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Species-specific at-vessel mortality of sharks and rays captured by demersal longlines

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ABSTRACT

Unmanaged fishing mortality is considered the biggest threat to sharks and rays, which are commonly discarded after being captured in commercial and recreational fisheries directed at more economically valuable fishery resources. Quantifying mortality prior to release (referred to as 'at vessel mortality', AVM) improves our understanding of the total mortality of sharks and rays. In this study, the effects of body size, sex, soak time, bottom depth and latitude on AVM were evaluated on a range of shark and ray species captured by demersal longlines off the coast of Western Australia. Our study provides new evidence for species not previously studied of the importance of deriving species-specific AVM as species was by far the most important predictor of AVM. Some species were inherently more susceptible to gear interactions than other species. Therefore, the probability of a species surviving the interaction with a fishing gear must be taken into consideration when making management recommendations because total mortality may be much greater than that estimated from retained catches only.

1. Introduction

Sharks and rays (elasmobranchs) are exploited globally in both recreational and commercial fisheries. In recent decades, fishing pressure on several elasmobranch stocks has increased due to the increasing value of their fins, meat, liver and gill rakers [1]. For the 2009–2013 period, only 9% of the average annual global catch of sharks and rays originated from sustainable sources, from which only 4% was managed sustainably [2]. Unmanaged fishing exploitation is considered the biggest threat to this group, from which 24% of the species are classed as 'threatened with extinction' based on IUCN Red List Assessments [1].

In general, sharks and rays are mostly captured as by-catch in multi-species fisheries targeted at other, often more commercially valuable, teleost and/or invertebrate species. At a global scale, shark bycatch has been poorly reported or not reported at all [3–6]. Management measures aimed at reducing shark and ray bycatch focus mostly on returning non-commercial species back to the water if incidentally captured [7], assuming that the released individuals survive the capture and release process. However, released or discarded individuals can experience mortality before (referred to as 'at-vessel mortality', AVM) or after (referred to as 'post-release mortality', PRM) release (e.g. [8–10]). Hence, the effectiveness of simply returning individuals back in the water as a way of minimising fishing mortality is uncertain [11]. By not accounting for AVM and PRM, the total mortality exerted on discarded species is underestimated and may impose risks to the sustainability of a stock, even if totally protected. This may directly undermine management and conservation efforts because the setting of sustainable harvest strategies depends on accurate understanding of total mortality [12].

This study evaluated the AVM of elasmobranch species taken in demersal longline gear off the coast of Western Australia (WA). Specifically, three years of scientific sampling were analyzed to assess the effects of body size, sex, soak time, bottom depth and latitude on the AVM of several tropical and temperate shark and ray species.

2. Methodology

2.1. Sampling

Individuals were sampled by scientifically trained observers between 2015 and 2017 on-board a research vessel using demersal longlines across WA at 267 sites (Fig. 1). Longlines were ~500 m long and comprised of ~50 12/0 J-shaped hooks baited with sea mullet and attached to the main line via ~2-m metal snoods. Gear was deployed at ~4 a.m. and retrieved at ~8 a.m. at depths of between 26 and 206 m, with the majority of the deployments between 40 and 90 m deep (Fig. 1A). For each gear deployment, date, time, and GPS location were recorded. Upon gear retrieval, all individuals were measured (to the

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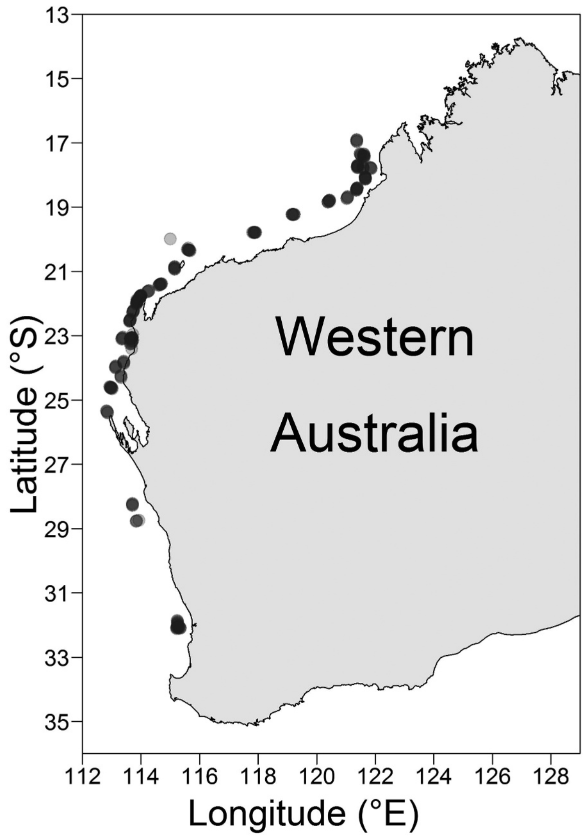

Fig. 1. Map of Western Australia showing the location of longline sampling events (dots). The color intensity of the dot is proportional to the number of sampling events done in each location.

nearest centimeter), sexed and identified to the lowest taxonomic level possible. Fork length (FL) was recorded for all individuals with the exception of zebra sharks, *Stegostoma fasciatum*, and rays of the families Rhynchobatidae and Rhinobatidae for which total length (TL) was recorded. The distinction of the closely related *Carcharhinus limbatus* and *C. tilstoni* was not possible in the field so the two species were analyzed as 'blacktip sharks'. Live individuals were tagged with conventional plastic Jumbo Rototags (Dalton Supplies, Australia) and released. Release condition was classed as 1 (individual swam off strongly and did not remain at the surface), 2 (individual swam off moderately strongly and typically swam at the surface for a period), or 3 (individual swam off in poor condition or did not appear to swim).

2.2. Statistical analyses

For determining AVM, individuals were classed as dead (i.e. individual in rigor mortis, stiff and/or lifeless, no physical activity or response to stimuli, jaws typically open) or alive (i.e. otherwise). Following [9], the proportion dead was the response variable of a Generalized Linear Model (GLM) with a binomial distribution and a logit link function. Species with no contrast in the response variable (i.e. either all dead or all alive) were excluded from the analysis. Due to the small sample sizes of several species (Table 1) a model with only the term 'species' (categorical variable) was used to test for differences in AVM among species. Next, for species with the largest sample sizes and sufficient contrast in the response variable (sandbar, milk and spot-tail sharks) the effects on AVM of sex (categorical variable), body size (continuous variable), soak time (i.e. the amount of time from when the first hook was set to the time the last hook was retrieved; continuous variable), bottom depth (continuous variable) and latitude (continuous variable) were tested. Analyses were done using the statistical package R [13]. For predictors that explained > 1% of the deviance, standardized model predictions were obtained using the 'predict' function included in the R base packages. Continuous explanatory variables were set to their means and categorical explanatory variables were set to their most common value in the data.

3. Results

A total of 25 shark and ray species (1476 individuals) were sampled (Table 1). Twelve species showed no contrast in AVM (i.e. individuals were either all alive or all dead). Sample sizes varied according to species' natural abundance, availability and longline catchability in the studied area with samples being largely dominated by sandbar sharks. A range of body sizes was sampled (Fig. 2A). For species with > 10 observations, AVM significantly differed among species, explaining 53.41% of the deviance (Table 2a). Lemon, pigeye, tiger, dusky, and sandbar sharks, and guitarfish and shovelnose rays had negligible or very low AVM. In contrast, spinner sharks had the highest AVM, followed by milk, spot-tail, sliteye, blacktip, silvertip and gummy sharks, and scalloped and great hammerheads (Table 1).

For sandbar sharks, AVM significantly decreased with body size and increased with bottom depth (Fig. 2). For sandbar, milk and spot-tail sharks, AVM significantly increased with soak time (Table 2b, Fig. 2). Body size, bottom depth and soak time, generally explained a small percentage of the deviance (Table 2b). Other terms explained < 1% of the deviance (Table 2b). Finally, the species with the highest AVM tended to have the lowest proportion of individuals released in condition 1 whereas those with the lowest AVM tended to have the highest proportion of individuals released in condition 1 (Fig. 3) (N.B., spinner sharks were not included in this analysis because all individuals were dead upon capture so release condition information was not available).

4. Discussion

In this study, species was by far the most important predictor of AVM. This is consistent with previous research on AVM for sharks and rays (e.g. [14,15]) and is a result of the inter-specific physiological responses to capture of sharks and rays (e.g. [16]). For example, [17] also found that spinner and blacktip sharks and hammerheads had much higher AVM than dusky, sandbar and tiger sharks in a commercial longline fishery on the east coast of Australia and [14] reported much higher AVM for blacktip sharks and hammerheads than for sandbar and tiger sharks in a demersal longline fishery in the Northwest Atlantic and Gulf of Mexico. Our study extends previous research by provisioning AVM information for previously unstudied species captured by demersal longlines.

The species that showed negligible AVM were either large-sized species or had benthic habits, whereas those with high AVM tended to be small-sized species. Body size can influence physiological responses, such as glucose dynamics, with larger individuals having a relatively higher volume of glycogen, which is used during the 'fight' response to capture [18]. However, maximum body size or habit alone are not necessarily good AVM predictors as AVM is highly dependent on species-specific physiology such as respiratory mode, tolerance to stress events and acidosis (e.g. [7,19,20]). For example, tiger sharks and great hammerheads are large-bodied species, however, great hammerheads showed higher AVM than tiger sharks due to their pronounced stress response from fighting when captured [21,22]. In addition, AVM can be influenced by fishing practices and environmental conditions such as depth, hook size and hook time, and water temperature (e.g. [15,23,24]).

Hook time (i.e. the amount of time individuals spent caught on a hook, typically measured using time-depth records (e.g. [25])) is generally a strong predictor of AVM (e.g. [15,17]). For the current study, this information was not available so soak time was used as a proxy which showed a significantly positive effect on AVM. However, this

Table 1
Observed at vessel mortality for the analyzed species. Species are sorted in increasing order of observed proportion dead.

Common name	Scientific name	Dead	Alive	Total	Proportion dead	SE
Lemon shark	*Negaprion acutidens*	0	23	23	0	–
Pigeye shark	*Carcharhinus amboinensis*	0	23	23	0	–
Whitespot shovelnose	*Rhynchobatus autraliae*	0	15	15	0	–
Guitarfish & shovelnose ray	Families Rhinobatidae & Rhynchobatidae	0	10	10	0	–
Zebra shark	*Stegastoma fasciatum*	0	8	8	0	–
Green sawfish	*Pristis zijsron*	0	2	2	0	–
Banded wobbegong	*Orectolobus ornatus*	0	2	2	0	–
Bull shark	*Carcharhinus leucas*	0	1	1	0	–
Spurdogs	*Squalus* spp.	0	1	1	0	–
Tawny nurse shark	*Nebrius ferrugineus*	0	1	1	0	–
Wobbegongs	*Orectolobus* spp.	0	1	1	0	–
Tiger shark	*Galeocerdo cuvier*	1	114	115	0.009	0.009
Dusky shark	*Carcharhinus obscurus*	1	75	76	0.013	0.013
Sandbar shark	*Carcharhinus plumbeus*	43	820	863	0.05	0.007
Great hammerhead	*Sphyrna mokarran*	4	9	13	0.308	0.128
Gummy shark	*Mustelus antarcticus*	6	10	16	0.375	0.121
Silvertip shark	*Carcharhinus albimarginatus*	5	8	13	0.385	0.135
Grey reef shark	*Carcharhinus amblyrhynchos*	1	1	2	0.5	0.354
Blacktip sharks	*Carcharhinus limbatus/tilstoni*	10	9	19	0.526	0.115
Scalloped hammerhead	*Sphyrna lewini*	20	8	28	0.714	0.085
Sliteye shark	*Loxodon macrorhinus*	12	3	15	0.8	0.103
Spot-tail shark	*Carcharhinus sorrah*	97	17	114	0.851	0.033
Milk shark	*Rhizoprionodon acutus*	85	13	98	0.867	0.034
Spinner shark	*Carcharhinus brevipinna*	15	1	16	0.938	0.061
Whitecheek shark	*Carcharhinus dussumieri*	1	0	1	1	–

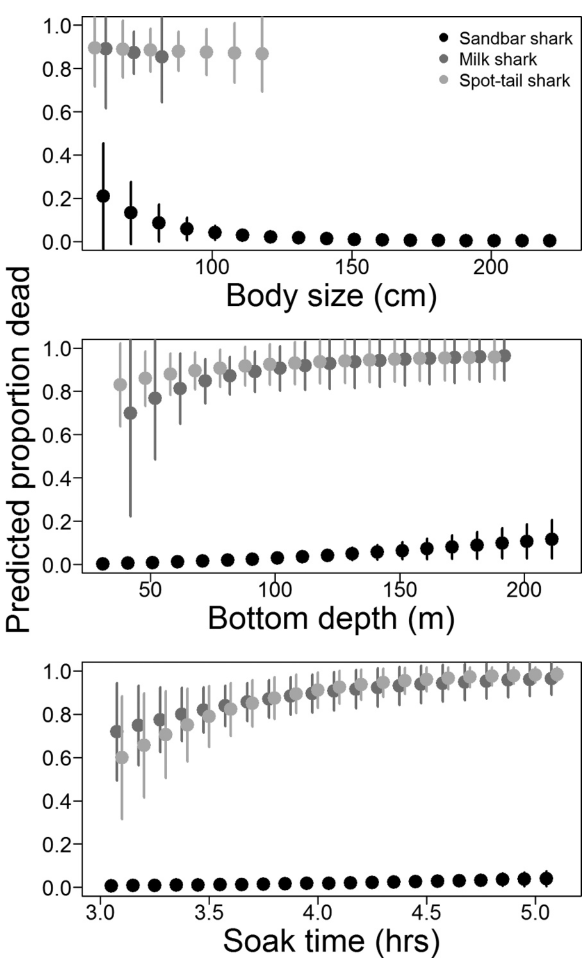

Fig. 2. Predicted proportion dead (± 1.96 standard errors) for the effects of body size, bottom depth and soak time for selected species.

term explained a small percentage of the deviance (Table 2). The lack of a stronger signal in AVM with soak time is likely due to the overall low contrast in the distribution of soak time values (Fig. 1A). Although a range of soak times were sampled, the vast majority of soak time values were between 3 and 4.5 h as most of the observations were done as part of a standardised scientific survey aimed at balancing mortality (for maximising tagging opportunities) and catch rates, and not at only testing the effect of soak time on AVM. Similarly, the lack of a stronger signal in AVM with other terms considered is likely due to the low contrast in the distribution of those terms (Fig. 1A) given the nature of the standardised survey.

This study was conducted as part of a scientific abundance survey and not onboard commercial longline vessels. However, our findings provide further and new evidence of how AVM differs among shark and ray species. The probability of a species of shark or ray surviving the interaction with commercial/recreational fishing gear must be taken into consideration when making management recommendations, as the assumption that all individuals of all species survive the catch and release process is not substantiated. Thus total mortality may be much greater than that estimated from retained catches only.

Our findings have wider ranging management implications, especially in fisheries where size and /or bag limits apply. In WA, for example, there is a total prohibition of the commercial take of shark or rays except for a small number of commercial fisheries that specifically target sharks [26]. Thus other commercial fisheries (line, trawl, trap, etc.) must discard/release all sharks and rays that are incidentally captured (though a small number of exceptions are in place). The numbers by species discarded in all commercial fisheries is currently poorly understood and efforts to redress these data gaps need to be considered. Further, WA has extensive recreational fisheries that interact with sharks and rays. While some species are able to be retained, there are size and bag limits, and totally protected species of sharks and rays (www.fish.wa.gov.au). Thus high proportions of sharks and rays are discarded, although identification to species level is relatively poor [27]. Nonetheless, the cumulative impacts of non-retained sharks and rays from commercial and recreational fisheries need to be considered when providing scientific advice around risks to sustainability and

Table 2
Summary of GLM analyses showing the significance and the percentage of deviance explained by (a) species, and (b) body size, bottom depth, soak time, sex, and latitude (selected species only).

Model term	P	% Deviance explained
Species	< 0.001	53.41
Total		53.41

Continue

Model term	Sandbar shark		Milk shark		Spot-tail shark	
	P	% Deviance explained	P	% Deviance explained	P	% Deviance explained
Body size	< 0.001	25.34	0.841	0.05	0.845	0.04
Bottom depth	< 0.001	4.98	0.226	1.95	0.567	0.35
Soak time	0.005	2.41	0.048	5.2	0.005	8.3
Latitude	0.606	0.08	0.415	0.88	0.393	0.79
Sex	0.397	0.22	0.488	0.64	0.671	0.19
Total		33.03		8.72		9.67

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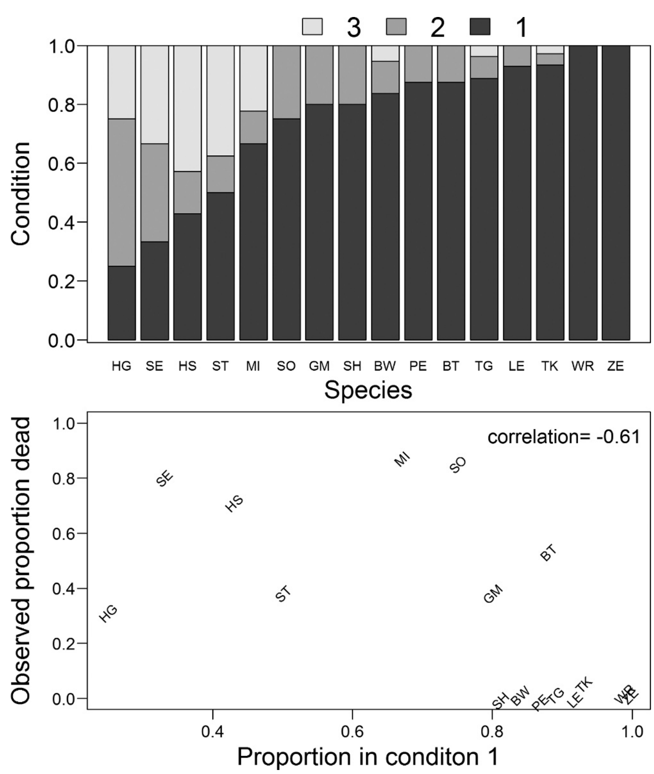

Fig. 3. Barplot of release condition (1, individual swam off strongly and did not remain at the surface; 2, individual swam off moderately strongly and typically swam at the surface for a period; 3, individual swam off in poor condition or did not appear to swim) by species. The lower panel shows the correlation between the proportion of individuals in condition 1 and the predicted proportion dead. HG, great hammerhead; SE, sliteye shark; HS, scalloped hammerhead; ST, silvertip shark; MI, milk shark; SO, spot-tail shark; GM, gummy shark; SH, guitarfish & shovelnose rays; BW, dusky shark; PE, pigeye shark; BT, blacktip sharks; TG, tiger shark; LE, lemon shark; TK, sandbar shark; W*R*, whitespot shovelnose; ZE, zebra shark.

applying management actions. Better information around discarding rates and species identification would allow for a better understanding of AVM, and estimates of PRM are also required to enable more robust estimates of total mortality and refinement of management for the ongoing sustainability of sharks and rays.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.marpol.2018.10.033.

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