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NOTE

Shark-like batoids in Pacific fisheries: prevalence and conservation concerns

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ABSTRACT: Shark-like batoids are a group of elasmobranchs with a body form similar to that of sharks (i.e. elongate body, well developed caudal and dorsal fins, and head, gill and mouth morphology similar to that of skates and sting rays). Despite a poor understanding of their biology, ecology and resilience to fishing, shark-like batoids are known to have been heavily exploited throughout the Indo-Pacific. Between 2007 and 2009, we recorded the occurrence of shark-like batoid species in the inshore gillnet fishery of Queensland (Australia) across 2 habitat types. *Glaucostegus typus* and *Anoxypristis cuspidata* were most frequently caught in intertidal habitats, whereas *Rhynchobatus* spp. dominated the catch in inshore coastal habitats. Comparison of gillnet catches to research longline sampling showed that not all size classes of shark-like batoids are captured by the gillnet fishery. Given that home-range size and habitat use by elasmobanchs can change between ontogenetic stages and species, vulnerability to fisheries may vary depending on overlap of preferred habitats and fishing activity and whether each size class is susceptible to the gear. Gillnets are highly selective for certain sizes classes; therefore, knowledge of which sizes and thus which life-history stages are susceptible is necessary to effectively regulate the use of this type of fishing gear. Understanding the occurrence and availability of shark-like batoid species to fishing activities and their contribution as bycatch/by-products in fisheries is critical to management and conservation of these species.

KEY WORDS: Shark-like batoid · Fishery · Availability · Bycatch

INTRODUCTION

Globally, batoids have become an increasingly large component of fisheries catch and in some cases have developed into target species in fisheries where they were once considered by-products or bycatch (Ministry of Marine Affairs and Fisheries 2003, White & Dharmadi 2007). Estimates from Indonesia, the world's largest elasmobranch fishing nation, suggest a 19% increase in the proportion of batoids to total elasmobranch catch between 1981 and 2003, with estimated landings in excess of 60 000 t (Ministry of Marine Affairs and Fisheries 2003, White & Dharmadi 2007). Shark-like batoids (families Rhinobatidae, Rhynchobatidae, Rhinidae, Pristidae) are taken for both flesh and fins and are caught by a variety of fishing gears, including trawl, gillnet, trap and seine nets and hooks (Bentley 1996, Chen 1996, White & McAuley 2003a, Compagno et al. 2006), but their presence in fisheries has been poorly studied. Fins of shark-like batoids, known as 'white-fin', are highly prized and are among the most lucrative of elasmobranch products (White & McAuley 2003a, Clarke et al. 2006a,b, Compagno et al. 2006).

Fishing effort for shark-like batoids, particularly from gillnet fisheries, is especially intense in South-

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East Asia (Bentley 1996, Chen 1996), where reductions in populations have been inferred from declining catch rates (White & McAuley 2003a,b). The gillnet fishery around the Aru Islands (Indonesia) grew rapidly from its inception in the 1970s, reaching a boom of 500 boats in the 1980s. Catch rates have steadily declined, as has the number of boats operating in the fishery (Chen 1996). No target fisheries exist for shark-like batoids in Australian waters; however, rhinobatids, rhynchobatids, rhinids and pristids are caught in trawl and gillnet fisheries (Stobutzki et al. 2002, Zhou & Griffiths 2008, Harry et al. 2011). It is unlikely that these species would become targeted in Australian waters given current regulations. However, given their susceptibility to multiple fishing gears and the value of their fins, it is likely that they will continue to be caught as bycatch and by-products in many locations.

Five shark-like batoid species are taken in Queensland (Australia) fisheries, and all are globally threatened based on International Union for Conservation of Nature (IUCN) assessments. The giant shovelnose ray *Glaucostegus typus* has been assessed as Vulnerable based on intensive fishing pressure and population declines in South-East Asia (White & McAuley 2003a). Although fishing effort in Australia is not as intense as in South-East Asia, *G. typus* has been classified as 'high risk' due to distributional overlap with inshore gillnet and prawn trawling fisheries in Western Australia, Northern Territory and Queensland in addition to low reproductive productivity (Salini et al. 2007). Whitespotted guitarfish (*Rhynchobatus* spp. complex) are susceptible to a variety of fishing gears and are thus caught by multiple artisanal and commercial fisheries throughout their range (McAuley & Compagno 2003, White & McAuley 2003b, Compagno & Marshall 2006). Targeted gillnet fisheries for these species in South-East Asia have declined significantly, reportedly due to declining catch rates (Chen 1996, McAuley & Compagno 2003, White & McAuley 2003b, Compagno & Marshall 2006). The intensity of fishing pressure and documented population declines throughout their range has prompted an IUCN classification of Vulnerable for all 3 species in the complex (McAuley & Compagno 2003, White & McAuley 2003b, Compagno & Marshall 2006). Similar to other sawfish (Simpfendorfer 2000, Cavanagh et al. 2003, Carlson et al. 2007), the narrow sawfish *Anoxypristis cuspidata* has suffered substantial reductions in abundance, with populations now fragmented throughout its range (Compagno et al. 2006). Consequently, *A. cuspidata* is listed as Critically Endangered globally (Compagno et al. 2006). *A. cuspidata* has previously been classified as being at high risk of depletion by fisheries operating in northern Australian waters, as it is susceptible to a range of gears, and little information is available regarding its biology (Ministry of Marine Affairs and Fisheries 2003, Peverell 2005, Salini et al. 2007).

The global status of shark-like batoids and the continuing demand for their fins mean that investigation of their interaction with fisheries is important. In this study, we examined the occurrence of this group of species in a gillnet fishery within the Great Barrier Reef World Heritage Area (GBRWHA), Australia, to: (1) determine the species and size composition of the shark-like batoid catch; (2) examine the influence of habitat and season on capture; and (3) determine the availability of these species to net fishing.

MATERIALS AND METHODS

Fishery-dependent sampling

Between March 2007 and December 2009, fishery observers onboard vessels operating in the commercial gillnet sector of the East Coast Inshore Finfish Fishery (ECIFF) within the GBRWHA recorded data on target species, gear type, location, effort and catch composition for 523 net shots. Data were grouped spatially into 2 nominal habitats (intertidal and inshore coastal) that correspond to discrete subcomponents of the ECIFF, each with different target species, fishing practices and management strategies (Harry et al. 2011). Within intertidal habitats (<2 m depth) an array of teleosts (*Lates calcarifer, Eleutheronema tetradactylum, Polydactylus macrochir*) are targeted using gillnets of stretched mesh sizes of 114 to 216 mm and lengths up to 600 m. Fishing in intertidal habitats occurs throughout the day/night and throughout the year. In inshore coastal habitats (>2 m depth), teleosts (mostly scombrids) are targeted during winter and spring, whereas sharks (*Carcharhinus tilstoni, C. limbatus, C. sorrah* and *Sphyrna lewini*) are targeted year-round. Up to 600 m of 165 mm stretched mesh gillnets are used. Shark-like batoids caught were identified and sexed. Length was measured as stretched total length (STL) in mm following Compagno (1984): the animal was placed ventral side down and the upper lobe of the caudal fin was depressed in line with the body axis.

Australian waters host a complex of whitespotted guitarfish species within the Family Rhynchobatidae, consisting of 3 distinct species (*Rhynchobatus aus-*

traliae, *R. laevis* and *R. palpebratus*). Although each of the species within the complex has been assessed as Vulnerable by the IUCN, the extent of individual species' declines and range reductions are hard to quantify given taxonomic confusion (McAuley & Compagno 2003, White & McAuley 2003a, Compagno & Marshall 2006). All 3 species were observed during fisheries-dependent and -independent sampling in the present study. However, visual identification of these species remains inconsistent, with possible changing colouration between life-history stages. Current management strategies within Queensland waters treat the species complex as a single group due to difficulties in identifying species. Thus, we have treated all individuals as a group that will herein be referred to as *Rhynchobatus* spp.

Fishery-independent sampling

Fishery-independent sampling using longline gear was conducted to examine whether the size of shark-like batoids caught in the ECIFF was a function of gear selectivity or distribution and seasonality of species. Longline sampling (268 sets) was conducted in Cleveland Bay (19° 12′ 3′′ S, 146° 54′ 4′′ E), in the central region of the GBRWHA, across all seasons and both habitat types between 30 January 2008 and 10 September 2009. All catch was identified, sexed and measured (STL) to the nearest cm.

Data analysis

A full factorial logistic generalised linear model (GLM) with a binomial error structure and logit link function was used to compare the probability of capture of individual species between seasons and habitats. Models included season (summer: Dec–Feb, autumn: March–Apr, winter: June–Aug, spring: Sept–Nov) and habitat (intertidal, inshore coastal) as factors, with an interaction term combining the 2 factors. Logistic models were used to deal with 0 inflated data typical of catch data. Capture abundance was not incorporated into the models due to low abundance in comparison to target species within the fishery. Chi-squared (χ^2) contingency tables were used to compare proportions of shark-like batoids caught between habitats. Two-sample Kolmogorov-Smirnov (KS) tests determined whether length–frequency distributions were significantly different between habitat types and gears. Data analyses for this study were conducted in the R environment (R Development Core Team 2009). All research activities were conducted under GBRMPA permit number G09/31573.1, G09/2985.1 and Queensland Department of Primary Industries and Fisheries permit number 144482. Treatment of all animals was conducted under ethical guidelines approved by James Cook University animal ethics number A1566.

RESULTS

Fishery-dependent gillnet catch composition

The observed gillnet shots caught 123 shark-like batoids, with *Anoxypristis cuspidata* being the most frequently caught (44.7%, n = 55), followed by *Rhynchobatus* spp. (39.8%, n = 49) and *Glaucostegus typus* (15.4%, n = 19). Catch composition between habitat types was heterogeneous (χ^2 = 40.86, df = 2, $p < 0.001$, Fig. 1a). *A. cuspidata* (n = 42) was most frequently caught in intertidal habitats, followed by *G. typus* (n = 18) and *Rhynchobatus* spp. (n = 12). The reverse was true for inshore coastal habitats, with

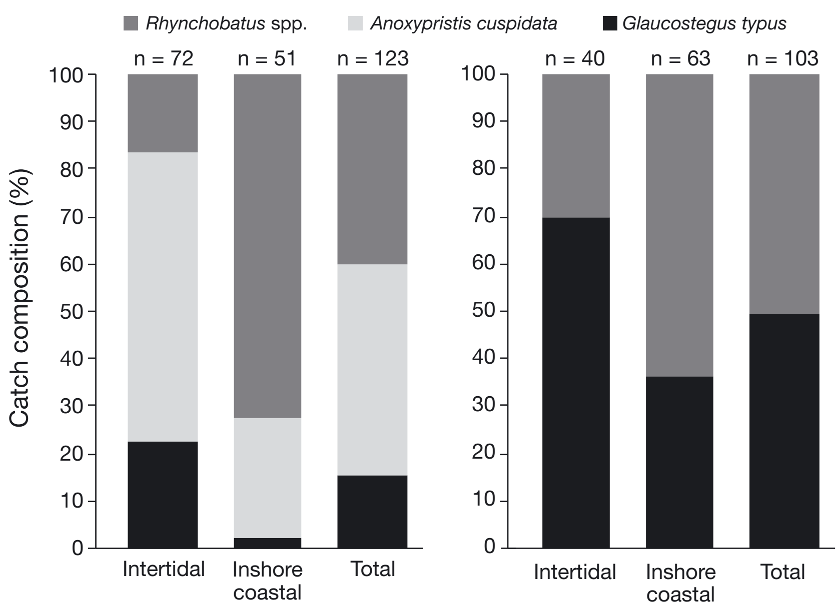


Fig. 1. *Glaucostegus typus*, *Rhynchobatus* spp. and *Anoxypristis cuspidata*. Catch composition of shark-like batoid species from (a) commercial gillnetting and (b) fishery-independent longline sampling

Rhynchobatus spp. (n = 37) most frequently caught, followed by *A. cuspidata* (n = 13) and *G. typus* (n = 1; Fig. 1a).

Fishery-independent longline catch composition

Longline shots captured 51 *Glaucostegus typus* and 52 *Rhynchobatus* spp. No *Anoxypristis cuspidata* were captured although many animals (n = 36) were captured in Cleveland Bay by commercial gillnet activity. Shark-like batoid catch composition was significantly different between habitats ($\chi^2 = 9.68$, df = 1, $p < 0.001$, Fig. 1b). *G. typus* was most frequently caught by longlines in intertidal habitats (70.0%, n = 28), whereas *Rhynchobatus* spp. dominated the catch in inshore coastal habitats (63.5%, n = 40).

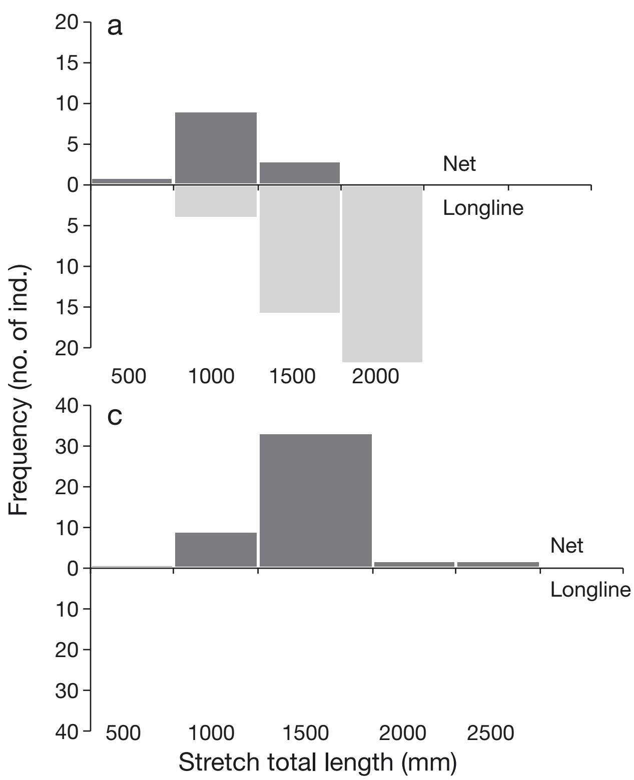
Size distribution of shark-like batoids between fishing gears and habitats

Gillnet-caught *Glaucostegus typus* ranged in size from 450 to 2430 mm (Fig. 2). Comparison of gillnet-caught shark-like batoid size ranges between habitats was not possible due to limited sample size. Despite the infrequency of capture within the inshore coastal habitat, the smallest and largest size classes of *Anoxypristis cuspidata* and *Rhynchobatus* spp. were caught in this habitat.

Glaucostegus typus caught by gillnets were significantly smaller (mean STL = 795 mm, range = 450–1350 mm) than longline-caught individuals (mean STL = 2067 mm, range = 1030–2760 mm; 2-sample KS test, $D = 0.94$, $p < 0.001$, Fig. 2a). Longline caught *G. typus* in intertidal habitat (mean STL = 1949 mm, range = 1030–2700 mm,) were similar in size to individuals caught in inshore coastal habitat (mean STL = 2232 mm, range = 1790–2760 mm; 2-sample KS test, $D = 0.37$, $p = 0.08$). *Rhynchobatus* spp. caught by gillnets (mean STL = 1213 mm, range = 680–2140 mm) were significantly smaller than individuals caught on longlines (mean STL = 1797 mm, range = 800–2310 mm; 2-sample KS test, $D = 0.69$, $p < 0.001$; Fig. 2b). Longline-caught *Rhynchobatus* spp. in intertidal habitats were a similar size (mean STL = 1791 mm, range = 1400–2120 mm) to those from inshore coastal habitats (mean STL = 1845 mm, range = 800–2310 mm; 2-sample KS test, $D = 0.20$, $p = 0.86$).

Probability of capture

Results of GLMs indicated that the probability of capturing *Glaucostegus typus* in gillnets was affected by season (with higher probability of cap-



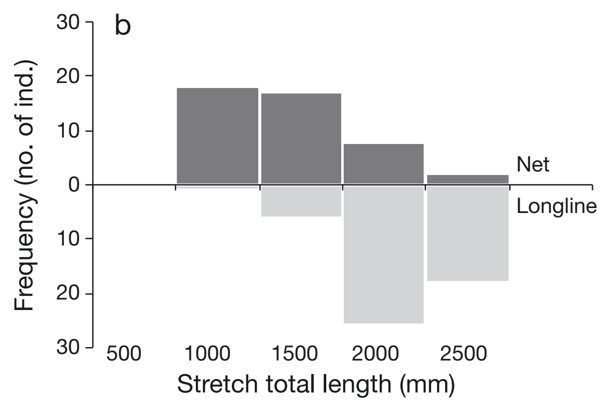


Fig. 2. *Glaucostegus typus*, *Rhynchobatus* spp. and *Anoxypristis cuspidata*. Size distribution of shark-like batoid species caught by gillnet and longline: (a) *G. typus*, (b) *Rhynchobatus* spp., (c) *A. cuspidata.* Note differences in axis scales

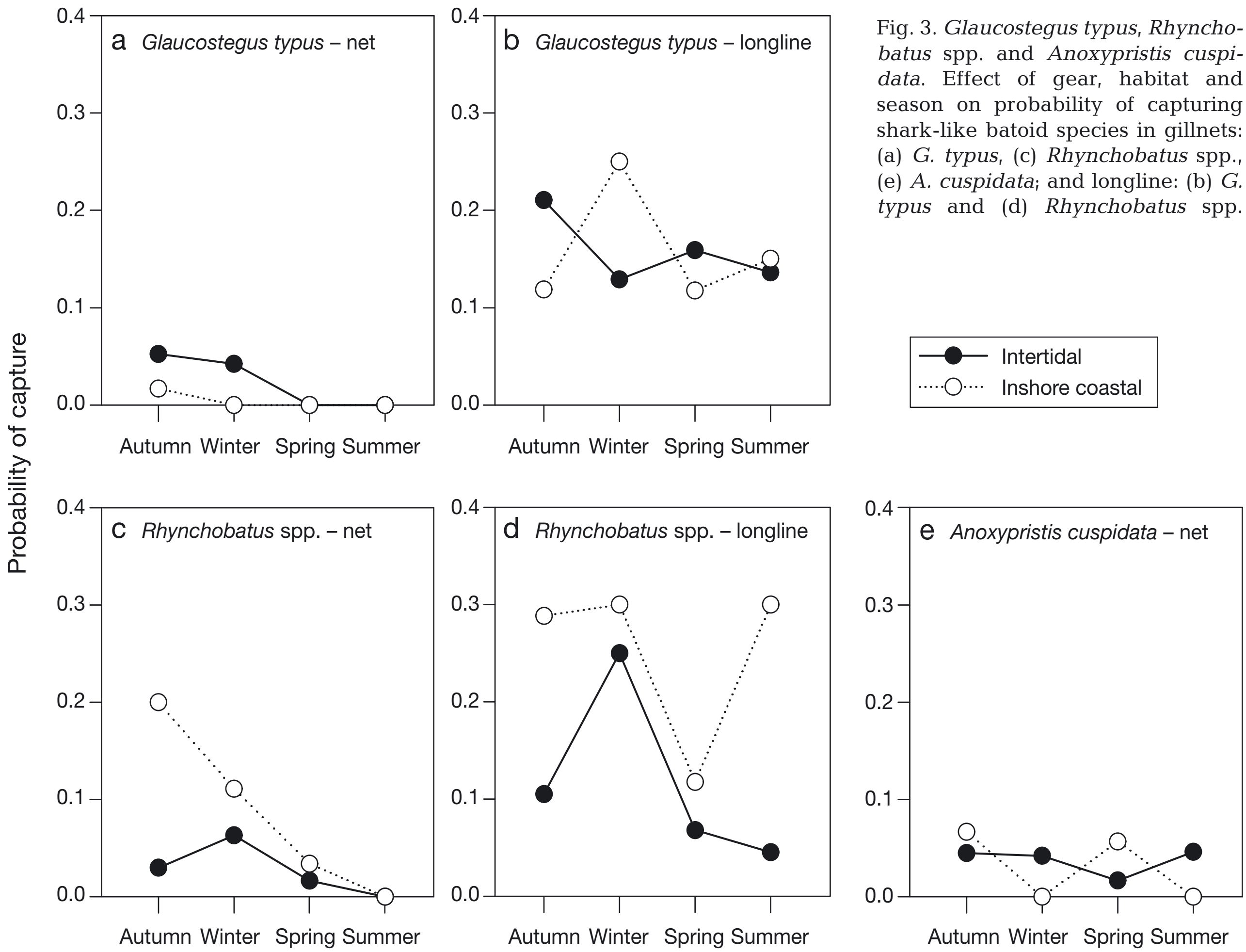


Fig. 3. *Glaucostegus typus*, *Rhynchobatus* spp. and *Anoxypristis cuspidata*. Effect of gear, habitat and season on probability of capturing shark-like batoid species in gillnets: (a) *G. typus*, (c) *Rhynchobatus* spp., (e) *A. cuspidata*; and longline: (b) *G. typus* and (d) *Rhynchobatus* spp.

ture during autumn and winter), but not habitat (Table 1, Fig. 3). The capture probability of *Rhynchobatus* spp. was affected by both season and habitat. Individuals were most likely to be caught in gillnets during summer and winter and less likely to be caught in intertidal than inshore coastal habitats (Table 1, Fig 3). Although habitat type and season affected the probability of capturing *Rhynchobatus* spp., there was no significant interaction between these factors. Capture of *Anoxypristis cuspidata* in gillnets was affected by habitat but not season, and we found no interaction between factors (Table 1, Fig. 3).

The probability of capture for *Glaucostegus typus* on longlines was not affected by season or habitat, and we observed no significant interaction between factors (Table 1, Fig. 3). The probability of capturing *Rhynchobatus* spp. on longlines was affected by habitat with lower catchability in intertidal than inshore coastal habitats. Season did not affect likelihood of capturing *Rhynchobatus* spp. Similar to gill-

Table 1. *Glaucostegus typus*, *Rhynchobatus* spp. and *Anoxypristis cuspidata*. Summary of generalised linear model analysis of shark-like batoid catch probability by gillnets and longlines. p-values < 0.05 indicate the factors that significantly contributed to the probability of a species being caught. Deviance (Dev) is a generalisation of the residual sum of squares.

	Gillnet			Longline		
	Dev	df	p	Dev	df	p
Glaucostegus typus						
Habitat	4.4	2	>0.05	0.2	1	>0.05
Season	18.1	9	>0.05	0.4	4	>0.05
Interaction	1.9	7	>0.05	6.0	3	>0.05
Anoxypristis cuspidata						
Habitat	11.7	2	>0.05	–	–	–
Season	11.3	9	>0.05	–	–	–
Interaction	10.1	7	>0.05	–	–	–
Rhynchobatus spp.						
Habitat	18.1	2	<0.01	16.4	1	<0.001
Season	28.6	9	<0.01	7.9	4	>0.05
Interaction	4.7	7	>0.05	2.4	1	>0.05

nets, no interaction between habitat and season was evident for longline-caught *Rhynchobatus* spp. (Table 1, Fig. 3).

DISCUSSION

Bycatch in gillnets: current situation

Glaucostegus typus, *Rhynchobatus* spp. and *Anoxypristis cuspidata* were all captured by gillnets, revealing that all are available to this gear at some level. The occurrence of these 5 species within Australian fisheries is significant due to our lack of knowledge of the species' biology and movement patterns, and data indicating that these species are heavily harvested in South-East Asia (Chen 1996, White & Dharmadi 2007). If Australian and Asian populations of these species are linked through movement, harvesting in both locations could compound mortality rates and population instability. In addition, the significant bycatch, even if not retained, may contribute to local decline in these species. Reports from observer programmes in Western Australian gillnet fisheries indicate that post-release survival of *A. cuspidata* is very low (R. McAuley pers. comm.), suggesting that the designation of *A. cuspidata* as no-take may have little effect in reducing fishing-related mortality. No information on post-release survival or sub-lethal effects is currently available for the interaction of *G. typus* or *Rhynchobatus* spp. with gillnets.

The size distribution of *Glaucostegus typus* caught in gillnet gear was skewed toward smaller size classes that represent juvenile and sub-adult individuals (Last & Stevens 2009). *Rhynchobatus* spp. caught in the gillnet gear had a wide size range predominantly comprised of immature individuals. In comparison, individuals of both species caught on longlines were skewed toward larger size classes. Under current fishing practices in the ECIFF, *G. typus* may exist in a gauntlet fishery where fishing mortality is restricted to juvenile age classes (Prince 2005). In regions such as Indonesia where gillnets of larger mesh sizes (>20 cm) are used (W. White pers. comm.), larger size classes (2300–3000 mm) of shark-like batoids are caught (White & Dharmadi 2007), and population declines have been observed (White & McAuley 2003b). *Anoxypristis cuspidata* was the most frequent shark-like batoid caught by gillnets. The high catch of *A. cuspidata* can be attributed to their toothed rostrum, which easily entangles in gillnet mesh (Simpfendorfer 2000). Given the high probability of entanglement of sawfish, it is likely that most individuals that interacted with gillnets were retained by them. The mean size of *A. cuspidata* was smaller in intertidal than inshore coastal habitats, which is consistent with findings from other gillnet fisheries operating in Northern Australian waters (Peverell 2005).

Despite being morphologically similar, *Rhynchobatus* spp. and *Glaucostegus typus* were not caught in equal numbers or comparable size classes by gillnet gear. Differences in catch rate may be a function of the way gillnets are used in regions where *Rhynchobatus* spp. are more common than *G. typus.* Gillnets can be selective for the type and size classes of fish they catch (Hamley 1975, Carlson & Cortes 2003), provided that the meshes are taut both vertically and horizontally. However, in the ECIFF, particularly in the inshore coastal component of the fishery, nets are often deeper than the water in which they are deployed. This allows the single mesh size and panel to adopt a bow, creating some of the characteristics of a trammel net. This loose net more easily entangles fish, particularly large-bodied species such as *Rhynchobatus* spp. that may not be enmeshed by a taut net with similar sized mesh. The non-selective entanglement characteristics of gillnets used in this way may explain the increased catch probabilities of *Rhynchobatus* spp.

Current management

The occurrence of shark-like batoids in mixed species fisheries such as the ECIFF is of concern, as elasmobranchs are often poorly reported (Bonfil 1994), which makes quantifying fishing mortality difficult. Where elasmobranch species compose only a small portion of the catch, fishery activity often continues long after their collapse (Graham et al. 2001). In light of these concerns, management recommendations were made for the ECIFF, including species-specific recording of some elasmobranch species (Gunn et al. 2008). Further, current mesh size restrictions limit fisheries interaction of the ECIFF with *Glaucostegus typus* to juveniles. It is unclear whether *Rhynchobatus* spp. are afforded the same protection. Larger *Rhynchobatus* spp. were caught on longlines rather than gillnets, suggesting a possible gauntlet fishery. However, despite limited information regarding the biology of these species, it is thought that members of the *Rhynchobatus* spp. complex do have different sizes of maturity (Last & Stevens 2009), making size a poor proxy for life-history stage. It is therefore unlikely that a gauntlet fishery exists for all members of the *Rhynchobatus* spp. complex encountered in the ECIFF.

Anoxypristis cuspidata and *Rhynchobatus* spp. were recommended to be made no-take species in the ECIFF (Gunn et al. 2008). Only *A. cuspidata* was made no-take, whilst bag limits have been imposed for *Rhynchobatus* spp. (5 trip^{-1}). Bag limits imposed to reduce fishing pressure may result in 'high grading', whereby smaller individuals retained by the fisher are disposed of so that larger, more valuable individuals can be marketed (Davis 2002). Under these circumstances, the ability to accurately assess impacts of fishing activity would be limited; additionally, the regulations (e.g. bag limits) imposed to prevent overfishing would be ineffective (Coggins et al. 2007). Further, classification of *A. cuspidata* as a no-take species may result in cryptic mortality, with fishers unwilling to report negative interactions. Reduction of fishing effort is the most effective solution for mitigating cryptic mortality (Pollock & Pine 2007). Unreported bycatch remains the greatest challenge for fisheries management (Alverson et al. 1994), and while it persists, the ability of managers to accurately estimate fishing mortality and assess population stability of non-target species will remain limited.

Insufficient data regarding the biology of bycatch species and their availability and occurrence in fisheries is a significant hindrance to assessing the viability of a population under existing fishing regimes, especially for elasmobranchs (Frisk et al. 2001). It is unclear what the ecological impact of fishing mortality sustained at the rate observed in this study will be on the long-term stability of shark-like batoid populations. Although we examined extensive observer survey data from the ECIFF, they represent only a small proportion of the total fishing effort and, consequently, total fishing mortality currently experienced by shark-like batoids within the GBRWHA. Amid fears for the long-term stability of these populations, semi-quantitative risk assessments have been conducted to assess susceptibility to current fishing regimes in Australian waters (Stobutzki et al. 2002, Salini et al. 2007, Zhou & Griffiths 2008). However, in the absence of information detailing life-history characteristics, demographic population modelling and taxonomic resolution in species identification of *Rhynchobatus* spp., the true impact of fisheries mortality is difficult to quantify. A clear understanding of the biology, ecology, species status and harvest by fisheries will be key to effective management of these species.

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