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Elasmobranch captures in the Fijian pelagic longline fishery

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ABSTRACT

1. Pelagic longline fisheries for relatively fecund tuna and tuna-like species can have large adverse effects on incidentally caught species with low-fecundity, including elasmobranchs.

2. Analyses of observer programme data from the Fiji longline fishery from 2011 to 2014 were conducted to characterize the shark and ray catch composition and identify factors that significantly explained standardized catch rates. Catch data were fitted to generalized linear models to identify potentially significant explanatory variables.

3. With a nominal catch rate of 0.610 elasmobranchs per 1000 hooks, a total of 27 species of elasmobranchs were captured, 48% of which are categorized as Threatened under the IUCN Red List. Sharks and rays made up 2.4% and 1.4%, respectively, of total fish catch. Blue sharks and pelagic stingrays accounted for 51% and 99% of caught sharks and rays, respectively.

4. There was near elimination of ‘shark lines’, branchlines set at or near the sea surface via attachment directly to floats, after 2011.

5. Of caught elasmobranchs, 35% were finned, 11% had the entire carcass retained, and the remainder was released alive or discarded dead. Finning of elasmobranchs listed in CITES Appendix II was not observed in 2014.

6. There were significantly higher standardized shark and ray catch rates on narrower J-shaped hooks than on wider circle hooks. Based on findings from previous studies on single factor effects of hook width and shape, the smaller minimum width of the J-shaped hooks may have caused the higher shark and ray catch rates. For sharks, the effect of hook width may have exceeded the effect of hook shape, where small increases in shark catch rates have been observed on circle vs J-shaped hooks.

7. Shark and ray standardized catch rates were lowest in the latter half of the year. Focusing effort during the second half of the year could reduce elasmobranch catch rates.

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INTRODUCTION

Mortality in pelagic fisheries directly impacts both market and non-market species, and can have broad effects on community and ecosystem structure, processes and stability (Goñi, 1998; Stevens *et al.*, 2000; Piovano *et al.*, 2009, 2010;

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Gilman *et al.*, 2013a, b; Polovina and Woodworth-Jefcoats, 2013). Fisheries that target species with r-selected life-history characteristics, including high fecundity, fast growth, and high natural mortality rates, such as tuna and tuna-like species (Scombridae), can have strong effects on incidentally caught species with k-selected life-history strategies, including low fecundity and slow growth, such as elasmobranchs (Dulvy *et al.*, 2008; Gilman, 2011; Croll *et al.*, 2015). As a result of their life-history characteristics and behaviours such as forming aggregations for mating and pupping and at nursery grounds, elasmobranchs and other k-selected species have low resistance and resilience to even low levels of anthropogenic sources of mortality (Casey and Myers, 1998; Musick, 1999; Hall *et al.*, 2000; Stevens *et al.*, 2000; Dulvy *et al.*, 2008). Longline fishing mortality affects the abundance of pelagic sharks much more strongly than most other pelagic apex predator species, where even moderate fishing mortality rates can trigger large population declines for some species (Musick *et al.*, 2000; Kitchell *et al.*, 2002).

Some species of elasmobranchs captured in pelagic longline fisheries are at risk of global extinction, and some populations are at risk of extirpation (Dulvy *et al.*, 2014; IUCN, 2015). There has been increasing concern in recent decades over the sustainability of elasmobranch mortality rates in pelagic longline fisheries, over the broad, community- and ecosystem-level effects from declines in abundance of species and sizes of elasmobranchs selectively caught by pelagic longline fisheries, as well as over the adverse socio-economic effects on longline fisheries from shark interactions (Musick *et al.*, 2000; Stevens *et al.*, 2000; Ward and Myers, 2005; Clarke *et al.*, 2006, 2011, 2013, 2014; Dulvy *et al.*, 2008; Ferretti *et al.*, 2008, 2010; Gilman *et al.*, 2008a, 2012; Mandelman *et al.*, 2008; Cortes *et al.*, 2010; Worm *et al.*, 2013). Longline fishing mortality of some elasmobranch species has the capacity to be sustainably managed if robust harvest strategies were adopted and there was high compliance with harvest controls (Walker, 1998; Musick *et al.*, 2000).

Mitigating fishing mortality of incidentally caught species that are relatively vulnerable to extinction owing to their life-history characteristics and susceptibility to capture and mortality in fisheries, which is one element of ecosystem-based fisheries management, has received substantial international attention since the late 1990s (Clarke *et al.*, 2014; Gilman *et al.*, 2014). A range of effective and commercially viable methods to mitigate problematic pelagic longline bycatch has been developed, although there has been mixed progress in uptake of these best practices (Gilman, 2011; Piovano *et al.*, 2012; Gilman *et al.*, 2014).

With increasing pelagic fishing catch and effort since the early 1950s, biomass and exploitation rate limit reference points of some stocks of main market species of tunas have been exceeded (Williams and Terawasi, 2014; ISSF, 2015). While the observed declines in abundance of highly fecund, broadcast spawning, market species are unlikely to result in irreparable harm or loss of populations, longline fisheries may cause broader protracted or permanent changes to the structure and functioning of pelagic ecosystems (Myers *et al.*, 1999; Essington, 2010; Gilman *et al.*, 2013a). There is increasing understanding of community- and ecosystem-level effects of the selective removals of pelagic apex predators by pelagic longline fisheries, largely from species- and more recently size-based ecosystem trophic interaction models and some empirical studies (Cox *et al.*, 2002; Kitchell *et al.*, 2002; Hinke *et al.*, 2004; Polovina *et al.*, 2009; Polovina and Woodworth-Jefcoats, 2013). Collateral, indirect effects of pelagic longline and other tuna fisheries include, for example, altered pelagic trophic structure and processes, where the selective removal of older age classes of a subset of species of a pelagic ecosystem apex predator guild has cascading effects on the pelagic ecosystem food web. For example, pelagic longline selective removal of apex predators has resulted in a top-down trophic effect by releasing pressure and increasing abundance of mid-trophic level species, altering the ecosystem size structure with a decline in abundance of large-sized species of fish and increase in abundance of smaller-sized species, and possibly altering the length–frequency distribution of populations subject to fishing mortality (Ward and Myers, 2005; Gilman *et al.*, 2012). The selective removal of some species from the pelagic ecosystem apex predators guild may alter the relative abundance of species within this trophic level, while the selective removal of large individuals could be a driver favouring genotypes for maturation at an earlier age, smaller-size and slower-growth, potentially altering the length–frequency distributions (size structure) and evolutionary characteristics of affected populations (Stevens *et al*., 2000; Ward and Myers, 2005; Zhou *et al*., 2010; Gilman *et al*., 2012).

Previous studies that have assessed elasmobranch catches in longline fisheries have largely been from developed countries, with very few papers focusing or including the Pacific Small Island Developing States (Gilman *et al*., 2008b, 2015; Bromhead *et al*., 2012; Godin *et al*., 2012; Favaro and Cote, 2015). Fiji, in the south-west Pacific Ocean, is composed of about 300 islands and has an exclusive economic zone (EEZ) of about 1 290 000 km^2. Its national commercial fishery focuses on tunas captured by pelagic longline gear. The domestic industrial tuna longline fleet developed in the 1990s and in these last 20 years has targeted primarily albacore tuna (Gillett, 2007; Fiji Offshore Fisheries Division, 2015). In 2014, there were 60 longline vessels licensed to fish in the Fiji EEZ, of which 50 were Fiji-flagged, and an additional 45 Fiji-flagged vessels were authorized to fish exclusively on the high seas and in EEZs of other Pacific Island States (Fiji Offshore Fisheries Division, 2015). In 2014, the Fiji national fleet landed 6703t of albacore tuna (50% of total retained catch), 3558t of yellowfin tuna (26%), 1560t of bigeye tuna (12%), and 1667t of other market species (billfishes and tuna-like species, 12%) (Fiji Offshore Fisheries Division, 2015). The Fiji albacore tuna longline fishery was certified according to the Marine Stewardship Council standards on 13 December 2012. Between 1999 and 2005, an estimated 78–90% of caught sharks were finned and their carcasses discarded (SPC unpublished data cited in Thomson, 2007).

The goal of this study was to assess the impact of the Fijian longline fishery on elasmobranchs by analysing the Fiji Observer Programme 2011–2014 dataset (1) to identify the groups of sharks (Selachii) and rays (Batoidea) most heavily caught, and (2) to identify potentially significant variables influencing catch rates of Selachii and Batoidea. Findings will help to improve the understanding of elasmobranch longline fishing mortality in Pacific Small Island Developing States.

METHODS

Data

Fiji Observer Programme (FOP) data for the Fiji longline tuna fishery were analysed. The Fiji longline observer programme dataset is subject to government confidentiality restrictions for the protection of confidential fisheries statistics. Third parties require authorization from Fiji Department of Fisheries to obtain access to data.

FOP data provided for this study by the Fiji Department of Fisheries, Offshore Division, covered 2367 longline sets, 85.80% targeting tunas, 0.08% targeting both tunas and swordfish, and 1.27% targeting both tunas and sharks. No information on target species was recorded for the remaining 12.85% of the sets. The study period, based on availability of FOP data for the Fiji longline fishery, was from January 2011 to December 2014. During this period, the observer coverage rate increased from 3.0% to 16.7% (Fiji Offshore Fisheries Division, 2015). FOP adheres to the Secretariat of the Pacific Community data collection protocols for tuna fishery observer programmes (SPC, 2011) and Fiji's observers are certified under the SPC/FFA PIRFO standards (Fiji Offshore Fisheries Division, 2013).

Statistical analysis

Generalized linear models (GLMs) were used to identify potentially significant variables influencing catch rates of Selachii and Batoidea in longline sets targeting only tunas (2031 sets). Only sets with information for all variables selected for inclusion as GLM terms were included in the study sample (1679 sets). Explanatory variables considered for inclusion in the model were the continuous variable 'number of hooks' (centring was done before the analysis) and factors 'type of hook' (J-shaped hooks, including J and Japanese tuna hooks; circle hooks; and sets employing a mix of

J-shaped and circle hooks in various proportions); 'bait size' (weight was used for this variable, which included two categories of small and large baits, determined using the median of weights used per set); 'branchline distance' (the distance between two consecutive branchlines was used; the variable was made up of two categories of short and long distance determined using median branchline distance in a set); 'year' (2011, 2012, 2013 and 2014); and 'quarter' (four 3-month periods categories were used: 1st quarter: January–March, 2nd quarter: April–June, 3rd quarter July–September, 4th quarter: October–December). The best fitting model was selected based on analysis of Akaike's Information Criterion (AIC), where the model with the lowest AIC value and the smallest difference in AIC values (ΔAIC) had the best fit to the dataset. GLMs were run with R statistical software version 3.2.0 (R Core Team, 2015) with packages doBy (Højsgaard and Halekoh, 2014), pscl (Jackman, 2015) and MASS (Venables and Ripley, 2002).

RESULTS

In total, 3859 elasmobranch captures were recorded, with an overall nominal catch per unit effort (CPUE) of 0.610 elasmobranchs per 1000 hooks (Table 1). Of the 3815 elasmobranchs observed captured for which information on the fate was recorded, 34.6% had fins retained and the remaining carcass discarded, 10.9% had the entire carcass retained, 45.8% were released alive, and 8.7% were discarded dead.

Selachii

Selachii constituted 2.4% of the total number of fish captured and composed 62.6% of the overall number of elasmobranchs caught. In total, 27

Table 1. Elasmobranchs capture per unit of effort (CPUE number of shark captures per 1000 hooks), separated for subclass, family (in alphabetical order) and species (in alphabetical order)

	Common English name	Scientific name	CPUE per 1000 hooks	IUCN category
Batoidea				
Dasyatidae	Pelagic stingray	*Pteroplatytrigon violacea*	0.2252	LC
Mobulidae	Giant oceanic manta ray	*Manta birostris*	0.0021	VU
Selachii				
Alopiidae	Pelagic thresher	*Alopias pelagicus*	0.0022	VU
	Bigeye thresher	*Alopias superciliosus*	0.0081	VU
	Thresher shark	*Alopias vulpinus*	0.0003	VU
Carcharhinidae	Silvertip shark	*Carcharhinus albimarginatus*	0.0022	NT
	Grey reef shark	*Carcharhinus amblyrhynchos*	0.0013	NT
	Bronze whaler	*Carcharhinus brachyurus*	0.0100	NT
	Silky shark	*Carcharhinus falciformis*	0.0430	NT
	Galapagos shark	*Carcharhinus galapagensis*	0.0003	NT
	Blacktip shark	*Carcharhinus limbatus*	0.0027	NT
	Oceanic whitetip shark	*Carcharhinus longimanus*	0.0174	VU
	Blacktip reef shark	*Carcharhinus melanopterus*	0.0003	NT
	Sandbar shark	*Carcharhinus plumbeus*	0.0016	VU
	Tiger shark	*Galeocerdo cuvier*	0.0014	NT
	Blue shark	*Prionace glauca*	0.1932	NT
	Whitetip reef shark	*Triaenodon obesus*	0.0005	NT
Dalatiidae	Kitefin shark	*Dalatias licha*	0.0002	NT
	Cookiecutter shark	*Isistius brasiliensis*	0.0014	LC
Lamnidae	Great white shark	*Carcharodon carcharias*	0.0002	VU
	Shortfin mako	*Isurus oxyrhinchus*	0.0670	VU
	Longfin mako	*Isurus paucus*	0.0144	VU
Somniosidae	Velvet dogfish	*Zameus squamulosus*	0.0003	
Sphyrnidae	Scalloped hammerhead	*Sphyrna lewini*	0.0030	EN
	Great hammerhead	*Sphyrna mokarran*	0.0019	EN
	Smooth hammerhead	*Sphyrna zygaena*	0.0024	EN
Triakidae	Whiskery shark	*Galeorhinus galeus*	0.0005	VU

IUCN category (LC = Least Concern, NT = Near Threatened, VU = Vulnerable, EN = Endangered) is provided for those species with adequate data (IUCN, 2015).

species of Selachii were observed captured (Table 1). Blue shark *Prionace glauca* was the predominant Selachii captured (50.6% of Selachii).

A number of distributions were initially considered to model the count data in a GLM framework (Zuur *et al.*, 2009): Poisson, zero-altered Poisson (ZAP), negative binomial (NB) and zero-altered negative binomial (ZANB). The Poisson distribution is commonly used to model count data, but initial model explorations indicated that the observed counts were zero-inflated. A hurdle model using a ZAP distribution was then used, which substantially improved the fit. Hurdle models are designed to account for two different processes being responsible for captures (versus non-capture) and for the number of fish captured (i.e. a different process is responsible for influencing the number of captures). Owing to overdispersion, a NB model was fitted, which further improved the fit compared with the Poisson models. Finally a hurdle model using a ZANB distribution was applied, which resulted in a small but significant additional increase in model fit (Table 2).

All four models were clearly distinguishable based on ΔAIC values (Table 2). The ZANB model best explained shark captures (Table 2). ZANB is a hurdle model that models the probability that a zero value (no capture) is observed based on zeros (no capture of sharks on the set) versus non-zeros (at least one capture of sharks in a set). Probability of capture was significantly influenced by quarter and type of hooks (Table 3). The odds ratio was 0.7220 (95%

Table 2. Model comparison using Akaike's Information Criterion (AIC). Models compared used Poisson distribution (Poisson), zero-altered Poisson distribution (ZAP), negative binomial distribution (NB) and zero-altered negative binomial (ZANB).

	AIC	ΔAIC
Selachii		
ZANB	4700.03	0.00
NB	4707.03	7.00
ZAP	4978.84	278.81
Poisson	5435.96	735.93
Batoidea		
ZANB	3542.35	0.00
NB	3570.47	28.12
ZAP	3570.57	28.22
Poisson	3887.14	344.79

Table 3. Significant variables modelled with ZANB (with coefficient estimate, standard error SE, and probability P). (A) Zeros component (binomial distribution). (B) Count component (truncated negative binomial distribution)

		Selachii						Batoidea					
		Zeros component			Counts component			Zeros component			Counts component		
		Coefficient estimate	SE	P	Coefficient estimate	SE	P	Coefficient estimate	SE	P	Coefficient estimate	SE	P
Year	2013				1.5309	0.4995	0.002						
Quarter	2nd quarter										−0.2746	0.1216	0.024
	3rd quarter	−0.3257	0.1480	0.028	−0.5550	0.1622	<0.001	−0.6988	0.1457	<0.001	−0.6988	0.1457	<0.001
	4th quarter	−0.5379	0.1524	<0.001	−0.3667	0.1720	0.033	−0.9240	0.1652	<0.001	−0.8074	0.1681	<0.001
Type of hooks	J	0.4127	0.1356	0.002				1.3645	0.1455	<0.001	0.7393	0.1234	<0.001
	Mix	0.6714	0.1890	<0.001							0.6334	0.1686	<0.001
Number of hooks		0.0003	<0.001	<0.001				0.0002	0.0001	0.018	0.0003	0.0001	0.011
Bait size	Small bait							0.3246	0.1215	0.008	0.4778	0.1157	<0.001
Branchline distance	Short							−0.4831	0.1162	<0.001	−0.2511	0.1118	0.025

CI: 0.5402–0.9650) in the 3rd quarter of the year and 0.5840 (95% CI: 0.4332–0.7872) in the 4th quarter, compared with the 1st quarter of the year, which was used as the reference category for this factor. The odds ratio of a capture in sets using only J-shaped hooks was 1.5109 (95% CI: 1.1584–1.9708) relative to sets using only circle hooks, and 1.9569 (95% CI: 1.3511–2.8344) for sets using a mix of J-shaped and circle hooks, again relative to sets with 100% circle hooks. The second part of ZANB modelled the non-zero observations by excluding the zero values with a truncated negative binomial distribution. The number of captures was significantly influenced by factors year and quarter, and by the covariate number of hooks (Table 3). In detail, the odds ratio for the number of captures in 2013 was 4.6221 (95% CI: 1.7365–12.3028) that in 2011. With respect to quarter, the odds ratio for the number of sharks captured in the 3rd quarter was 0.5741 (95% CI: 0.4177–0.7889) that in the 1st quarter of the year, and in the 4th quarter the odds ratio was 0.6930 (95% CI: 0.4947–0.9709) that in the 1st quarter. The odds ratio for the number of sharks captured also increased with increasing number of hooks per set (1.0003, 95% CI: 1.0001–1.0004).

Shark species in CITES appendix II

Captures of oceanic whitetip shark Carcharhinus longimanus

When using the full dataset, which includes longline sets targeting both tunas and sharks, for the period 2011–2012, all 17 oceanic whitetips captured were discarded after finning (a practice in which fins are removed and retained, while the rest of the body is discarded at sea). In 2013, 62 oceanic whitetips were captured, of which for 13% the entire fish was retained, 60% were discarded after finning, 8% were discarded dead and 19% were released alive. Of the 30 whitetip sharks captured in 2014, for 7% the entire fish was retained, 3% were discarded after finning, 27% were discarded dead and 63% released alive (Figure 1).

Captures of hammerhead sharks Sphyrna lewini, Sphyrna mokarran *and* Sphyrna zygaena

When using the full dataset, 46 hammerhead sharks were captured in the period 2011–2014, 87% of which were caught during 2013. The majority of hammerheads (80%) were discarded after finning (Figure 2). In 2014 only two hammerheads were observed captured, of which one was retained and the other released alive.

Captures of great white shark Carcharodon carcharias

A single specimen was captured in 2013, which was finned.

Batoidea

Batoidea constituted 1.4% of the total number of fish captured and 37.4% of the total number of captured elasmobranchs. Pelagic stingrays *Pteroplatytrigon violacea* made up 98.7% of the rays (Table 1).

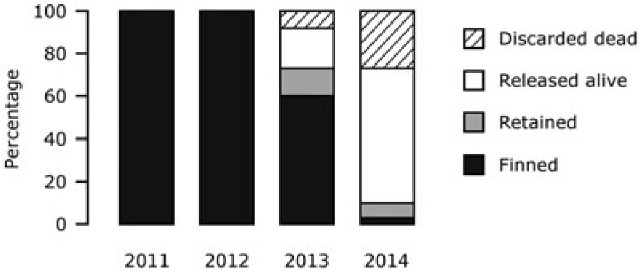

Figure 1. Fate of oceanic whitetip sharks *Carcharhinus longimanus* after capture in the longline gear (expressed as percentage per year, N = 109).

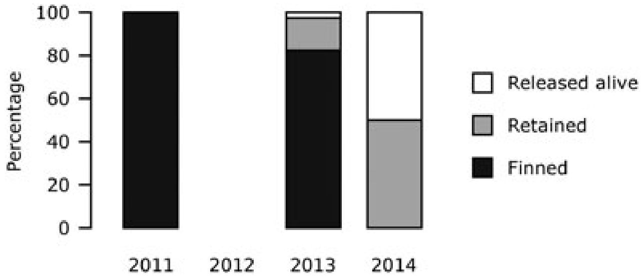

Figure 2. Fate of hammerhead sharks *Sphyrna lewini*, *Sphyrna mokarran* and *Sphyrna zygaena* after capture in the longline gear (cumulative data expressed as percentage per year, N = 46).

As was done for the Selachii, a number of distributions were initially considered to model the Batoidea count data in a GLM framework: Poisson, ZAP, NB and ZANB.

Models were clearly distinguishable based on ΔAIC values except ZAP and NB (Table 2), for which ΔAIC was 0.10. The best fitting model to explain rays captures was ZANB, which scored the lowest AIC. As explained previously in the Selachii section, ZANB is a hurdle model that allows the separation of variables influencing the probability of a capture (using the category 0 for no capture and the category 1 for at least one capture recorded in a set) from those that influence the number of captures (where only observation of captures are used, and no capture observations are excluded). Probability of capture was significantly influenced by several factors (quarter, type of hooks, bait size, and branchline distance) and by the continuous variable number of hooks (Table 3). The odds ratio of a capture in the 3rd quarter was 0.2503 (95% CI: 0.1807–0.3466), compared with the 1st quarter, while the odds ratio of capture in the 4th quarter was 0.3969 (95% CI: 0.2872–0.5487) relative to the 1st quarter. The odds ratio of capture on J-shaped hooks was 3.9137 (95% CI: 2.9427–5.2053) relative to sets using only circle hooks. The odds ratio for small bait was 1.3834 (95% CI: 1.0903–1.7554), and that of short branchlines distance (a proxy to indicate shallower hook soak depth) was 0.6168 (95% CI: 0.4912–0.7746). The odds ratio of a capture with an increasing number of hooks per set was 1.0002 (95% CI: 1.00004–1.0004). The same factors (quarter, type of hook, bait size, and branchline distance) and the continuous variable number of hooks per set also significantly influenced the number of rays captured (Table 3). The odds ratio of the number of rays captured was 0.7599 (95% CI: 0.5988–0.9644) in the 2nd quarter of the year, 0.4972 (95% CI: 0.3737–0.6616) in the 3rd quarter, and 0.4460 (95% CI: 0.3208–0.6200) in the 4th quarter, relative to the 1st quarter. For the type of hook, the odds ratio of number of captures on sets with 100% J-shaped hooks was 2.0945 (95% CI: 1.6447–2.6674) relative to sets using only circle hooks, and was 1.8840 (95% CI: 1.3538–2.6218) for sets using a mix of circle and J-shaped hooks relative to sets using only circle hooks. The odds ratio for small bait size was 1.6122 (95% CI: 1.2805–2.0227), and 0.7780 (95% CI: 0.6249–0.9686) for short branchline distance. The odds ratio for the number of rays captured also increased with increasing number of hooks per set (1.0003, 95% CI: 1.0001–1.0005).

Ray species in CITES appendix II

Captures of manta ray Manta birostris

Using the full dataset, which includes longline sets targeting both tunas and sharks, 13 manta rays were captured in the period 2011–2014, of which 77% were captured during 2014. 39% of manta rays were finned with the remaining carcass discarded (Figure 3).

DISCUSSION

On-board observers recorded the use of ‘shark lines’ in more than half of observed sets in 2011 (59% of sets monitored), while in the next 2 years it dropped to about 1% (0.8% in 2012 and 1.1% in 2013). In 2014 there were no records of shark line use. This rapid decline in shark line use was likely a response to a national ban on shark lines that came into effect in 2012 (Fiji Offshore Division, 2013). This preceded the adoption in 2014 of a replacement conservation and management measure (CMM) on sharks by the Western and Central Pacific Fisheries Commission (WCPFC) that allowed parties, including Fiji, to either ban the use of wire leaders on branchlines or the use of shark lines (WCPFC, 2014). Shark lines place baited hooks near the surface by attaching branchlines directly to floats instead of to the

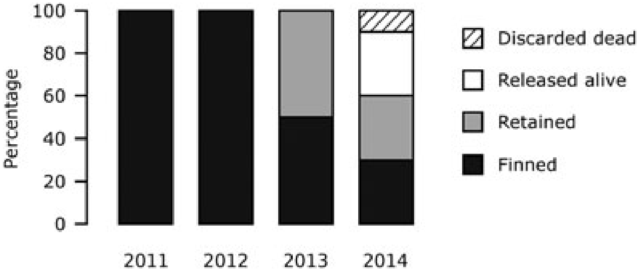

Figure 3. Fate of manta ray Manta birostris *after capture in the longline gear (expressed as percentage, N = 13).*

mainline, and large pieces of tuna or incidental catch are often used for bait. Catch rates of some shark species on shark lines have been found to be significantly higher and haulback survival rates significantly lower than on hooks between floats (Bromhead *et al*., 2012; Caneco *et al*., 2014; Gilman and Hall, 2015). Banning shark lines effectively reduces shark catch rates and does not pose a conflict with by-catch mitigation of other taxonomic groups of conservation concern (Gilman *et al*., 2016).

Hook type had a significant effect on capture probability for both shark and ray standardized catch rate models. The odds of shark capture on sets that used only J-shaped hooks were about 1.5 times greater than on sets that used only circle hooks. Sets using only J-shaped hooks had even greater odds of capturing rays, estimated to be about 4 times higher than sets using only circle hooks. There are potential confounding factors in this variable, because several sizes of hooks with different minimum widths were deployed, even within the same set, and because the J-shaped hook category included both Japanese tuna hooks and J hooks, which both have a point directed away from the shank, but have differences in other design elements (e.g. Japanese tuna hooks have a bend in the upper portion of the shank, J hooks have a straight shank). Hook shape and minimum width have been documented to significantly affect shark and ray catch rates (reviewed in Gilman and Hall, 2015; Gilman *et al*., 2016). Most previous studies have found higher shark catch rates on circle hooks than on J-shaped hooks, and lower ray catch rates the wider the hook (Vega and Licandeo, 2009; Ward *et al*., 2009; Piovano *et al*., 2010; Curran and Beverly, 2012; Serafy *et al*., 2012; Andraka *et al*., 2013). However, as in the current study, most of these past studies had simultaneous variability in hook shape and width, leader material and other potentially significant explanatory variables. Circle hooks tend to result in lower rates of foul hooking and tend to catch in the corner of the mouth, while J-shaped hooks tend to result in deep hooking. Owing to the prevalent hooking location, when non-wire leaders are used, J-shaped hooks are expected to result in lower shark catch rates than circle hooks, as deeply-hooked sharks are able to bite through the non-wire leader, while mouth-hooked sharks cannot escape by biting through the leader. For species that tend to be caught by ingesting a baited hook, hook size affects susceptibility to capture, as the larger the hook, the lower the probability that an organism can fit it in its mouth (Yokota *et al*., 2012).

Type of hooks, bait size and branchline distance influenced the number of rays captured but not that of sharks. In sets using J-shaped hooks (either all hooks were J-shaped or a portion of the hooks were J-shaped), the use of small bait resulted in an increased capture rate of rays, while short branchline distance (<17 m) (an indicator that the gear soaked at a relatively shallow soak depth), decreased the odds of ray capture. While no significant interaction among these factors was observed in the current study, J-shaped hooks and small-sized bait were found to be associated with a higher capture rate of pelagic stingrays in a longline fishery in the Mediterranean Sea (Piovano *et al*., 2010). In accordance with a WCPFC CMM designed to reduce sea turtle bycatch (WCPFC, 2008), Fiji Fisheries Offshore Division has required the use of dehookers for turtles hooked in the mouth or foul hooked in the body, and line-cutters when hooks are ingested deeply (Fiji Offshore Division, 2013). The measure also prescribes sea turtle bycatch mitigation measures by shallow-set longline fisheries targeting swordfish (either use ‘large’ circle hooks, fish bait, or other measure approved by the Commission). Even though this requirement was not prescribed for use by longline fisheries targeting tunas, the Fiji Fisheries Offshore Division has encouraged the use of circle hooks by the Fiji longline fishery in order to contribute to reducing sea turtle bycatch (Fiji Offshore Division, 2013, 2015).

The variable number of hooks per set was a significant term in the standardized shark and ray catch rate models. The number of hooks deployed per set is a measure of relative longline fishing effort routinely included in catch rate standardization models. Based on the observed effect of this variable, a reduction in the number of vessels and/or a reduction in the number of larger vessels, which are capable of deploying a larger number of hooks per set and to fish in less favourable weather conditions than smaller vessels, would reduce shark and ray catch levels. The number of Fiji-licensed longline vessels decreased from 121 in 2011 to 105 in 2014, and during this same period the number of longline vessels longer than 31 m decreased from 59% to 45% (Fiji Offshore Fisheries Division, 2015).

The variable season also significantly influenced both shark and ray standardized catch rates. In the 3rd and 4th quarters there were lower standardized catch rates, which was a larger effect for sharks than rays. Changes in El Niño Southern Oscillation (ENSO) phases and other large-scale climate variability such as Pacific Decadal Oscillation phases which occurred during the study period may have resulted in inter-annual and longer-scale changes in the relative abundance of shark species within the fisherys fishing grounds, influencing catch rates (Lehodey, 2001; Lehodey *et al.*, 2015). For example, the onset of an El Niño phase in 2013, and the observed 2.5 times higher nominal shark catch rate in the Fiji fishery in 2013 relative to 2012, suggests that ENSO phase affects shark relative abundance and catch rates. Unfortunately, any correlation between capture rates and relative abundance of sharks due to responses to ENSO or other cyclical climate variability is difficult to test owing to a lack of information on shark relative abundance.

Global levels of reported landings of sharks and rays has increased steadily from 1950, peaking in 2003, followed by a small (15%) decline (Davidson *et al.*, 2015). The majority of elasmobranchs are long-lived, with late age-at-maturity and low fecundity. This slow life-history strategy makes sharks less able to cope with direct or indirect mortality due to fishing activities (Dulvy *et al.*, 2008). As a result, several shark species have been classified as Near Threatened or Threatened according to IUCN categories (IUCN, 2015). Of the 27 species of sharks observed captured in the Fiji fishery, 41% are Near Threatened under the IUCN Red List, and 48% are categorized as Threatened (either Vulnerable or Endangered) (Table 1).

The oceanic whitetip shark (*Carcharhinus longimanus*), scalloped hammerhead shark (*Sphyrna lewini*), great hammerhead shark (*Sphyrna mokarran*), smooth hammerhead shark (*Sphyrna zygaena*), and manta rays (*Manta* spp.) were included in CITES Appendix II in 2014.[1] Fiji is a member of the Western and Central Pacific Fisheries Commission, which has adopted a binding measure that bans the retention of oceanic whitetip sharks (WCPFC, 2011). Data collected by on-board observers show that even though the fishery has not fully complied with the measure, a clear improvement was detected from 2011 to 2014: the percentage of oceanic whitetips released alive increased from 0% in 2011 to 63% in 2014 (Figure 1). Also, while 100% of oceanic whitetips were finned in 2011 and 2012, and 60% were finned in 2013, only 3% were finned in 2014. Large reductions in fishing mortality rates may be needed to address the poor conservation status of some shark populations (Casey and Myers, 1998). For example, a reduction in fishing mortality rate of about 40% and 60% was proposed by Myers and Worm (2005) as needed to ensure the survival of oceanic whitetip and scalloped hammerhead sharks in the Atlantic Ocean.

Capture rates of hammerhead sharks were highly variable by year during the 4 year time series. Most were captured in 2013. Most caught hammerheads were finned (80%). In 2014 only two hammerheads were captured, one was retained, and none were finned (Figure 2). Manta rays also exhibited a significant difference in captures by year, with the highest nominal catch rate occurring in 2014. Altogether, more than half the manta rays captured were either finned (39%) or retained (30%) (Figure 3). Even though the total mortality rate of manta rays recorded for the Fiji longline fishery was high, the number caught was low. In 2014 33% of caught manta rays were released alive and 10% discarded dead (and thus not retained nor finned). In Fiji, the authority for marine species listed in Appendix II of CITES is the Department of Fisheries. Compliance with the CITES Appendix II listing of hammerheads and

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[1] Decision of 12/06/2013, to come into effect on 14/09/2014 (see checklist.cites.org)

manta rays (*Mobula* spp.) will likely result in further reductions in finning of these species.

The two elasmobranch species with the highest capture rate in the Fiji longline fishery were pelagic stingray and blue shark. Neither species is categorized as Threatened by IUCN (the former is listed as LC, the latter as NT; IUCN, 2015). Their capture is common in pelagic longline fisheries throughout the Pacific, Atlantic and Indian Oceans, as well as in the Mediterranean Sea (Domingo *et al*., 2005; Gilman *et al*., 2008b; Piovano *et al*., 2009, 2010). They are considered less sensitive to fishing mortality due to their relatively high fecundity rate and resilience (Cortes, 2002), but an increase in their capture rates in the last decade has raised concern (Davidson *et al*., 2015). In Fiji, blue shark was already the most common elasmobranch captured by the domestic longline fleet more than 15 years ago, while at that time pelagic stingray was not even in the top five elasmobranch species by number of captures (Swamy, 1999). The increase in pelagic stingray captures might be the result of a higher observer coverage rate and improvements in observer data recording as bycatch became an increasingly prominent issue. Or there may have been an increase in pelagic stingray local abundance, which in the tropical Pacific Ocean may have resulted from a decline in predation caused by reductions in local abundance of apex predator species that prey on pelagic stingrays, and a decline in competition from reduced local abundance of sympatric competitors (Ward and Myers, 2005; Baum and Worm, 2009).

Proper data collection and stock assessment are the most useful tools to identify the pressure that shark populations can sustain. Increased on-board observer coverage rates and improvements in data collection protocols for pelagic longline fleets is necessary to support more robust statistical analyses, including to improve the accuracy and precision of elasmobranch catch and survival rate estimates. This in turn would enable improved accuracy of assessments of the population-level effects of fishing mortality on pelagic sharks and rays. A key improvement needed in longline observer data collection is to accurately identify all caught elasmobranchs to species level. As our knowledge of basic biological information for most elasmobranch stocks is severely deficient (Dulvy *et al*., 2014; Croll *et al*., 2015), increased on-board observer coverage rates would also contribute to filling these critical information gaps, for example, by documenting sex, maturity, and reproductive stage of both rare and common elasmobranch species captured in longline fisheries.

It has been argued that management of activities to protect sharks should focus on identifying levels of sustainable catch, rather than prohibiting shark fishing (Clarke *et al*., 2013). Longline fishing mortality of some elasmobranch stocks has the capacity to be sustainably managed if robust harvest strategies are adopted and high compliance with harvest control rules, one element of a harvest strategy, occurs (Walker, 1998; Musick *et al*., 2000). However, there are deficits in fundamental biological information for most elasmobranch stocks (Walker, 1998; Shotton, 1999; Musick *et al*., 2000). There is also high uncertainty in estimates of fishing mortality levels, in particular of rare, but also of common elasmobranch stocks caught in pelagic longline fisheries (Worm *et al*., 2013; Clarke *et al*., 2006, 2014; Gilman *et al*., 2016). These information gaps need to be filled in order for management systems to develop harvest strategies with high certainty of achieving sustainable exploitation.

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