SC-04-19

4th Meeting of the Southern Indian Ocean Fisheries Agreement (SIOFA) Scientific Committee

25–29 March 2019, Yokohama, Japan

Draft manuscript for an ecological risk assessment for the effects of bottom fishing gears on deepwater chondrichthyans in high seas areas of the Southern Indian and South Pacific oceans

Relates to agenda item: 7　　　Working paper ☒ Info paper ☐

Delegation of Australia

Abstract

This paper provides a draft manuscript for an ecological risk assessment for the effects of bottom fishing gears on deepwater chondrichthyans in high seas areas of the Southern Indian and South Pacific Oceans.

Recommendations

It is recommended that the SC:

- **Note** that this PSA and SAFE analysis has identified a number of species of deepwater chondrichthyans at high or extreme relative vulnerability to fishing using demersal trawl, midwater trawl, demersal longline and demersal gillnet gears;

- **Note** that a number of these species assessed to be at the high or extreme vulnerability are taken in association with commercial deepwater shark fisheries;

- **Note** there is limited catch, effort and biological information for many species of deepwater chondrichthyan;

- **Note** that some species of deepwater chondrichthyans are highly vulnerable to overfishing due to their life history characteristics; and

- **Recommend** to the Meeting of the Parties that stock assessment for species of deepwater chondrichthyans taken in association with commercial deepwater shark fisheries is urgently required to estimate sustainable yields and mitigate the potential for overexploitation that has been seen in similar fisheries globally.

Ecological risk assessment for the effects of bottom fishing gears on deepwater chondrichthyans in high seas areas of the Southern Indian and South Pacific oceans

L. Georgeson, C. L. Rigby, T.J. Emery, S. J. Nicol, M. Fuller, J. Hartog, A. J. Hobday, C. A. Simpfendorfer

Corresponding author details

L. Georgeson, Australian Bureau of Agricultural and Resource Economics and Sciences, Department of Agriculture and Water Resources, GPO Box 858, Canberra, ACT, 2601, Australia. Tel: +61 2 6272 5845; email: lee.georgeson@agriculture.gov.au.

Abstract

The risks posed by demersal fishing to species and populations of deepwater chondrichthyans (sharks, skates, rays and chimaeras) are poorly understood, particularly in areas beyond national jurisdiction. We adapted Productivity-Susceptibility Analysis (PSA) and Sustainability Assessment for Fishing Effects (SAFE) methods within the Ecological Risk Assessment for the Effects of Fishing (ERAEF) framework to assess the vulnerability of 174 deepwater chondrichthyans to demersal trawl, midwater trawl, demersal longline and demersal gillnet fishing gears in the Southern Indian and South Pacific Oceans. A number of species were categorised as being at high or extreme vulnerability to all gears, including some in the Southern Indian Ocean that are taken in association with commercial deepwater shark fisheries. Overall, there was good concurrence between PSA and SAFE results at the upper end of the vulnerability spectrum for Southern Indian Ocean fisheries, and poorer concurrence for South Pacific Ocean fisheries, in which more species were assessed to be at higher vulnerability using the SAFE method than the PSA. This was unexpected because the PSA is usually assumed to be more precautionary, and could be a concern to managers seeking to use information from these lower 'tiers' of the ERAEF hierarchy to implement management actions. Despite a number of methodological limitations of this assessment, such methods can be used effectively to prioritise management action for those species considered to have the highest vulnerability to fishing. Given the findings of this assessment, we advocate for implementation of identification protocols for deepwater chondrichthyans and improved understanding of species biology (particularly age data, species distribution and stock structure). For species taken in relatively high volumes in association with commercial deepwater shark fisheries, stock assessments to inform harvest strategies is required to mitigate the potential for overexploitation that has occurred in other similar fisheries globally.

Key words: elasmobranchs, non-target species, ecosystem approach to fisheries, productivity-susceptibility analysis, high seas fisheries, RFMO/As

Introduction

A recent global assessment estimated that 25% of the world's chondrichthyans (sharks, skates and chimaeras) are threatened with extinction (Dulvy et al., 2014). Some of these species are caught in deep-sea demersal fisheries, such as those operating in the Southern Indian and South Pacific oceans under the regional management of the Southern Indian Ocean Fisheries Agreement (SIOFA) and the South Pacific Regional Fisheries Management Organisation (SPRFMO). In their role as regional fisheries management organisations/agreements (RFMO/As), SIOFA and SPRFMO are required to assess the status of principal deep-sea fishery resources targeted, and, to the extent possible, taken as bycatch and caught incidentally in deep-sea fisheries.

Deepwater chondrichthyans can be particularly vulnerable to overfishing due to their exceptionally low production potential (e.g. low fecundity, slow growth, late maturity and long life spans), with low productivity also reducing their capability to recover once populations are depleted (Simpfendorfer and Kyne 2009, Rigby et al. 2015). Deficiencies in existing catch, effort and biological (e.g. age, distribution and population genetics) information for these deepwater shark species can make assessment of their vulnerability to overfishing difficult (McLean et al., 2015; Verissimo et al., 2012), especially when coupled with existing taxonomic uncertainties (Straube et al., 2011). The difficulties in collecting estimates of biomass and fishing mortality can necessitate the application of data limited assessment methods (e.g. Dowling et al., 2008; Dichmont and Brown, 2010; Marchal et al., 2013), such as ecological risk assessment (ERA) to enable an assessment of the vulnerability of species to fisheries interactions (Williams et al., 2018). Vulnerability in this context is defined following Griffiths et al., (2017) as the potential for the productivity of a stock to be diminished beyond expected natural fluctuations by direct and/or indirect fishing interactions.

ERA has been applied successfully around the globe in situations where fishing mortality is unknown but information on the distribution of fishing effort and the basic biology of species may be available (e.g. Milton et al. 2001; Stobutzki et al. 2002; Zhou and Griffiths 2008; Zhou et al. 2007, 2012). Hobday et al., (2011) developed the hierarchical Ecological Risk Assessment for the Effects of Fishing (ERAEF) framework with the intention to enable risk to be managed through the implementation of management actions at different stages of the hierarchy, from the largely qualitative analysis of risk based on expert opinion and stakeholder feedback (level 1), to a more focused and semi-quantitative approach (level 2), and finally to a highly focused and fully quantitative approach (level 3). The management response at each level may include additional assessment, identification of appropriate management or mitigation strategies, or scenarios in which no additional management actions are required. At the lower levels of the hierarchy, ERAEF is generally acknowledged to be more precautionary (i.e. missing information results in higher risk), which can lead to a greater number of false positives (species assessed to be high risk that may actually be low risk).

Over the last decade, ERA methods have improved (see, for example, Zhou et al. 2013; Zhou et al. 2019; Griffiths et al. 2018) and are increasingly being used as a tool to inform management, noting that most only generate proxy estimates of biomass depletion ($B_{current}$) and fishing mortality ($F_{current}$) (e.g. Dowling et al. 2016). Although many of these methods can be applied at a lower cost per assessment than methods that are more commonly applied to information-rich fisheries, the task of assessing all target and non-target species with ERAs in fisheries with a large number of data-deficient species is not trivial. ERA provides a useful, inexpensive tool to prioritise vulnerable (or high risk) species where the impacts of fishing may be sufficient to warrant further quantitative assessment or other management intervention.

The most widely used ERA approach in fisheries is the semi-quantitative Productivity-Susceptibility Analysis (PSA), which considers risk to species as a function of their biological productivity and their susceptibility to fishing using various gears (Hobday et al., 2011; Patrick et al., 2009). PSA is considered particularly useful for evaluating the vulnerability of a large number of data-limited non-target species in a way that can be easily interpreted by fisheries managers and policy makers (Williams et al., 2018; Griffiths et al., 2017). Consequently, PSA is the primary ERA method recommended by the Marine Stewardship Council (MSC) for fisheries seeking certification for eco-labelling purposes (MSC, 2010).

More quantitative methods such as Sustainability Assessment for Fishing Effects (SAFE) (Zhou et al. 2007, 2012, 2016, 2019) and EASI-Fish (Griffiths et al. 2018), on the other hand, derive a proxy for fishing mortality based on the susceptibility of species in relation to productivity, with some of these methods also capable of quantifying cumulative impacts across multiple fisheries (Griffiths et al. 2018; Zhou et al. 2019). Both the PSA and SAFE methods have been applied to teleosts and chondrichthyans in Australia (Zhou and Griffiths 2008; Zhou et al. 2009; Zhou et al. 2011; Zhou et al. 2019) and in high seas areas in the Atlantic Ocean (Arrizabalaga et al., 2011; Cortés et al., 2010), the Western and Central Pacific Ocean (Kirby et al., 2006), the Eastern Pacific Ocean (Griffiths et al., 2017) and the Indian Ocean (Murua et al., 2009; Murua et al; 2018). Zhou et al. (2016) demonstrated that estimates of F from SAFE were comparable to those derived from data-rich quantitative stock assessments in most cases, and that SAFE overestimated F (i.e. overestimated risk) in all other cases. An advantage of SAFE is that in addition to prioritisation of species for quantitative assessment or other management actions, the proxy estimate of $F_{current}$ can be also used within an interim harvest strategy with defined limit reference points and agreed management rules (e.g. Zhou et al. 2012). However, such an approach is not advocated in this instance due to various methodological limitations.

In this paper we apply PSA and SAFE methods based on that of Hobday et al., (2011) and Zhou and Griffiths (2008) to assess the vulnerability of 174 deepwater chondrichthyans to demersal trawl, midwater trawl, demersal longline and demersal gillnet fishing gears in the Southern Indian and South Pacific Oceans under the regional management of SIOFA and the SPRFMO[1]. Both PSA and SAFE analyses can be used to identify those species considered to be the most vulnerable (or at highest risk) to different types of fishing gear and to which resources can be directed to either implement mitigation measures or prioritise data collection and further research. We discuss the results in the context of regional management of high seas fisheries, relevance to fishery managers, key data deficiencies and limitations of the analysis.

Methods

Formation of species list and data collection

To undertake the PSA and SAFE analyses, species lists for the Southern Indian and South Pacific Oceans were derived using available catch records and various sources in the published literature (e.g. Last and Stevens 2009; Ebert 2013; Ebert et al., 2013; Ebert 2014;

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[1] The use of demersal gillnet gears was prohibited in the South Pacific Ocean in 2012 by the SPFRMO and this gear type is not assessed for this fishery area.

Ebert 2016; Ford et al. 2015; Last et al., 2016) and refined using input from chondrichthyan experts in Australia, New Zealand and the United States. Species were included on the list if they were thought to occur, and interact with gears, in each gear-type 'fishery'. The total number of species on the list was 112 in the Southern Indian Ocean and 101 in the South Pacific Ocean, with 40 species included in both species lists. The species lists are only subsets of all chondrichthyan species present in the two areas, and may include species for which there are few or no records of interaction. Some species known to be present in the two areas were excluded if they have a mainly coastal distribution and are not exposed to high seas fishing, or if they occur in habitat that is unsuitable for fishing. For the purposes of this study, 'deepwater' chondrichthyans were defined as those that spend most of their lifecycle at depths below 200 m depth, as described by Kyne and Simpfendorfer (2007).

Life-history attributes for each deepwater shark species were compiled from the relevant published literature. A paucity of biological information to inform productivity for a large number of species resulted in the attribution of proxy biological characteristics from similar (e.g. congeneric or co-familiar) species. (See Table Sx). This was done using expert input, and was only applied in situations where it was deemed that the use of proxy attributes would be reasonably robust and would represent a better option than simply assuming no data, which is the default approach in such circumstances. Species distribution data were sourced from the FAO Catalogue of Species—Geonetwork database (http://www.fao.org/geonetwork/srv/en/main.search), the IUCN Red List (https://www.iucnredlist.org/) and various sources in the published literature. The FAO Catalogue of Species generally had the most recent distribution data, so this was used in the first instance if available. Fishing effort and bycatch data were requested from all relevant nations that have reported deep-sea bottom fishing in the southern Indian and South Pacific Oceans from 2012 to 2016. A complete fishing effort dataset was available for the South Pacific Ocean gear types but effort data for some bottom fishing gears was unavailable for the Southern Indian Ocean, which may increase the uncertainty of results for this area.

Productivity-Susceptibility Analysis (PSA)

PSA (Stobutzki et al. 2002; Hobday et al. 2011) is based on scoring productivity and susceptibility attributes to estimate relative potential vulnerability. The productivity (P) attributes (Table 1) are assumed to influence the intrinsic rate of increase (r) and the susceptibility (S) attributes are assumed to influence catchability (q). The productivity score is calculated as the average of the seven productivity attributes. Susceptibility (S) is estimated as the product of four susceptibility attributes (Table 2). Attributes used in the PSA are typically scored a 1 (low vulnerability), 2 (medium vulnerability) or 3 (high vulnerability). In line with a precautionary approach, missing attributes are scored a 3. Data deficient species are classified as those missing three or more P and/or S attributes. Low productivity species with high susceptibility scores are considered to be the most vulnerable, while high productivity species with low susceptibility scores are considered to be the least vulnerable. Species are assigned to an overall vulnerability category (high, medium or low) by dividing the 2-dimensional Euclidean distance ($\sqrt{P^2 + S^2}$) into equal thirds, such that scores <2.64 are low vulnerability, between 2.64 and 3.18 are medium vulnerability, and >3.18 are high vulnerability (Williams et al., 2018).

Productivity attributes

Productivity attributes were estimated from life history traits based on those proposed by Hobday et al., (2011) and modified to be relevant to chondrichthyans, as outlined in Table 1. The correlation between these life history traits and productivity has been well established for chondrichthyans (Dulvy et al., 2008; Hutchings et al., 2012; Clarke et al; 2018). For this study, *P3: Fecundity* metrics were redefined from those used for teleosts in Hobday et al. (2011) to be relevant to deepwater chondrichthyans. The default Hobday et al. (2011) attribute values for *P4: Average maximum size* and *P5: Average size at maturity* were based on a large database of teleosts and chondrichthyans and described a strong negative relationship between size and productivity, resulting in larger species exhibiting lower productivity and smaller species exhibiting higher productivity. An analysis of the size-productivity relationship using data from the global database for deepwater chondrichthyans held by James Cook University (JCU), in Australia, estimated the relationship to be weaker than that suggested by these default values, with both small and large deepwater chondrichthyans exhibiting similar productivity. Consequently, these attributes were rescaled to be relevant to deepwater chondrichthyans.

Table1: Productivity attributes and risk categorisations (adapted from Hobday et al. 2011)

Attribute	Low productivity (high vulnerability, score 3)	Medium productivity (medium vulnerability, score 2)	High productivity (low vulnerability, score 1)
P1. Average age at maturity	>15 years	5–15 years	<5 years
P2. Average maximum age	>25 years	10–25 years	<10 years
P3. Fecundity ***(redefined and rescaled for deepwater chondrichthyans)***	<10 pups/egg cases per year	10-20 pups/egg cases per year	>20 pups/egg cases per year
P4. Average maximum size ***(rescaled for deepwater chondrichthyans)***	>200 cm	70–200 cm	<70 cm
P5. Average size at maturity ***(rescaled for deepwater chondrichthyans)***	>150 cm	40–150 cm	<40 cm
P6. Reproductive strategy	Live bearer	Egg case layer	Broadcast spawner (teleosts)*
P7. Trophic level	>3.25	2.75–3.25	<2.75

*** Not used in this assessment**

Susceptibility attributes

Susceptibility was estimated based on traits proposed by Hobday et al., (2011, following Walker 2005) and outlined in Table 2. *S1: Availability* was calculated as the overlap of species distribution within the SIOFA and SPRFMO areas and the spatial footprint of fishing effort for each gear (between 2012 and 2016) at a 20 minute resolution. Vulnerability was only assessed within the SIOFA and SPRFMO areas because the inclusion of species distribution data outside the fisheries would act to bias results due to the spatial limitations of the method that only considers overlap between fishing effort and species distribution within a defined area (e.g. each respective RFMO/A area). *S2: Encounterability* was calculated as the proportion of vertical overlap between fishing effort and species depth ranges (Table 3). The middle 90 percent (i.e. from the 5^{th} to 95^{th} percentiles) of fishing depth records for each gear was defined as the core depth range. Using this approach, outliers, zeros and data deemed to be implausible were discarded. *S3: Selectivity* categorisations were informed by an analysis of available literature for gear selectivity (e.g. Kirkwood and

Walker 1986 for gillnet selectivity) and expert input (trawl and line gears). *S4*: *Post capture mortality* (PCM) scores were formulated through a desktop analysis of the role of each species in each fishery (target, bycatch and discard species).

Table 2. Susceptibility attributes and risk categorisations (adapted from Hobday et al. 2011)

Attribute	Low susceptibility (low vulnerability, score = 1)	Medium susceptibility (medium vulnerability, score = 2)	High susceptibility (high vulnerability, score = 3)
S1. Availability	<10% horizontal overlap	10-30% horizontal overlap	>30% horizontal overlap
S2. Encounterability *(modified using gear depth data)*	Low vertical overlap with fishing gear (<10%) based on middle 90% of the fishing depth range by gear type	Medium vertical overlap with fishing gear (10-30%) based on middle 90% of the fishing depth range by gear type	High vertical overlap with fishing gear (>30%) based on middle 90% of the fishing depth range by gear type
S3. Selectivity (scores vary by gear type)	Demersal and midwater trawl: 0-15 cm; > 500 cm max. length Line: 0-40 cm; >500 cm max. length	Demersal and midwater trawl: 15-30 cm; 400-500 cm max. length Line: 40-80 cm; 200-500 cm max. length	Demersal and midwater trawl: 30-400 cm max. length Line: 80-200 cm max. length
S4. Post-capture mortality (scores may vary by fishery and gear type)	Evidence of post capture release and survival*	Bycatch or discarded species (limited evidence of survival)	Target or byproduct species (retained)

*** Not used in this assessment**

Table 3: Core depth range (5th-95th percentiles) of gears used to inform encounterability for the SIOFA and SPRFMO PSA assessments (calculated using available fishing effort data for 2012–2016)

Gear	SPRFMO depth min. (m)	SPRFMO depth max. (m)	SIOFA depth min. (m)	SIOFA depth max. (m)
Demersal trawl	520	1069	700	1235
Midwater trawl	327	548	430	970
Demersal longline	230	654	597	1716
Demersal gillnet	-	-	810	1390

Sensitivity analysis of spatial overlap

Spatial distribution data varied significantly between data sources for some species (e.g. FAO Geonetwork vs. IUCN Red List). Consequently, the selection of these data influences *S1: Availability* scores. To evaluate sensitivity to the overlaps between fishing effort and species distribution in the PSA assessment, the estimated overlap used to calculate the *S1: Availability* attribute was varied by both positive and negative 10%, 20%, 30% increments. The *S1: Availability* attribute was then re-discretised into the attribute scores and the susceptibility score recalculated. The number of species changing to a lower or higher risk category were recorded.

Sustainability Assessment for the Effects of Fishing (SAFE)

The SAFE method (Zhou et al. 2007, Zhou and Griffiths 2008, Zhou et al. 2009, Hobday et al. 2011; Zhou et al. 2016; Zhou et al. 2019) as applied in ERA provides an absolute measure of risk by estimating the fishing mortality rate F (expressed as the estimated fraction of the population that has died as a result of fishing), as well as quantitative reference points associated with it. The method as applied here uses three parameters: spatial overlap, catchability and post capture mortality as described by Zhou et al. (2011) to determine the fishing mortality F_{CURR} as:

$$F_{CURR} = \frac{\sum a_t}{A} q^h q^\lambda (1 - s)(1 - E)$$

where a_t and A represent the area fished and a species' distribution area (i.e. spatial overlap), respectively, q^h and q^λ are the habitat-dependent encounterability and size- and behaviour-dependent catch rate ('catchability'), E is the escapement rate (i.e. the amount of the population that does not get caught by fishing) and s is the post-capture survival rate. Methods for estimating spatial overlap vary depending on the fishery characteristics, including the configuration of gears. Similarly, q^h, q^λ, E and s vary depending on the biology of the species. Zhou et al. (2012) describe the different methods used for estimating these parameters for trawl, longline and gillnet fisheries, with these methods underlying the model used for this analysis.

The SAFE method relates life history traits that inform natural mortality (M), growth rate and intrinsic rate of increase (r) to biological reference points using six formulae derived from Pauly (1980), Quinn and Deriso (1999), Hoenig (1983), Jensen (1996) and fishbase.org (see Zhou et al. 2012 for additional detail). The model uses the average of the six methods for defining the midpoint on the productivity axis. Where information is not available for one or more methods, the model uses the average of the remaining methods. Data deficient species in the SAFE are classified as those for which fishing mortality (F)-based reference points (Box 1) could not be estimated due to missing productivity attribute data. The result is that F can be considered against F_{msm}, F_{lim} and F_{crash}, giving an absolute measure of risk (Box 2).

Box 1: Biological reference points used in SAFE assessment.

F_{msm} – Fishing mortality rate corresponding to maximum sustainable fishing mortality (*MSM*) at B_{msm} (biomass that supports *MSM*, equivalent to *MSY*) F_{lim} – Fishing mortality rate corresponding to limit biomass B_{lim}, where B_{lim} is defined as 50% biomass that supports the *MSM* F_{crash} – minimum unsustainable fishing mortality rate that theoretically may lead to population extinction in the long term

Box 2: SAFE vulnerability categories

Low – $F<F_{msm}$ **Medium** – $F_{lim}>F>F_{msm}$ **High** – $F_{crash}>F>F_{lim}$ **Extreme** – $F>F_{crash}$

Results

Productivity-Susceptibility Analysis (PSA)

Tables Sx and Sx in supplementary material provide details of the PSA results for both Southern Indian and South Pacific Oceans. There were a total of 10, 12, 8 and 6 chondrichthyan species ranked as high vulnerability in the Southern Indian Ocean to demersal trawl, midwater trawl, demersal longline, and gillnet fisheries respectively (Table 4). In the South Pacific Ocean, there were a total of 8, 3 and 7 species ranked as high vulnerability to demersal trawl, midwater trawl and demersal longline fisheries respectively (Table 4).

Out of the 101 species assessed in the Southern Indian Ocean, none were classified as data deficient (i.e. missing three or more productivity or susceptibility attributes), while in the South Pacific Ocean, one (*Squalus fernandezianus*) of the 112 species assessed were classified as data deficient. Productivity attributes from congeneric species were applied to 60 species in the Southern Indian Ocean and 76 species in the South Pacific Ocean.

Chondrichthyan species classified as high vulnerability across all fisheries in the Southern Indian Ocean included *Centrophorus granulosus*, *Dalatias licha*, *Chimaera buccanigella* and *Chimaera willwatchi*. Chondrichthyan species classified as high vulnerability across all fisheries in the South Pacific Ocean included *Squalus fernandezianus* and *Hexanchus nakamurai*.

The vulnerability scores by region (Southern Indian and South Pacific Oceans) and fishery (i.e. gear type) are shown in Figures 1a and 1b. The vulnerability scores for most fisheries (midwater trawl in South Pacific a clear exception) cluster closely along the horizontal axis of the PSA plots (i.e. >2.0 productivity score) because the biological attributes of many chondrichthyans are similar. In contrast, there was more resolution in the vertical axis, due to different susceptibilities between species. For example, in the Southern Indian Ocean, productivity scores for all high risk species ranged from 2.29 to 2.86, while susceptibility scores ranged from 1.42 to 3.

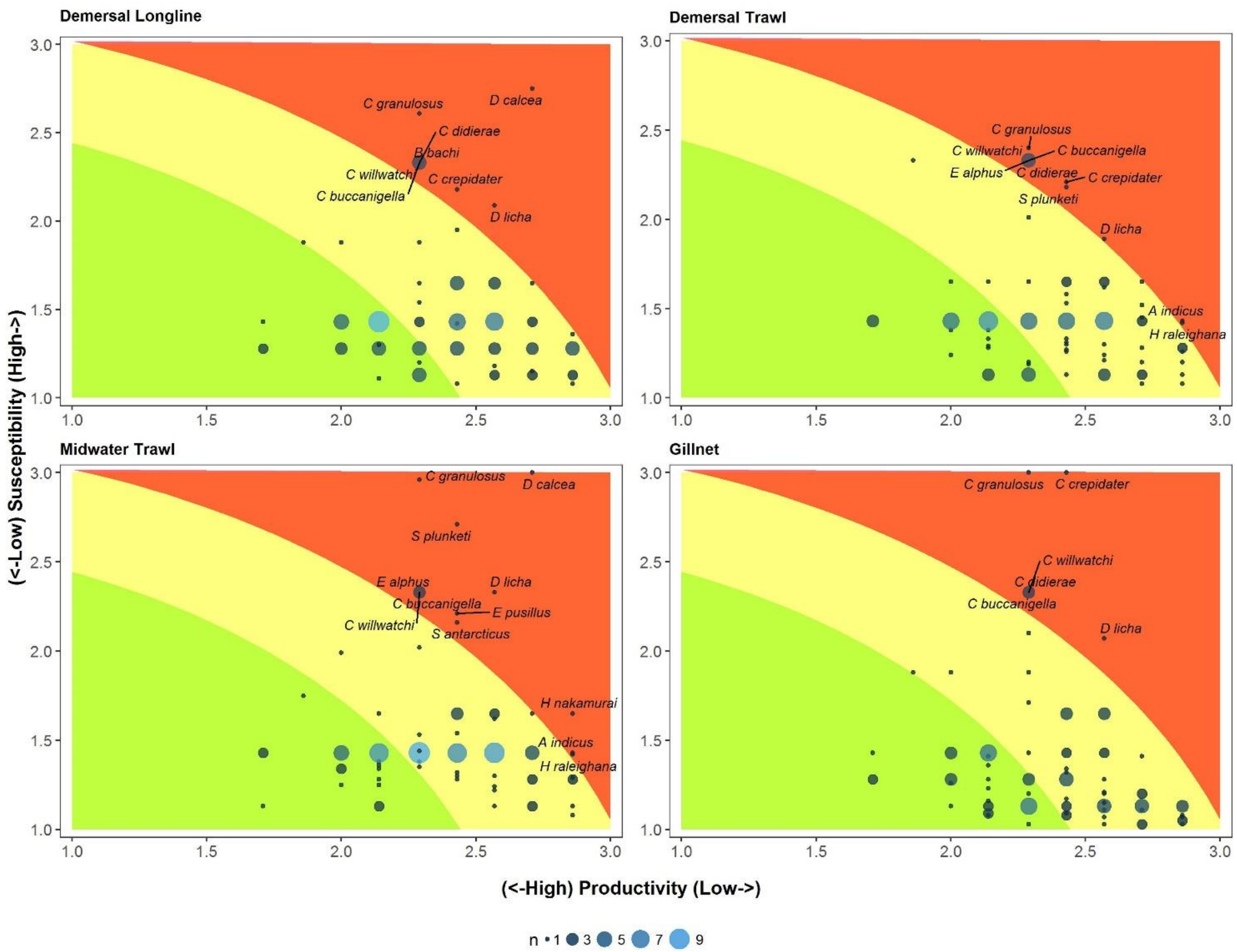

Figure 1a. PSA results for 101 chondrichthyan species thought to occur and have the potential to interact with longline, demersal and midwater trawl and gillnet fisheries in the Southern Indian Ocean. Size of symbol represents number (n) of species with the same vulnerability score.

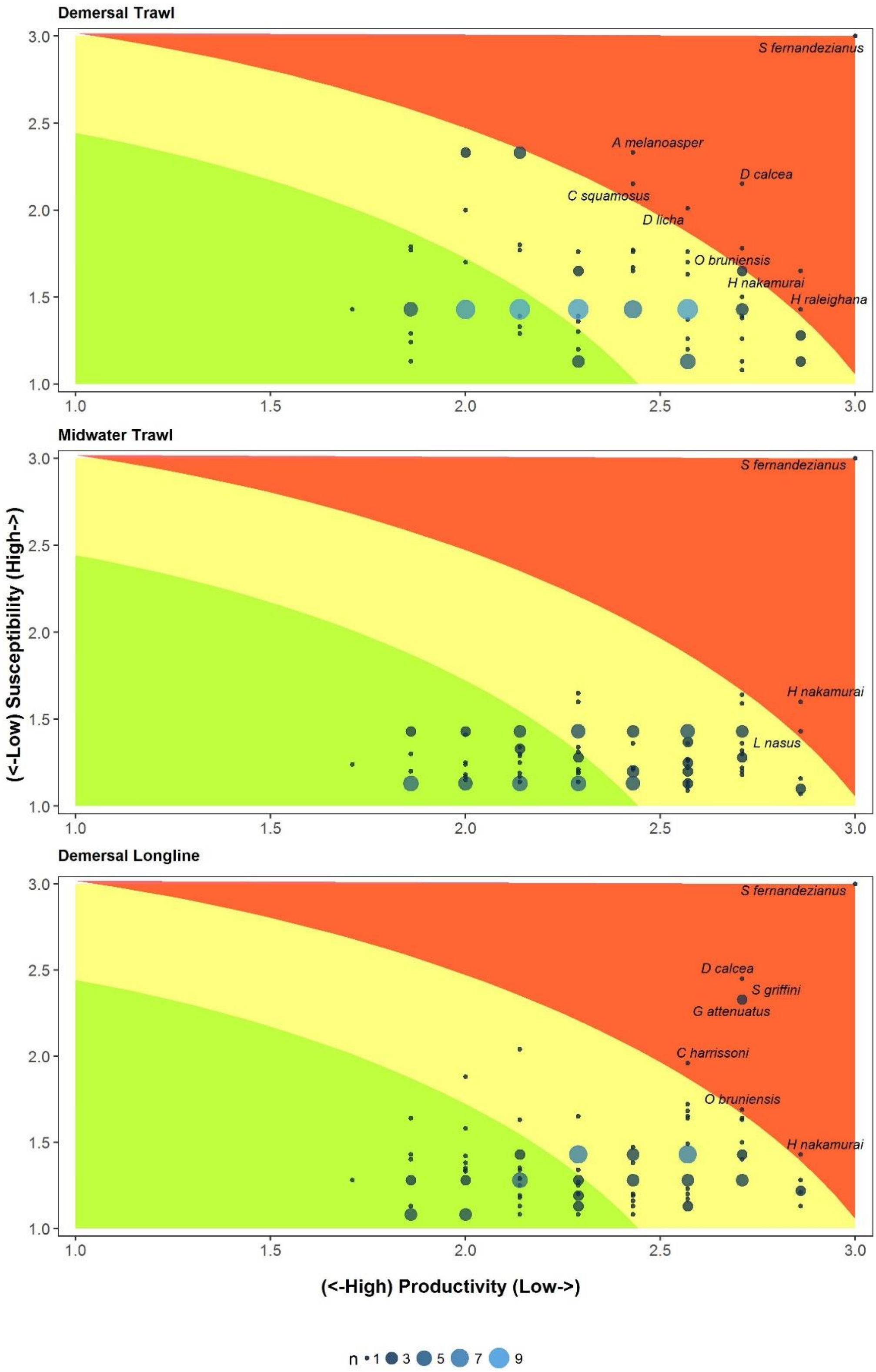

Figure 1b. PSA results for 112 chondrichthyan species thought to occur and have the potential to interact with longline, demersal and midwater trawl fisheries in the South Pacific Ocean. Size of symbol represents number (n) of species with the same vulnerability score.

Sustainability Assessment for the Effects of Fishing (SAFE)

Tables Sx and Sx in supplementary material provide details of the SAFE results for both Southern Indian and South Pacific Oceans. The SAFE classified a total of 11, 12, 9 and 4 chondrichthyan species as high (F>F_{LIM}) or extreme (F>F_{CRASH}) vulnerability in the Southern Indian Ocean area to demersal trawl, midwater trawl, demersal longline and gillnet fisheries respectively (Table 4). In the South Pacific Ocean, there were a total of 20, 4 and 17 species classified as high (F>F_{LIM}) or extreme (F>F_{CRASH}) vulnerability to demersal trawl, midwater trawl and demersal longline fisheries respectively. Out of the 101 species assessed in the Southern Indian Ocean, only two (*Mitsukurina owstoni* and *Benthobatis moresbyi*) were missing data needed to calculate F_{MSM}, F_{LIM} and F_{CRASH}, while in the South Pacific Ocean, four (*Echinorhinus cookei*, *Oxynotus bruniensis*, *Mitsukurina owstoni*, *Squalus fernandezianus*) of the 112 species assessed were missing these data.

Chondrichthyan species classified as high or extreme vulnerability across all fisheries (Table 5) in the Southern Indian Ocean included: *Centrophorus granulosus*, *Centroselachus crepidater* and *Zameus squamulosus*. An additional four species were classified as high or extreme vulnerability across demersal trawl, midwater trawl and demersal longline fisheries in the Southern Indian Ocean including: *Dalatias licha*, *Chimaera buccanigella*, *Chimaera didierae* and *Chimaera willwatchi*.

Chondrichthyan species classified as high or extreme risk across all fisheries (Table 6) in the South Pacific Ocean included *Echinorhinus cookei*, *Mitsukurina owstoni*, *Oxynotus bruniensis* and *Squalus fernandezianus*. An additional seven species were classified as high or extreme vulnerability across all fisheries with the exception of midwater trawl in the Southern Indian Ocean including *Dalatias licha*, *Squalus acanthias*, *Deania calcea*, *Centrophorus harrissoni*, *Hydrolagus bemisi*, *Centrophorus squamosus* and *Chimaera carophila*.

A comparison between the PSA and SAFE vulnerability scores for all species in the Southern Indian and South Pacific Oceans is displayed in Figures 2a and 2b. For the Southern Indian Ocean, the results indicate some level of consistency between the PSA and SAFE results for those species at the extreme/high end of the vulnerability spectrum. Conversely, in the South Pacific Ocean, it appeared the PSA was biased towards false negatives, with a large number of species classified as medium vulnerability in the PSA but high or extreme risk in the SAFE. Nonetheless, many species classified as medium vulnerability by the PSA in both the Southern Indian and South Pacific Oceans were ranked as low risk by the SAFE (Figures 2a and 2b).

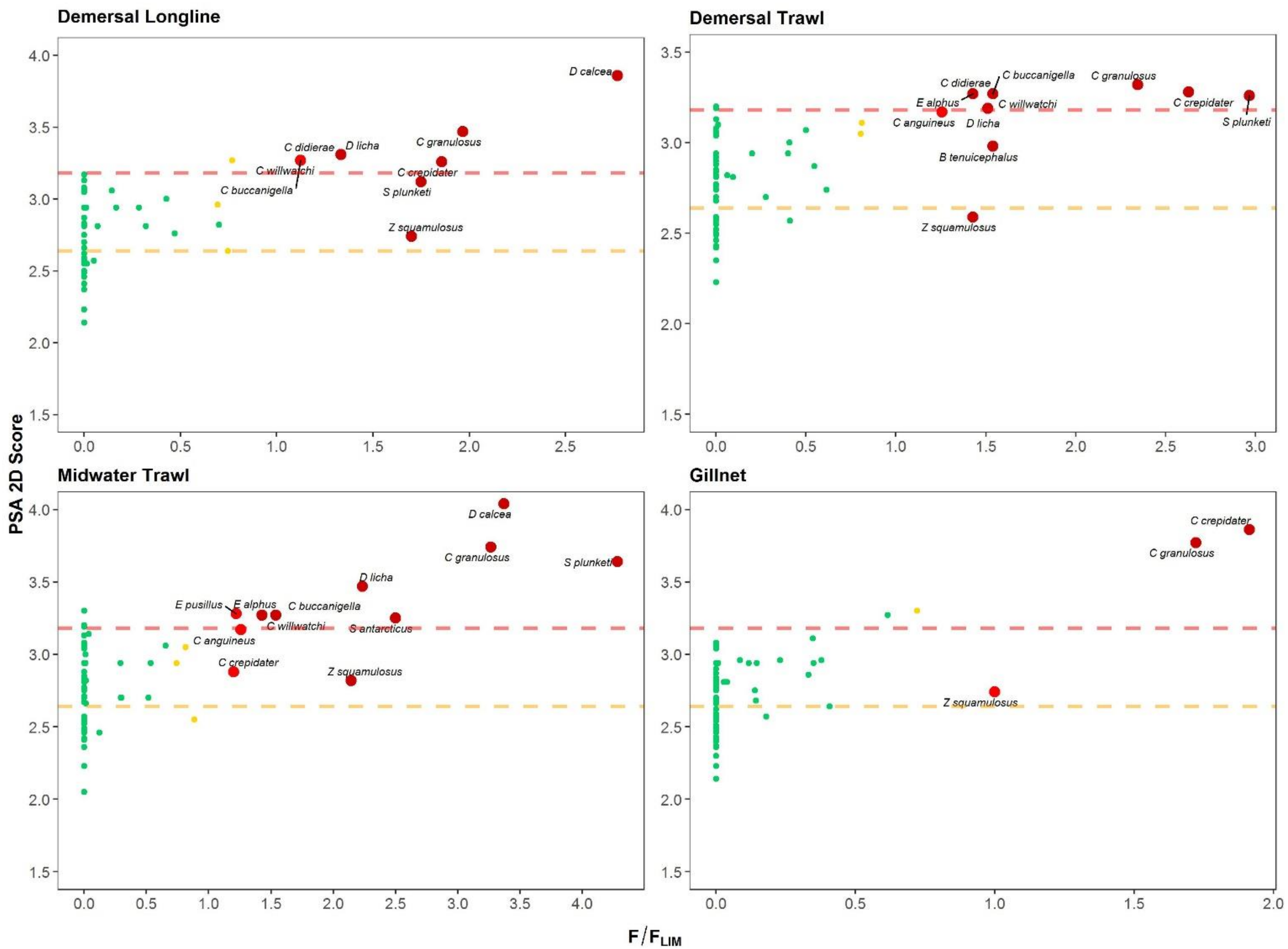

Figure 2a: Relationship between SAFE and PSA results for 101 chondrichthyan species thought to occur and have the potential to interact with demersal longline, demersal trawl, midwater trawl and demersal gillnet fisheries in the Southern Indian Ocean. Points are coloured dark red, light red, orange and green to signify species classified as extreme, high, medium and low vulnerability respectively in the SAFE. Dashed red and orange lines represent PSA risk high and medium score boundaries. Two species are not shown on the panels as *F*-based reference points were unable to be calculated.

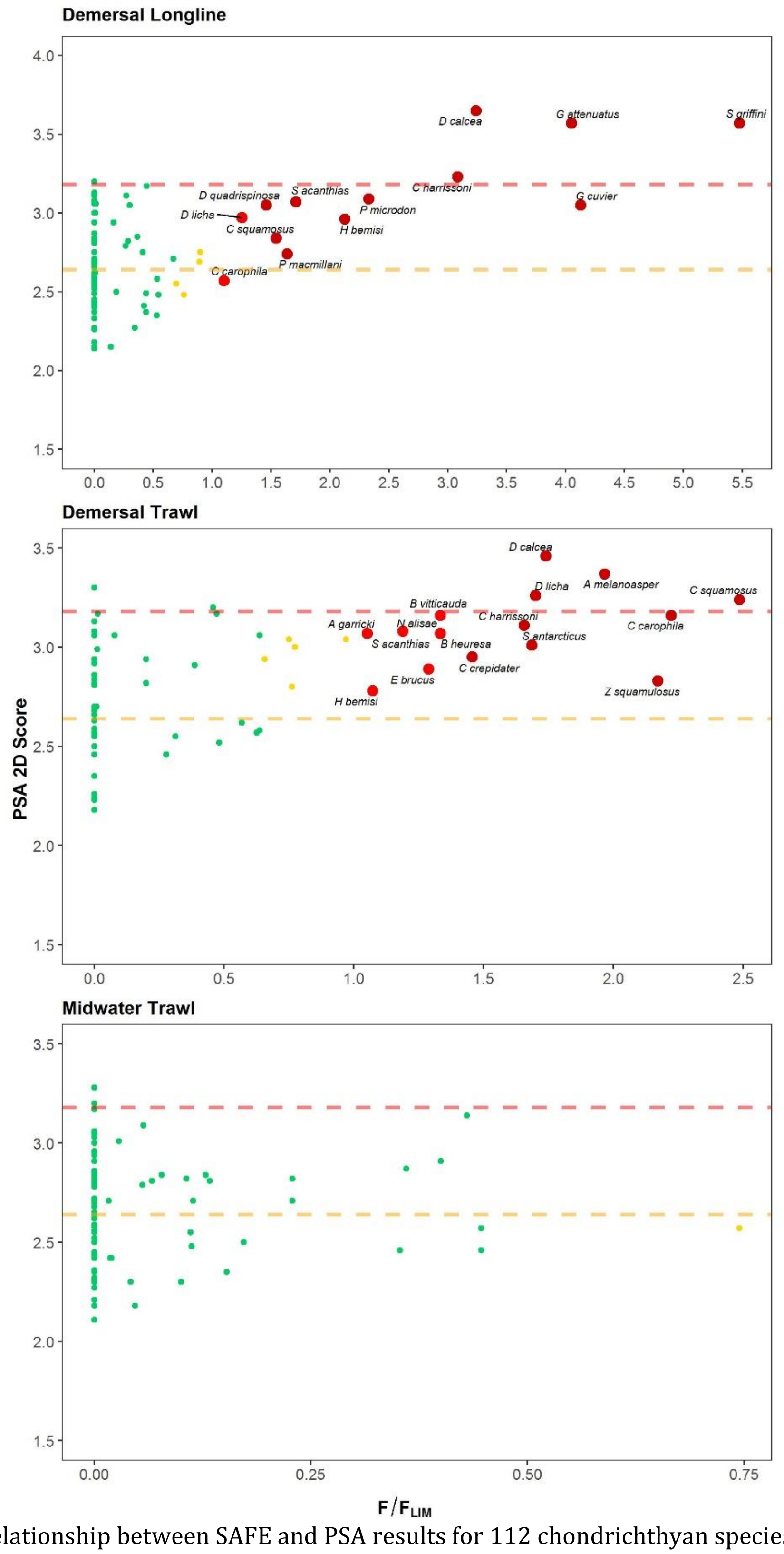

Figure 2b: Relationship between SAFE and PSA results for 112 chondrichthyan species thought to occur and have the potential to interact with demersal longline, demersal trawl and midwater trawl fisheries in the South Pacific Ocean. Points are coloured dark red, light red, orange and green to signify species classified as extreme, high, medium and low vulnerability respectively in the SAFE. Dashed red and orange lines represent PSA risk high and medium score boundaries. Four species are not shown on the panels as *F*-based reference points were unable to be calculated.

Table 4. Count of data robust and data deficient species assessed to be at high vulnerability (PSA) and high and extreme vulnerability (SAFE) for each fishery in the Southern Indian Ocean and South Pacific Ocean. Data deficient species are classified as those missing three or more productivity and/or susceptibility attributes (PSA) and for which *F*-based reference points could not be estimated due to missing biological data (SAFE).

	Southern Indian Ocean								**South Pacific Ocean**					
	Demersal gillnet		**Demersal longline**		**Demersal trawl**		**Midwater trawl**		**Demersal longline**		**Demersal trawl**		**Midwater trawl**	
	PSA	*SAFE*	*PSA*	*SAFE*	*PSA*	*SAFE*	*PSA*	*SAFE*	*PSA*	*SAFE*	*PSA*	*SAFE*	*PSA*	*SAFE*
Data Robust	6	3	8	9	10	11	12	12	6	13	7	16	2	0
Data Deficient	0	1	0	0	0	0	0	0	1	4	1	4	1	4
Total	**6**	**4**	**8**	**9**	**10**	**11**	**12**	**12**	**7**	**17**	**8**	**20**	**3**	**4**

Table 5. Matrix of high (and extreme) vulnerability species from either the PSA or SAFE for each fishery in the Southern Indian Ocean

Southern Indian Ocean	**Demersal longline**		**Demersal trawl**		**Midwater trawl**		**Gillnet**	
Species	**PSA**	**SAFE**	**PSA**	**SAFE**	**PSA**	**SAFE**	**PSA**	**SAFE**
Deania calcea	High	Extreme	Medium	Medium	High	Extreme	Medium	Low
Centrophorus granulosus	High	Extreme	High	Extreme	High	Extreme	High	Extreme
Dalatias licha	High	Extreme	High	Extreme	High	Extreme	High	Medium
Bythaelurus bachi	High	Medium	Medium	Medium	Medium	Medium	Medium	Low
Chimaera buccanigella	High	High	High	Extreme	High	Extreme	High	Low
Chimaera didierae	High	High	High	Extreme	Medium	Low	High	Low
Chimaera willwatchi	High	High	High	Extreme	High	Extreme	High	Low
Centroselachus crepidater	High	Extreme	High	Extreme	Medium	High	High	Extreme
Scymnodon plunketi	Medium	Extreme	High	Extreme	High	Extreme	Medium	Low
Zameus squamulosus	Medium	Extreme	Low	Extreme	Medium	Extreme	Medium	High
Etmopterus alphus	Medium	Medium	High	Extreme	High	Extreme	Medium	Low
Apristurus indicus	Medium	Low	High	Low	High	Low	Medium	Low
Harriotta raleighana	Medium	Low	High	Low	High	Low	Medium	Low
Bythaelurus tenuicephalus	Medium	Medium	Medium	Extreme	Low	Medium	Medium	Low
Chlamydoselachus anguineus	Medium	Low	Medium	High	Medium	High	Medium	Low
Hexanchus nakamurai	Medium	Low	Medium	Low	High	Low	Medium	Low
Etmopterus pusillus	Medium	Low	Medium	Low	High	High	Medium	Low
Somniosus antarcticus	Medium	Low	Medium	Low	High	Extreme	Medium	Low
Mitsukurina owstoni	Medium	Low	Medium	Low	Medium	Low	Medium	Extreme

Table 6. Matrix of high (and extreme) vulnerability species from either the PSA or SAFE for each fishery in the South Pacific Ocean

South Pacific Ocean	Demersal longline		Demersal trawl		Midwater trawl	
Species	**PSA**	**SAFE**	**PSA**	**SAFE**	**PSA**	**SAFE**
Squalus fernandezianus	High	Extreme	High	Extreme	High	Extreme
Deania calcea	High	Extreme	High	Extreme	Medium	Low
Gollum attenuatus	High	Extreme	Medium	Low	Medium	Low
Squalus griffini	High	Extreme	Medium	Medium	Medium	Low
Centrophorus harrissoni	High	Extreme	Medium	Extreme	Medium	Low
Hexanchus nakamurai	High	Low	High	Low	High	Low
Oxynotus bruniensis	High	Extreme	High	Extreme	Medium	Extreme
Mitsukurina owstoni	Medium	Extreme	Medium	Extreme	Medium	Extreme
Echinorhinus cookei	Medium	Extreme	Medium	Extreme	Medium	Extreme
Pseudotriakis microdon	Medium	Extreme	Medium	Medium	Medium	Low
Squalus acanthias	Medium	Extreme	Medium	Extreme	Medium	Low
Deania quadrispinosa	Medium	Extreme	Medium	Medium	Medium	Low
Galeocerdo cuvier	Medium	Extreme	Medium	Low	Medium	Low
Dalatias licha	Medium	High	High	Extreme	Medium	Low
Hydrolagus bemisi	Medium	Extreme	Medium	High	Low	Low
Centrophorus squamosus	Medium	Extreme	High	Extreme	Medium	Low
Parmaturus macmillani	Medium	Extreme	Low	Low	Low	Low
Chimaera carophila	Low	High	Medium	Extreme	Low	Medium
Apristurus melanoasper	Medium	Low	High	Extreme	Medium	Low
Harriotta raleighana	Medium	Low	High	Low	Medium	Low
Brochiraja vitticauda	Low	Low	Medium	High	Low	Low
Notoraja alisae	Low	Low	Medium	High	Low	Low
Brochiraja heuresa	Low	Low	Medium	High	Low	Low
Apristurus garricki	Low	Medium	Medium	High	Low	Low
Somniosus antarcticus	Medium	Medium	Medium	Extreme	Medium	Low
Centroselachus crepidater	Medium	Low	Medium	Extreme	Medium	Low
Echinorhinus brucus	Low	Low	Medium	High	Low	Low
Zameus squamulosus	Low	Low	Medium	Extreme	Low	Low
Lamna nasus	Medium	Low	High	Low	High	Low

Table 7. Sensitivity analysis for Southern Indian and South Pacific Ocean species that change vulnerability categories when *S1: Availability* scores are varied by negative and positive 10%, 20% and 30% increments. Note that X denotes no change.

Fishery	Gear and *Species*	-30	-20	-10	PSA Vulnerability	+10	+20	+30
Southern Indian Ocean	**Demersal trawl**							
	Centrophorus granulosus	Medium	Medium	X	High	X	X	X
	Centroselachus crepidater	Medium	Medium	X	High	X	X	X
	Chlamydoselachus anguineus	X	X	X	Medium	X	High	High
	Dalatias licha	Medium	Medium	Medium	High	X	X	X
	Scymnodon plunketi	Medium	Medium	X	High	X	X	X
	Zameus squamulosus	X	X	X	Low	X	Medium	Medium
	Midwater trawl							
	Chlamydoselachus anguineus	X	X	X	Medium	X	High	High
	Etmopterus pusillus	Medium	Medium	X	High	X	X	X
	Somniosus antarcticus	Medium	Medium	Medium	High	X	X	X
	Zameus squamulosus	X	X	X	Low	X	X	Medium
	Demersal longline							
	Centrophorus granulosus	Medium	X	X	High	X	X	X
	Centroselachus crepidater	Medium	Medium	X	High	X	X	X
	Dalatias licha	Medium	Medium	X	High	X	X	X
	Scymnodon plunketi	X	X	X	Medium	X	High	High
	Demersal gillnet							
	Dalatias licha	Medium	Medium	X	High	X	X	X
South Pacific Ocean	**Demersal trawl**							
	Apristurus ampliceps	X	X	X	Low	Medium	Medium	Medium
	Apristurus exsanguis	X	X	X	Low	X	Medium	Medium
	Centrophorus harrissoni	X	X	X	Medium	X	High	High
	Centrophorus squamosus	Medium	Medium	Medium	High	X	X	X
	Dalatias licha	Medium	Medium	X	High	X	X	X
	Etmopterus molleri	X	X	X	Low	X	Medium	Medium
	Hydrolagus bemisi	Low	X	X	Medium	X	X	X
	Oxynotus bruniensis	Medium	Medium	X	High	X	X	X
	Squalus acanthias	X	X	X	Medium	X	X	High
	Zameus squamulosus	Low	X	X	Medium	X	X	X

	Midwater trawl							
	N/A							
	Demersal longline							
	Centrophorus harrissoni	Medium	Medium	Medium	High	X	X	X
	Etmopterus lucifer	Low	Low		Medium	X	X	X
	Mitsukurina owstoni	X	X	X	Medium	High	High	High
	Oxynotus bruniensis	Medium	Medium	Medium	High	X	X	X
	Pseudotriakis microdon	X	X	X	Medium	X	X	High
	Squalus acanthias	X	X	X	Medium	X	X	High

Recommendations

It is recommended that the SIOFA SERAWG:

- **Note** that this PSA and SAFE analysis has identified a number of species of deepwater chondrichthyans at high or extreme relative vulnerability to fishing using demersal trawl, midwater trawl, demersal longline and demersal gillnet gears;

- **Note** that a number of these species assessed to be at the high or extreme vulnerability are taken in association with commercial deepwater shark fisheries;

- **Note** there is limited catch, effort and biological information for many species of deepwater chondrichthyan;

- **Note** that some species of deepwater chondrichthyans are highly vulnerable to overfishing due to their life history characteristics; and

- **Recommend** that the SC recommend to the Meeting of the Parties that stock assessment for species of deepwater chondrichthyans taken in association with commercial deepwater shark fisheries is urgently required to estimate sustainable yields and mitigate the potential for overexploitation that has been seen in similar fisheries globally.

Acknowledgments

The authors thank representatives of the respective scientific committees of the Southern Indian Ocean Fisheries Agreement (SIOFA) and South Pacific Regional Fisheries Management Organisation (SPRFMO) for their cooperation in providing necessary data and for reviewing results, as well as the respective RFMO/A secretariats. We also thank representatives and members of the Southern Indian Ocean Deepsea Fishers Association, namely Graham Patchell and Brian Flanagan, for their efforts providing relevant bycatch data collected and photographs taken on board FVs Will Watch and Nikko Maru. Martin Cryer (NZ MPI) is thanked for his assistance providing data for South Pacific fisheries. We are grateful for advice received from David Ebert (Pacific Shark Research Center, Moss Landing Marine Laboratories) on the development of species lists and species identification. GIS analysts from the FAO (Emmanuel Blondel and Fabio Carocci) and the IUCN (Max Fancourt) are also thanked for their assistance in providing species distribution data.

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