correlations would suggest that two or more attributes are explaining the same factors, which would lead to overemphasis of their effect. One of the correlated attributes should, therefore, be removed.

The total susceptibility or productivity ranking of a species was determined by the following equation:

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

where S_i is the total susceptibility or productivity ranks for species *i,* w_j is the weighting for attribute *j,* R_i is the rank of species *i* for attribute *j* and *n* is the number of attributes on each axes.

The attributes were weighted to reflect the relative importance of each attribute in determining the overall characteristic and the robustness and quality of the data (Table 1), the later in terms of the amount of species-specific information and the scale of the information available. The attributes that were seen as major determinants of the susceptibility or recovery and with more robust data were weighted highest. This weighting was done in collaboration with the NPF Fishery Assessment Group.

The total susceptibility and productivity ranks for the species were graphed to determine the relative sustainability of the species caught as by-catch by prawn trawlers. The species least likely to be sustainable would be identified as the species with the highest ranks on both axes.

Contour lines were drawn on the graph to group species that would be similar with respect to their sustainablity. As neither susceptibility nor productivity alone provides a complete index to the sustainability of species, the index is a combination of these. Productivity 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 is symmetrical and given this assumption the contour lines follow the equation

$$16(y - 0.75)(x - 0.75) = 4, 9, 16, 25, 36, 49 \qquad (2)$$

Results

At least 79 species of elasmobranchs from 18 families, occur in the NPF region (Table 2). Of these, 56 species (16 families) have been recorded in the prawn trawl fishery by-catch (Table 2). The Carcharhinidae and Dasyatidae, the most species-rich families in the region, have the highest number of species recorded in by-catch (Table 2). There are 9 families in which all species occurring in this region have been recorded in by-catch (Table 2).

Recent surveys (Stobutzki *et al*., 2002) show that the highest overall catch rates were *Carcharhinus tilstoni, C. dussumieri, Rhynchobatus djiddensis* and *Himantura toshi* (Table 3). These four species contributed almost 65% of the observed elasmobranch catch. *Carcharhinus dussumieri* and *C. tilstoni* were recorded in 20% of all trawls, *R. dijiddensis* in 14% and *H. toshi* in 17%.

The 56 species of elasmobranchs recorded as by-catch in the NPF were ranked on each of the attributes on the two axes (Table 4). When the ranks of the species on the two axes were plotted (Fig. 2). *Dasyatis brevicaudatus, Pristis pectina, P. clavata, P. microdon, P. zijsron* and *Himantura jenkinsii* rank the lowest on the combination of the two axes, suggesting that they are the least likely to be able to sustain capture as by-catch. The species *Eusphyrna blochii, H. toshi, C. macloti* and *C. tilstoni* ranked the highest on the two axes, suggesting they are the most likely to be able to sustain capture as by-catch.

Discussion

Of the elasmobranch species known to occur in this region, 71% are taken as by-catch in the NPF. The highly diverse by-catch is characteristic of tropical prawn trawl fisheries (Hall, 1999). There are no long-term data available from which changes in catch rates of elasmobranch species can be examined. While shark by-product is recorded in NPF logbooks the data are of limited value as they are not validated and not species-specific. Pender *et al.* (1992) surveyed the by-catch in Northern Territory waters of the NPF during the 1980s. Rhynchobatids (71% of the elasmobranch catch), carcharhinids (12%) and dasyatids (11%) dominated the catch (Pender *et al*., 1992). All species recorded by Pender *et al*. (1992) were recorded in our study. Direct comparisons of the catch rates between Pender *et al.* (1992) and the current study are not possible due to differences in the gear, season and region.

Elasmobranchs, in general, are more susceptible to overfishing than bony fishes, but there is likely to be a range of sensitivities among the species (Walker, 1998; Stevens *et al*., 2000). The process we have applied here examines these different sensitivities and highlights those species whose populations are most likely to be affected by the NPF. The process is designed to deal with the high diversity of the by-catch and the paucity of information available for most species. Our process is similar to that used by the IUCN Red lists, that categorize species with respect to the threat of extinction worldwide. The IUCN use criteria on the extent of population decrease, area of occurrence, percent of population that are mature and the probability of extinction (IUCN, 1996). The IUCN criteria have been modified for application to marine fishes and for smaller geographic scales (Musick, 1998).

Several authors have examined the variable resilience of elasmobranch species to fishing pressure. These approaches have focused on life history characteristics of species that influence the recovery of populations, including reproductive and growth parameters (reviewed by Stevens *et al*., 2000). Our process is similar to these, but focuses at the level of an individual fishery, incorporating fishery-specific information on the susceptibility of species to the fishery. A significant issue with all methods is the ability to calculate the range of parameters required for a large number of species (Stevens *et al*., 2000). The semi-quantitative method we have developed maximizes what can be determined from the data available and enables consistency across the species. The species' attributes include those that influence the probability of extinction of species and their sensitivity to overfishing (McKinney, 1997: Carlton *et al*., 1999; Roberts and Hawkins, 1999; Stevens *et al*., 2000). This analysis provides a process for highlighting information gaps and prioritizing species for future management and research. This process does not replace traditional methods of population assessment but provides a rapid assessment of the species, so that traditional methods can be focused on the high-risk species.

The species that were least likely to be sustainable in the by-catch of the NPF were *D. brevicaudatus, P. pectinata, P. clavata, P. microdon, P. zijsron* and *Himantura jenkinsii* (Fig. 2). The pristids and *H. jenkinsii* had ranks of 1 on the susceptibility axis, the lowest possible rank, while *D. brevicaudatus* ranked 1.15 (Table 4?). These species are demersal, are rare in the by-catch, and at least for the pristids (which have restricted depth distributions) are likely to be rare naturally. Nothing is known about their survival. Their diets include benthic organisms and are 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 productivity of these species is also low (Table 4?). The rarity of the species in the by-catch means that no data are available to estimate the probability of breeding before capture, removal rate, total biomass or the mortality index for most of these species, and they therefore received ranks of 1 for these criteria. In general these are large animals and therefore, likely to have lower productivity and slower recovery of their population than smaller species. The annual fecundity was low for all species.

The pristids are the focus of increasing international concern, because their populations are declining worldwide (Stevens *et al*., 2000). They are rarely seen today in areas where they were previously abundant (Simpfendorfer, 2000). This decrease in pristid populations has resulted in four species being listed on the IUCN 1996 Red List (Bailie and Groombridge, 1996). Of the species studied here, *P. pectinata* and *P. microdon* are listed as endangered. Recent demographic analysis of pristid populations suggests that their recovery will take several decades even if given effective conservation (Simpfendorfer, 2000).

In comparison, the species that were most likely to be able to sustain capture in the by-catch of the NPF were *H. toshi, E. blockii, C. macloti* and *C. tilstoni.* These species had a lower susceptibility to capture and mortality due to trawling (Table 4?). With the exception of *H. toshi*, these are pelagic species, lowering the likelihood of capture in prawn trawls. For the species where data were available, their survival was higher in trawls. The depth range of the species was wide and their catch rates during the day were the same as or higher than at night. This provides some refuge from the night-time commercial trawling. The data available suggest that their productivity is higher than most (Table 4?). Individuals of most of these species are likely to have bred before capture and they are smaller. These species were common in the by-catch, enabling estimates of their removal rate, which was low and their mortality index average. However, all species had low annual fecundities.

This assessment of the elasmobranch by-catch is an important first step in ensuring their sustainability as it provides a focus for future research and management. There is a clear need to collect information to fill in the gaps in the knowledge of the biology of the least sustainable species. By-catch management actions should also focus on this species group. The current ranking is constrained by the available data and assumptions of the methods (Stobutzki *et al*., 2002). The influence of the lack of species-specific information on the ranks should be taken into account, as it may increase the rank of 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. In the region of the NPF there are fisheries that target sharks, as well as other fisheries that take elasmobranchs as by-catch. As elasmobranch species are relatively mobile and their populations may have a wide range, they may be impacted by several fisheries. The cumulative impact of several fisheries may result in an unsustainable impact overall. For example, the pristids are likely to be impacted by the inshore and estuarine gillnet fisheries in this region.

The process undertaken in this research is the first time elasmobranch by-catch has been assessed on this scale. The results highlight the diversity of elasmobranch by-catch in the NPF and the species that are least likely to be sustainable. We have also highlighted the limited information available for making this assessment. However, our method was designed to maximize the use of this information. The process we have developed has been designed to be transferable to other fisheries and is likely to be of greatest benefit where diversity is high and information limited.

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Table 1. The species attributes used to assess 1) the relative susceptibility of by-catch species to capture and mortality due to prawn trawls and 2) their productivity, or ability to recovery after depletion due to trawling, these combine to provide the ranks for the axes in Fig. 2. For each attribute the definition of the three ranks is given as well as weighting score and the percentage of species for which species-specific information was used to rank them. The attributes are discussed in detail in Stobutzki *et al.* (2002).

Criteria	**Weight**	**Species-specific Information (%)**	**Rank** 3	2	1
1) Susceptibility					
Water column position	3	100	Demersal or benthic	Not applicable	Benthopelagic or pelagic
Survival	3	18	Probability of survival < 33%	Probability of survival between 33% and 66%, inclusive	Probability of survival > 66%
Range	2	71	Species range ≤ 3 fishery regions	3 fishery regions < species range ≤ 6 fishery regions	**Species range > 6 fishery regions**
Day/night catchability	2	32	Higher catch rate at night	No difference between night and day	Higher catch rate at day
Diet	2	55	Known to, or capable of, feeding on commercial prawns or benthic organisms	Not applicable	Feed on pelagic organisms
Depth range	1	**100**	**Less than 60 m**	Not applicable	Deeper than 60 m
2) Productivity					
Probability of breeding	3	42	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	100	Maximum disc width > 1755 mm	853 mm < maximum disc width ≤ 1755 mm	Maximum disc width ≤ 853 mm
			Maximum total length > 4781 mm	1861 mm < maximum total length ≤ 4781 mm	Maximum total length ≤ 1861 mm
Removal rate	3	**79**	**Removal rate > 66%**	33 % < removal rate ≤ 66 %	33 % ≤ removal rate
Annual fecundity	1	**52**	**Annual fecundity ≤ 5 young per year**	5 young per year < annual fecundity ≤ 19 young per year	Annual fecundity > 19 young per year
Mortality index	1	64	mortality index > 3.47	0.92 < mortality index ≤ 3.47	mortality index ≤ 0.92

Table 2. The elasmobranch species that are known to occur in the region of the NPF and of these, those that have been recorded in NPF by-catch. The label in parenthesis refers to Fig. 2.

	Recorded in by-catch		
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	(Cm)	*Carcharinus melanopterus*
	Carcharhinus sorrah	(Cs)	*Loxodon macrorhinus*
	Carcharhinus tilstoni	(Ct)	*Rhizoprionodon oligolinx*
	Galeocerdo cuvier	(Gc)	*Triaenodon obesus*
	Negaprion acutidens	(Na)	
	Prionace glauca	(Pg)	
	Rhizoprionodon acutus	(Rac)	
	Rhizoprionodon taylori	(Rta)	
Dasyatididae	*Amphotistius annotata*	(Aa)	*Dasyatis fluviorum*
	Dasyatis brevicaudatus	(Db)	*Taeniura lymma*
	Dasyatis leylandi	(Dl)	
	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		(Ac)	
	Anoxypristis cuspidata		
	Pristis clavata	(Pc)	
	Pristis microdon	(Pm)	
	Pristis pectinata	(Pp)	
	Pristis zijsron	(Pz)	
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*	(Rty)	*Aptychotrema* sp. A
Rhynchobatidae	*Rhynchobatus djiddensis*	(Rd)	
	Rhina ancylostoma	(Ran)	

Table 3. The percentage of trawls in which species were caught, mean catch rate (*n* km^{-2} = number of individuals per km^2 trawled, se = standard error) and the percentage of elasmobranch catch contributed by each species, based on Stobutzki *et al.* (2002).

			n km^{-2}		
Family	Species	% of trawls	mean	se	% of catch
Carcharhinidae		0.10	0.58	0.41	0.26
	Carcharhinus albimarginatus				
	Carcharhinus amboinensis	0.20	0.04	0.04	0.02
	Carcharhinus dussumieri	20.57	38.80	4.89	17.54
	Carcharhinus fitztroyensis	0.20	0.80	0.40	0.35
	Carcharhinus macloti	0.20	0.98	0.50	0.43
	Carcharhinus sorrah	1.67	1.47	0.57	0.65
	Carcharhinus tilstoni	19.49	44.20	5.98	20.07
	Galeocerdo cuvier	0.20	0.01	0.00	< 0.01
	Negaprion acutides	0.10	0.00	0.00	< 0.01
	Rhizoprionodon acutus	9.15	10.61	1.63	4.83
	Rhizoprionodon taylori	0.10	0.00	0.00	< 0.01
Dasyatididae	*Amphotistius annotata*	1.97	1.56	0.41	0.74
	Dasyatis kuhlii	2.56	1.48	0.56	0.69
	Dasyatis leylandi	15.35	9.44	1.18	4.48
		0.10	0.00	0.00	< 0.01
	Dasyatis *sp. A*				
	Dasyatis thetidis	0.49	0.03	0.01	0.01
	Himantura fai	0.10	0.01	0.00	< 0.01
	Himantura granulata	0.20	0.01	0.01	< 0.01
	Himantura jenkinsii	0.59	2.11	0.77	0.95
	Himantura sp. A	2.17	0.11	0.04	0.05
	Himantura toshi	17.72	27.85	3.10	12.84
	Himantura uarnak	0.98	1.44	0.58	0.70
	Himantura undulata	0.89	0.96	0.40	0.43
	Pastinachus sephen	3.44	0.69	0.31	0.31
	Taeniura meyeni	0.10	0.40	0.28	0.18
	Urogymnus asperrimus	0.39	0.40	0.28	0.18
Ginglymostomatidae	*Nebrius ferrugineus*	0.10	0.58	0.41	0.26
Gymnuridae	*Gymnura australis*	5.91	8.02	1.64	3.82
Hemiscylliidae	*Chiloscyllium punctatum*	5.41	11.83	1.96	5.42
	Hemigaleus microstoma	9.84	9.64	1.55	4.56
	Hemipristis elongatus	0.20	0.02	0.02	0.01
Myliobatidae	*Aetobatus narinari*	0.30	0.60	0.41	0.27
	Aetomylaeus nichofii	1.08	1.57	0.61	0.74
Orectolobidae	*Orectolobus ornatus*	0.10	0.52	0.52	0.27
Pristidae	*Anoxypristis cuspidata*	0.98	0.71	0.42	0.32
	Pristis zijsron	0.10	0.02	0.02	0.01
Rhinobatidae	*Rhinobatos typus*	0.39	0.02	0.01	0.01
Rhynchobatidae	*Rhina ancylostoma*	0.89	0.10	0.04	0.05
	Rhynchobatus djiddensis	14.27	30.87	3.39	14.26
Scyliorhinidae	*Atelomycterus fasciatus*	0.49	0.18	0.08	0.08
Sphyrnidae	*Eusphyra blochii*	0.20	0.04	0.04	0.02
	Sphyrna lewini	2.95	6.91	1.52	3.07
	Sphyrna mokarran	0.39	0.02	0.02	0.01
Stegostomatidae	*Stegostoma fasciatum*	2.17	2.17	1.02	1.10

Table 4. The ranking of species with respect to the attributes that contribute to their susceptibility to capture and mortality due to trawling and their productivity. The weight of each attribute in determining the overall ranking is shown in parentheses, * indicates where species-specific information was not available. The information was obtained from Compagno (1984a; 1984b), Last and Stevens (1994) and Frose and Pauly (1999).

		Susceptibility							**Productivity**					
Family	**Species**	**Water column position (3)**	**Survival (3)**	**Range (2)**	**Day/ night (2)**	**Diet (2)**	**Depth range (1)**	**Total rank**	**Breeding (3)**	**Max. size (3)**	**% biomass removed (3)**	**Annual fecundity (2)**	**Mortality index (1)**	**Total rank**
Carcharhinidae	*Carcharhinus albimarginatus*	1	3*	3	3*	2	1	2.23	3*	2	2	2	3*	2.33
	Carcharhinus amboinensis	3	3*	3	3*	3	1	2.85	3	2	3	2	2	2.50
	Carcharhinus brevipinna	1	3*	3*	3*	1	1	2.08	3*	1	3*	2	3*	2.33
	Carcharhinus dussumieri	3	2	2	1	3	1	2.15	1	2	1	3	3	1.75
	Carcharhinus fitztroyensis	1	3*	3	3*	3	3	2.54	2	2	2	3	2	2.17
	Carcharhinus leucas	3	3*	3*	3*	3	1	2.85	3	1	3*	3	3	2.50
	Carcharhinus limbatus	1	3	3*	3*	1	3	2.23	3*	1	3*	3	2	2.42
	Carcharhinus macloti	1	3*	3	1	2	1	1.92	2	2	1	3	2	1.92
	Carcharhinus sorrah	1	3	2	3*	3	1	2.23	3	1	1	3*	2	1.92
	Carcharhinus tilstoni	1	2	2	2	3	1	1.85	3	1	1	3	1	1.83
	Galeocerdo cuvier	1	3*	3	3*	3	1	2.38	2	3	1	1	2	1.83
	Negaprion acutides	3	3*	3	3*	3	1	2.85	1	2	3	2	3*	2.08
	Prionace glauca	1	3*	3*	3*	1	1	2.08	3*	2	3*	1	3*	2.42
	Rhizoprionodon acutus	3	3	1	1	3	1	2.23	3	1	1	3	3	2.00
	Rhizoprionodon taylori	3	3*	3	1	3	1	2.54	1	1	1	3	2	1.42
Dasyatididae	*Amphotistis annotatus*	3	3*	2	2	3*	1	2.54	2*	3	1	3*	2	2.17
	Dasyatis brevicaudatus	3	3*	3*	3*	3*	1	2.85	3	3	3*	3	2	2.92
	Dasyatis kuhlii	3	3*	2	3	3*	1	2.69	2	1	1	3	3*	1.75
	Dasyatis leylandi	3	2	1	3	3	1	2.31	2	1	1	3*	3*	1.75
	Dasyatis sp. A	3	3*	3	3*	3*	1	2.85	2	1	3	3*	3*	2.25
	Dasyatis thetidis	3	3*	3	3*	3*	1	2.85	3*	2	1	3*	3	2.25
	Himantura fai	3	3*	3	3*	3*	1	2.85	3*	2	1	3*	3*	2.25
	Himantura granulata	3	3*	3	3*	3	1	2.85	3*	2	1	3*	3*	2.25
	Himantura jenkinsii	3	3*	3	3*	3*	3	3.00	3*	2	2	3*	3	2.50

	Himantura sp. A	3	3*	2	3*	3*	1	2.69	3*	1	1	3*	1	1.83
	Himantura toshi	3	2	1	2	3	1	2.15	1	1	1	3	2	1.42
	Himantura uarnak	3	3*	3*	3*	3*	1	2.85	3*	2	1	3*	3	2.25
	Himantura undulata	3	3*	2	2	3*	1	2.54	3*	2	1	3*	3	2.25
	Pastinachus sephen	3	3*	2	3*	3	3	2.85	1	3	1	3*	2	1.92
	Taeniura meyeni	3	3*	3	3*	3*	1	2.85	3	3	1	3	3	2.50
	Urogymnus asperrimus	3	3*	3	3*	3*	1	2.85	3	2	1	3	3	2.25
Ginglymostomatidae	*Nebrius ferrugineus*	3	3*	3	3*	3	1	2.85	1	2	1	2	3*	1.58
Gymnuridae	*Gymnura australis*	3	2	1	2	3*	3	2.31	1	1	1	3	2	1.42
Hemiscylliidae	*Chiloscyllium punctatum*	3	3*	2	3	3	1	2.69	3*	1	1	3*	3	2.00
	Hemigaleus microstoma	3	3	1	3*	2	1	2.38	2	1	1	2	1	1.42
	Hemipristis elongatus	1	3*	3	3*	2	1	2.23	2	2	1	3	3	2.00
Myliobatidae	*Aetobatus narinari*	1	3*	3	3*	2	1	2.23	3*	3	1	3	2	2.42
	Aetomylaeus vespertilio	1	3*	3*	3*	3*	1	2.23	3*	2	3*	3*	2	2.67
	Aetomyleus nichofii	1	3*	2	3	2*	1	2.08	3*	1	1	3	2	1.92
Narcinidae	*Narcine westraliensis*	3	3*	3*	3*	2	1	2.69	3*	1	3*	3*	3*	2.50
Orectolobidae	*Orectolobus ornatus*	3	3*	3	3	3	1	2.85	3*	2	1	3*	3*	2.25
Pristidae	*Anoxypristis cuspidata*	3	3*	3*	2	3*	3	2.85	3	1	1	3	3*	2.00
	Pristis clavata	3	3*	3*	3*	3*	3	3.00	3*	2	3*	3*	3*	2.75
	Pristis microdon	3	3*	3*	3*	3*	3	3.00	3*	1	3*	3*	3*	2.50
	Pristis pectinata	3	3*	3*	3*	3*	3	3.00	3*	3	3*	2	3*	2.83
	Pristis zijsron	3	3*	3	3*	3*	3	3.00	3*	2	1	3*	3*	2.25
Rhinobatidae	*Rhinobatos typus*	3	3*	3	3*	3*	1	2.85	3*	1	1	3*	3	2.00
Rhynchobatidae	*Rhina ancylostoma*	3	3*	2	3	3	1	2.69	3*	1	1	3*	3	2.00
	Rhynchobatus djiddensis	3	1	2	3*	3*	1	2.23	3	2	1	3*	2	2.17
Scyliorhinidae	*Atelomycterus fasciatus*	3	3*	3	3*	3*	1	2.85	2	2	2	3	3	2.25
	Galeus sp. A	3	3*	3*	3*	3*	1	2.85	3*	1	3*	3*	3*	2.50
Sphyrnidae	*Eusphyra blochii*	1	3*	3	2	3	1	2.23	2	1	1	2	2	1.50
	Sphyrna lewini	1	3*	3*	3*	1	1	2.08	3*	2	1	2*	2*	2.00
	Sphyrna mokarran	1	3*	3	3*	2	1	2.23	2	3	1	2*	3	2.08
Squatinidae	*Squatina* sp. A	3	3*	3*	3*	3*	1	2.85	3*	1	3*	3*	3*	2.50
Stegastomatidae	*Stegastoma fasciatum*	3	3*	3*	3	3	3	3.00	2*	2	1	3*	3	2.00

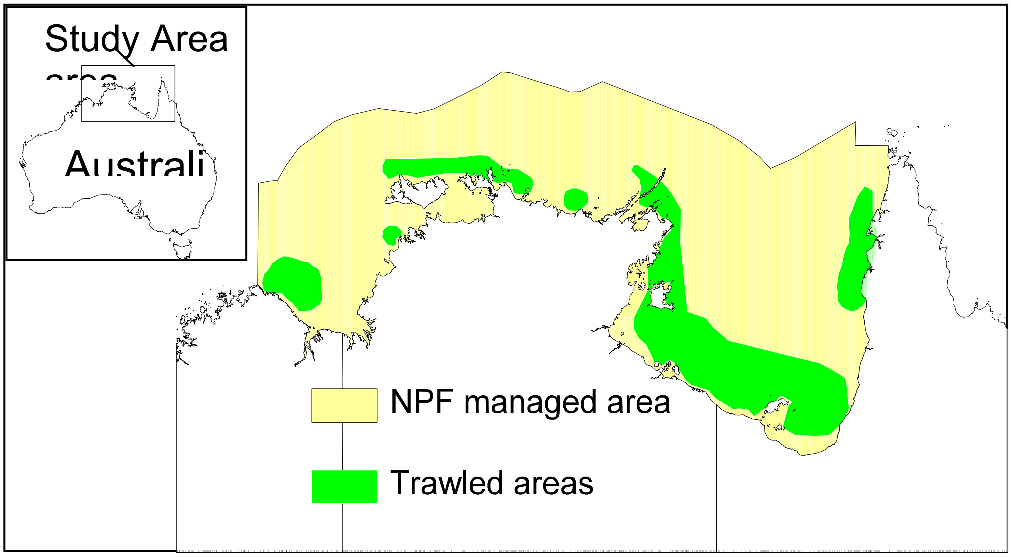

Fig. 1. The managed area of the Australian Northern Prawn Fishery and within this the areas where commercial prawn trawling occurs.

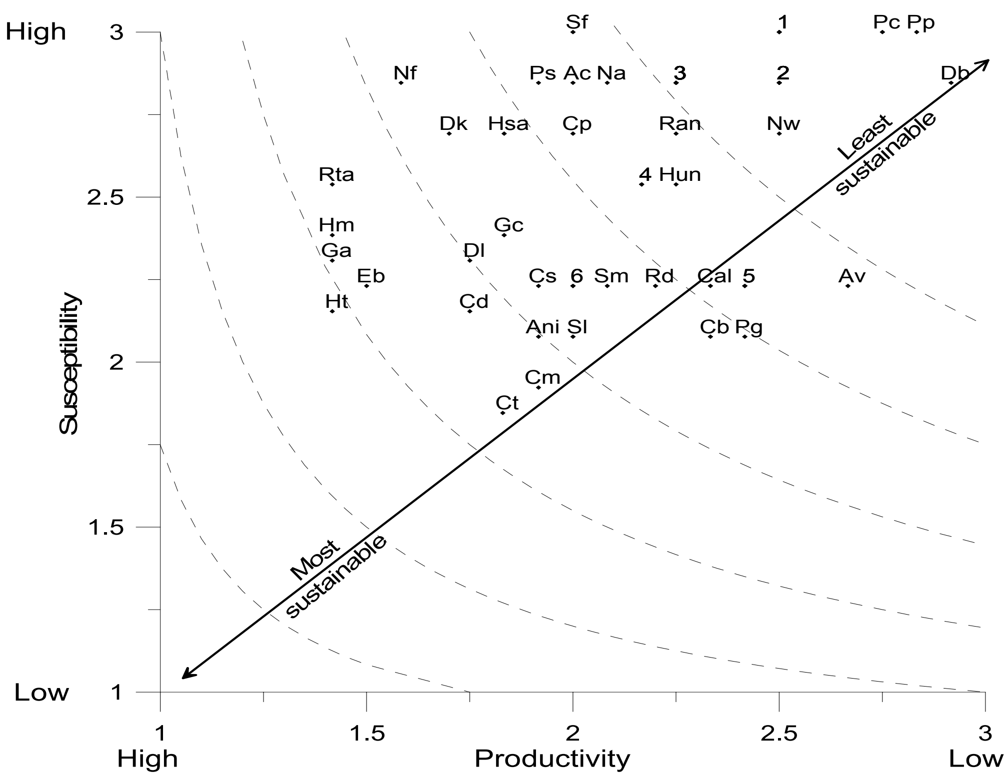

Fig. 2. The ranking of elasmobranch by-catch species with respect to criteria that reflect their susceptibility to capture and mortality due to prawn trawling and their productivity. These factors combine to reflect the relative ability of species to sustain capture as prawn trawl by-catch in the NPF and therefore their relative priority with respect to research and management. The labels follow Table 2 (1 = Hj, Pm, Pz; 2 = Cam, Cle, Dt, Gsa, Ssa, Tm; 3 = Af, Dsa, Hf, Hg Hua, Oo, Rty, Ua; 4 = Cf, Aa; 5 = Ana, Cli; 6 = Rac, He). Modified from Stobutzki *et al.* (2002).