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Ecological risk assessment in the southern Indian Ocean: Towards better seabird bycatch mitigation

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Abstract

1. Fisheries bycatch has been identified as the most serious threat to many seabird species and there is an increasing awareness of the responsibility of fisheries management bodies to include the impact on non-target species in their management and regulatory frameworks.
2. In 2022, an ecological risk assessment (ERA) for seabirds and fisheries was presented to the Scientific Committee of the Southern Indian Ocean Fisheries Agreement (SIOFA). This ERA identified 32 seabird species that regularly occurred in the SIOFA Area, of which 11 were determined as being at high risk. This high-risk group included 10 albatross species that have the greatest likelihood of interacting with SIOFA managed fisheries in Subareas 1, 2 and 3b (west of 40° E) where they overlap with the pelagic longline fishery.
3. Although the pelagic longline fishery for *Ruvettus pretiosus* is the largest fishery under the auspices of SIOFA, in terms of catch and number of vessels, the existing management measures of SIOFA focused on demersal fisheries and did not include any mitigation requirements for pelagic longlines. In response to the outcomes of the ERA, a proposed amendment to SIOFA's management measures was presented by France to the Meeting of Parties of SIOFA and led to the revision of SIOFA's seabird bycatch mitigation measures in respect of pelagic longlines, making them consistent with those agreed by the Indian Ocean Tuna Commission.
4. Regulatory diffusion, the increased likelihood of adoption of regulation by one agency if that regulation has been adopted by another agency, contributed to the relatively rapid transition from the identification of the risk posed by pelagic longline vessels to the change in regulations to address those risks in SIOFA.

KEYWORDS

bycatch mitigation, endangered species, industrial longline fisheries, regulation, seabirds, Southern Indian Ocean Fisheries Agreement (SIOFA)

1 | INTRODUCTION

Fisheries bycatch has been identified as the most serious threat to many seabird species (Phillips et al., 2016; Dias et al., 2019). In particular, albatrosses and large petrels, that are typically long-lived species, with life-history traits such as delayed maturity and low reproductive rates, are sensitive to even small increases in mortality rates as a result of interaction with fisheries (Hamer, Schreiber & Burger, 2001). Seabirds are attracted to fishing vessels by the availability of fishing waste and baits, which increases the risk of fatal interactions with fishing gear (Phillips et al., 2016). In trawl fisheries, birds can be killed in collisions with warp cables as well as drowning in nets, while in longline fisheries birds are killed when they seize baited hooks at the surface and drown as the line sinks.

There is an increasing awareness of the responsibility of fisheries management bodies to include the impact on non-target species in their management and regulatory frameworks, including through the FAO Code of Conduct for Responsible Fisheries (FAO, 1995; Beal et al., 2021). The increasing availability of examples of successful mitigation measures to reduce seabird bycatch (e.g., Reid, Sullivan & Clark, 2010; Løkkeborg, 2011; Maree et al., 2014; Dasnon et al., 2022) and their formulation into best practice advice by The Agreement on the Conservation of Albatrosses and Petrels (ACAP https://www.acap.aq/resources/bycatch-mitigation/mitigation-advice) provides a sound basis for addressing seabird bycatch issues.

In 2021, the Scientific Committee of the Southern Indian Ocean Fisheries Agreement (SIOFA) recommended an ecological risk assessment (ERA) approach for seabirds and SIOFA fisheries, requiring a review of the effectiveness of SIOFA's existing measures to address seabird bycatch (SIOFA, 2021b). Undertaking an ERA of this type provides a formal mechanism to determine:

i. which taxa are at risk from interactions with fisheries;
ii. the particular fisheries, areas and/or times of year when interactions occur; and
iii. the actions, including research, that can be taken to better quantify and mitigate any impacts.

Approaches to conducting ERAs for seabirds have been applied in several fisheries management bodies that are relevant to SIOFA as they involve many of the same seabird species and fishery types (Waugh et al., 2012; Small, Waugh & Phillips, 2013). Although the details of the methods and implementation of ERAs differ between organizations, the overarching principles are generally consistent with the tiered approach developed by Hobday et al. (2011). The principle elements of the tiered approach to ERA are:

Level 1. provides a comprehensive process that examines the distribution of species and activities of interest to establish qualitative measures of the scale, intensity and consequence of any interactions;

Level 2. a semi-quantitative productivity–susceptibility analysis that further develops the potential consequences of any interactions on species of interest; and

Level 3. a highly quantitative, model-based analysis, involving the taxa identified as being at high risk in the Levels 1 and 2 analyses.

In developing an ERA, it is essential that the interpretation of the outputs is guided by data availability and the assumptions that are made where data are scarce and/or missing. Fortunately, the tiered approach provides a mechanism to progress an ERA that takes account of, but is not curtailed by, these concerns when assembling the comprehensive information needed to categorize the scale and intensity aspects of a Level 1 assessment and the semi-quantitative level 2 assessment.

Collating all available data to determine which species of seabirds should be included in an ERA across the entire SIOFA area, an area of 27 million km^2 that extends from the tropics to the subantarctic (Figure 1), is inherently challenging. However, the aim here is to ensure that while such a list of species may not be comprehensive, it should be representative of the biology and ecology of all species that are likely to interact with fisheries in the southern Indian Ocean region (see, e.g., Le Corre et al., 2012; Delord et al., 2013; Delord et al., 2014). This means that any species that occur in the area, but are not explicitly included, would be likely to share the ecological and behavioural traits that guide the development of mitigation strategies and would therefore benefit from the introduction of such measures.

The main fisheries under the jurisdiction of SIOFA (see SIOFA, 2022a) are conducted by trawl vessels that predominantly target alfonsino (*Beryx* spp.) and orange roughy (*Hoplostethus atlanticus*); demersal longline vessels that target Patagonian toothfish (*Dissostichus eleginoides*), and/or other deep-water species such as wreckfish (*Polyprion* spp.) and bluenose warehou (*Hyperoglyphe antarctica*); and pelagic longline vessels that target 'oilfish' (described as including oilfish *Ruvettus pretiosus* and escolar *Lepidocybium flavobrunneum*; Delegation of Chinese Taipei, 2022). All of these fishery types are known to have high seabird bycatch rates based on data from other fisheries for these target species (or similar species) which use the same gear types (Dias et al., 2019).

The aims of this study were to:

i. undertake a multi-species, level 2 ERA for seabirds in the SIOFA Area, to identify the species and fishery types where the greatest risks occurred;
ii. propose potential mitigation actions that could be implemented to address those risks; and
iii. review the policy mechanisms involved in adopting regulations to reduce risks to seabirds.

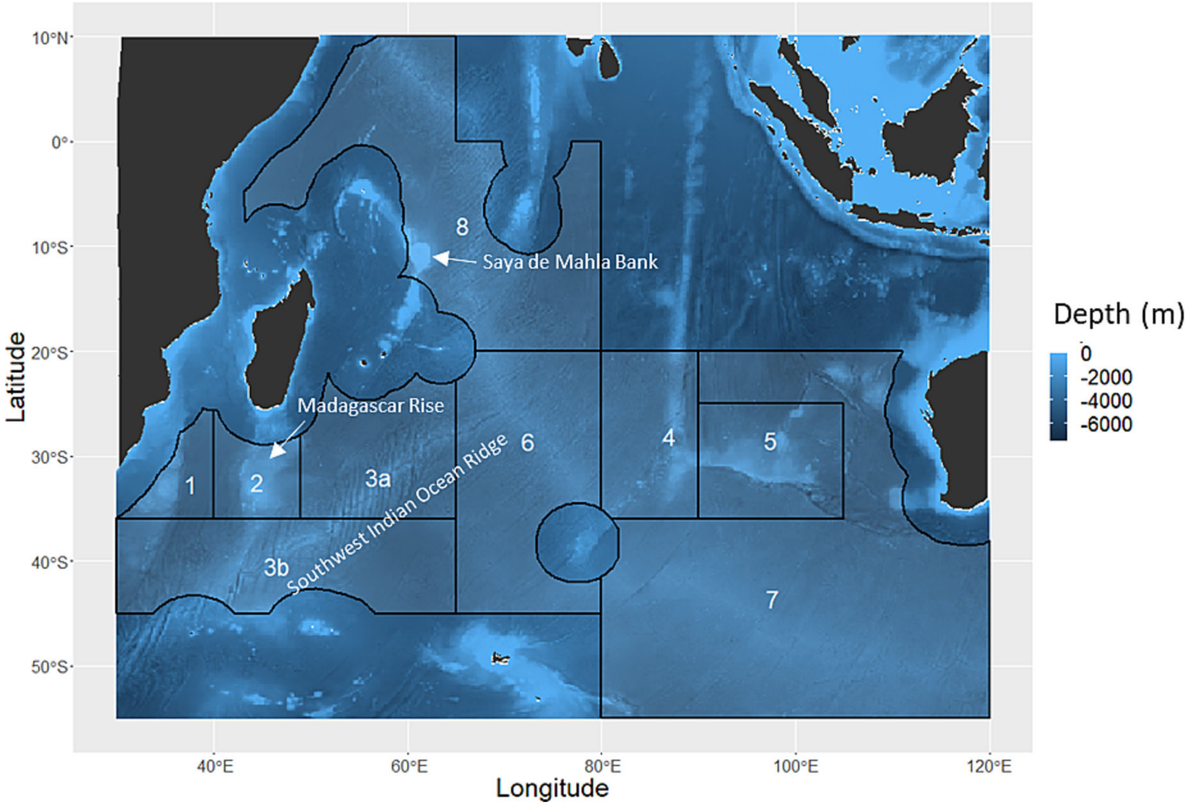

FIGURE 1 The Southern Indian Ocean Fisheries Agreement Area with subareas labelled numerically, important geographic features mentioned in the text are labelled.

2 | METHODS

2.1 | Fishing distribution

Fishing data were made available from the SIOFA Secretariat for the period 2016 to 2020 with catch and effort data summed into 5° latitude × 5° longitude cells for each fishery type (i.e., trawl, demersal longline, pelagic longline and hand-operated line) in the SIOFA Area.

2.2 | Seabirds

For seabird species that occur, or are likely to occur, in the SIOFA Area, the following information was compiled for each species:

i. Conservation status and population trend.
ii. Key biological parameters including clutch size and age at first breeding.
iii. Susceptibility to fisheries interaction.

Based on the approach of Baker et al. (2002), all species of flying seabirds exceeding ~500 g in weight that occur in the Indian Ocean were included (i.e., all albatross, both species of giant petrel, all *Procellaria* petrels, all shearwaters and some *Pterodroma* petrels). Other species that have been observed interacting with fishing vessels, including those vessels operating in the Indian Ocean, were also included. Data on seabird distribution, conservation status, population status, overlap and likelihood of interacting with fisheries and vital rates were obtained from species assessments developed by ACAP (http://www.acap.au), the International Union for Conservation of Nature (IUCN https://www.iucnredlist.org/), Carneiro et al. (2020) and the BirdLife International Seabird Tracking Database (http://www.seabirdtracking.org/).

The extent of overlap with each fishery/gear type for those species included in Carneiro et al. (2020) was the proportion of 5° × 5° cells in which the fishery occurred, which were also used by the species of interest based on the 5° × 5° utilization maps downloaded from https://datadryad.org/stash/dataset/doi:10.5061/dryad.z612jm685. For other species the extent of overlap was based on visual comparison of the species distribution maps at https://www.iucnredlist.org/.

The data on each species and the spatial overlap with fishing activity were used to produce a risk score (modified from Baker & Wanless (2010) and references therein) for that species-fishing activity combination according to the following scoring procedure:

a. IUCN status: Critically Endangered = 3, Endangered = 2, Vulnerable = 1, Near Threatened = 0.5 and Least Concern = 0.
b. Breeding population status: decline = 2, stable = 1, increase = 0 and unknown = 1.

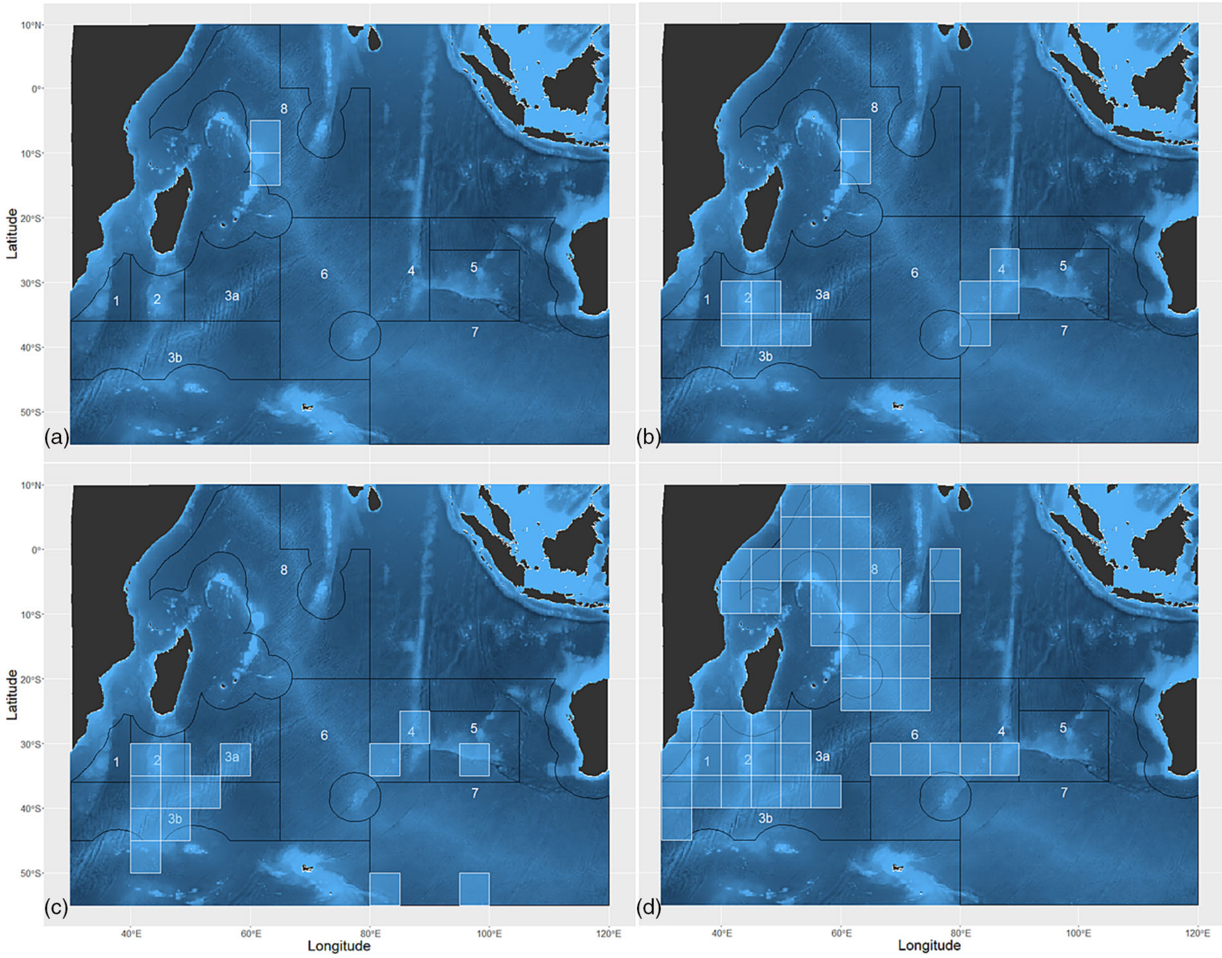

FIGURE 2 Fishing occurrence in Southern Indian Ocean Fisheries Agreement fisheries by gear type in 5° × 5° cells (white cells) for (a) hand-operated pole and line, (b) trawl, (c) demersal longline and (d) pelagic longline. Southern Indian Ocean Fisheries Agreement subareas and bathymetry scale are as in Figure 1.

c. Degree of overlap with SIOFA fishery: high (≥60%) = 3, medium (25% to 59%) = 2, low (≤25%) = 1. Where there were different scores for an individual species (e.g., by season or by fishery), the overlap was scored according to the higher value.
d. Behavioural exposure (Vulnerability) to capture: high = 3, medium = 2, low = 1, based on the tendency to follow fishing vessels and relative incidence in bycatch other fisheries based on species assessments for albatrosses and petrels developed by ACAP (https://www.acap.aq/resources/acap-species).
e. Susceptibility measure (S) – the mean of scores for (a) to (d).
f. Life-history strategy: biennial breeder, single egg clutch = 3, annual breeder, single egg clutch = 2, annual breeder, multiple egg clutch = 1.
g. Median age at first breeding: ≤5 years = 1, 5–7.5 years = 2, ≥7.5 years = 3.
h. Productivity measure (P) – the mean of the scores for (f) life-history strategy and (g) median age of first breeding.

The measures of relative risk (R) for each species were then estimated following the method of Williams et al. (2011) as the Euclidean distance from the species to the origin for a simple two-dimensional plot of productivity (P) on susceptibility (S) such that $R = ((P)^2 + (S)^2)^{1/2}$. All analyses were conducted in R (v4.1.2; R Core Team, 2022).

3 | RESULTS

Hand-operated pole and line fisheries were conducted in SIOFA Subarea 8 in the region of the Saya de Mahla Bank (Figure 2a). Trawl fishing occurred in 11 of the 5° × 5° cells on the Madagascar rise and the South-west Indian Ocean Ridge between 40° and 60° E (SIOFA Subareas 2 and 3), the ridges in western Indian Ocean in SIOFA Subarea 4 and in SIOFA Subarea 8 in the region on the Saya de Mahla Bank (Figure 2b). Demersal longline fishing occurred in 14 of the 5° × 5° cells, primarily on the Madagascar Rise and the South-west Indian Ocean Ridge between 40° and 60° E in SIOFA Subareas 2 and 3: with fishing also in SIOFA Subareas 4, 5 and 7 (Figure 2c). Pelagic longline fishing has the widest spatial distribution, occurring in 50 of the 5° × 5° cells, with fishing taking place mainly west of 80° E (Figure 2d).

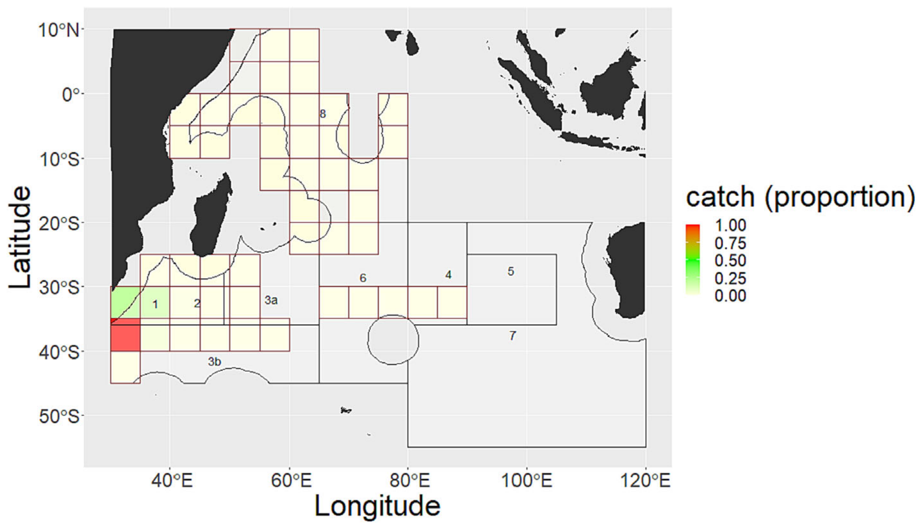

FIGURE 3 Spatial distribution of the proportion of the total catches in pelagic longline fishing in the Southern Indian Ocean Fisheries Agreement Area.

There are large differences in the levels of fishing effort between the trawl ($n = 3$ registered vessels), demersal longline ($n = 4$ registered vessels) and pelagic longline ($n = 49$ registered vessels) fisheries (https://www.apsoi.org/mcs/authorised-vessels). This is also reflected in the relative catches with more than 50% of all catches reported from SIOFA fisheries during the period 2017–2020 taken by pelagic longline (see Annex D of SIOFA, 2022a). Although the extent of occurrence of pelagic longlines is greater than the other fisheries, the distribution of catches was highly concentrated in Subareas 1 and 3b in the south-west part of the SIOFA Area (Figure 3).

There were 32 seabird species that were identified as regularly occurring in the SIOFA area (Table 1). The list of 32 seabird species included, *inter alia*, 14 species of albatross, two giant petrels, five shearwaters, three *Pterodroma* petrels, two *Procellaria* petrels and two penguins. The seabird overlap scores were similar for trawl and demersal longline fishing, reflecting their similar distribution and extent, the overlap values with pelagic longline were lower (Table 2).

Examples of the spatial utilization in the SIOFA Area of different seabird species (Figure 4) illustrate the differences in utilization distribution for four albatross species. Amsterdam albatross from Amsterdam Island were distributed across a broad longitudinal range between 30° and 40° S; wandering albatross from South Georgia and sooty albatross were predominantly west of 80° E and between 35° and 45° S; white-capped albatross from Auckland Island were predominantly east of 80° E and between 30° and 45° S; and Tristan albatross from Gough Island were predominantly west of 60° E and between 30° and 45° S.

The results of the risk assessment scoring (Table 3) are ranked according to the total risk score for each species. The risk scores ranged from 1.8 to 4.07, and of the 32 species comprised, 11 species with a risk score of ≥3 (high risk), 11 species with scores ≥2.5–<3 (medium risk) and 10 species with risk scores <2.5 (low risk). Species with a high-risk score included 10 albatrosses and one *Pterodroma* petrel. The highest risk score was for Tristan albatross, while all of the *Diomedea* albatrosses (wandering, antipodean, Amsterdam and northern royal) as well as Barau's petrel were also in the high-risk group of species.

4 | DISCUSSION

4.1 | Identification of risk

Overall, the ERAs for seabirds identified that the highest risk species have the greatest likelihood of interacting with SIOFA fisheries in SIOFA Subareas 1, 2 and 3b (west of 40° E). This sector has the greatest density of utilization by the highest at-risk seabirds; indeed, the highest density of Tristan albatross occurs in the same 5° cell as the greatest proportion of catches taken with pelagic longlines. The non-breeding distribution of Barau's petrel (Pinet et al., 2011) indicates that they may overlap with pelagic longline fishing in the southern section of Subarea 8. It is apparent that while the majority of the high-risk seabird species overlap with all fishery types in the SIOFA Area, the greatest likelihood of interactions is with the pelagic longline fishery.

Chinese Taipei reported that between 9 and 45 vessels fished for oilfish from 2000 to 2019; the largest number of vessels in any fishery in SIOFA (SIOFA, 2022a). The area where the majority of the oilfish catches are taken (and by inference the area of highest effort) in the pelagic longline fishery is west of 45° E in SIOFA Subareas 2 and 3b; an area in which many of the same pelagic longline vessels are known to catch high-risk seabirds including wandering, sooty and grey-headed albatrosses (Huang & Liu, 2010).

The impacts of catching high-risk seabird species in pelagic and demersal longline fisheries is well documented (e.g., Barbraud et al., 2012; Clay et al., 2019) and the risks can be substantially reduced through the implementation of the mitigation measures outlined in ACAP's best practice advice (Dasnon et al., 2022). These measures aim to reduce the potential for seabirds to access baited hooks through branch line weighting, setting at night to avoid capture of diurnal feeding albatrosses and using bird-scaring (tori) lines when lines are

TABLE 1 Characteristics of seabirds known or likely to be caught in SIOFA longline fisheries.

Species	Scientific name	Indian Ocean status	IUCN status	Pop trend	SIOFA overlap	Vulnerability	Life-history characteristics	Median age at first breeding
King penguin	*Aptenodytes patagonicus*	B	LC	I	Low	Low	3	5
Northern rockhopper penguin	*Eudyptes moseleyi*	B	En	D	Low	Low	2	4.7
Wandering albatross	*Diomedea exulans*	B	Vu	D	Medium	High	3	9
Antipodean albatross	*Diomedea antipodensis*	M	En	D	Low	High	3	9*
Amsterdam albatross	*Diomedea amsterdamensis*	B	En	I	High	High	3	9*
Tristan albatross	*Diomedea dabbenena*	M	Cr	D	High	High	3	9.7
Northern royal albatross	*Diomedea sanfordi*	M	En	D	Medium	High	3	8
Sooty albatross	*Phoebetria fusca*	B	En	D	High	Low	3	10
Light-mantled albatross	*Phoebetria palpebrata*	B	NT	D	Medium	Low	3	7
Black-browed albatross	*Thalassarche melanophrys*	B	LC	I	Medium	High	2	9
Campbell albatross	*Thalassarche impavida*	M	Vu	I	Low	High	2	9*
Shy albatross	*Thalassarche cauta*	M	NT	S	Low	High	2	7*
White-capped albatross	*Thalassarche steadi*	M	NT	D	Medium	High	3	7*
Grey-headed albatross	*Thalassarche chrysostoma*	B	En	D	Medium	High	3	10
Atlantic yellow-nosed albatross	*Thalassarche chlororhynchos*	M	En	D	Low	High	2	9
Indian yellow-nosed albatross	*Thalassarche carteri*	B	En	D	High	High	2	9
Southern giant petrel	*Macronectes giganteus*	B	LC	I	Medium	Low	2	7
Northern giant petrel	*Macronectes halli*	B	LC	I	Medium	Low	2	7
Southern fulmar	*Fulmarus glacialoides*	M	LC	S	Low	Low	2	10
Cape petrel	*Daption capense*	B	LC	S	Medium	Low	2	5
Great-winged petrel	*Pterodroma macroptera*	B	LC	D	Medium	Medium	2	6.5
White-headed petrel	*Pterodroma lessonii*	B	LC	D	Medium	Low	3	6.5*
Barau's petrel	*Pterodroma baraui*	B	En	D	Medium	Low	3	6.5*
Grey petrel	*Procellaria cinerea*	B	NT	D	Low	High	2	7
White-chinned petrel	*Procellaria aequinoctialis*	B	Vu	D	Medium	High	2	6.5
Wedge-tailed shearwater	*Ardenna pacifica*	B	LC	D	Medium	Low	2	6*
Short-tailed shearwater	*Ardenna tenuirostris*	M	LC	D	Low	High	2	6*
Sooty shearwater	*Ardenna grisea*	M	NT	D	Low	High	2	6

TABLE 1 (Continued)

Species	Scientific name	Indian Ocean status	IUCN status	Pop trend	SIOFA overlap	Vulnerability	Life-history characteristics	Median age at first breeding
Great shearwater	*Ardenna gravis*	M	LC	S	Low	High	2	6
Flesh-footed shearwater	*Ardenna carneipes*	B	NT	D	Low	High	2	6*
Cory's shearwater	*Calonectris borealis*	M	LC	U	Low	Low	2	6.5
Cape gannet	*Morus capensis*	B	En	D	Low	Low	2	3.5

Note: In compiling this list species, it is acknowledged that species such as southern royal albatross (*Diomedea epomophora*), Salvin's albatross (*Thalassarche salvini*), Buller's albatross (*Thalassarche bulleri*) and streaked shearwater (*Calonectris leucomelas*) are known to occur occasionally in the Indian Ocean; however, the available tracking data suggest that these species occur predominantly/exclusively in the Pacific Ocean and are not likely to be routinely recorded in the Indian Ocean. Indian Ocean Status: B – breeding population in Indian Ocean; M – breeds elsewhere but migrates to Indian Ocean during non-breeding period. IUCN status: Cr – Critically Endangered; En – Endangered; Vu – Vulnerable; NT – Near Threatened; LC – Least Concern (as at September 2022). Population trend: D – declining; S – stable; I – increasing; U – unknown. SIOFA Overlap: spatial overlap with SIOFA fisheries based on Carneiro et al. (2020) or visual comparison with BirdLife tracking analyses. Vulnerability: Behavioural susceptibility to capture – based on tendency to follow fishing vessels and relative bycatch rate. Life-history characteristics: 3 (biennial, one egg clutch); 2 (annual, one egg clutch); 1 (annual, >1 egg clutch). Median age at first breeding: * refers to data that were estimated based on similar species.

TABLE 2 Seabird overlap (%) for demersal longline, trawl and pelagic longline fisheries in SIOFA based for those species included in Carneiro et al. (2020).

Species	Demersal longline	Trawl	Pelagic longline
Amsterdam albatross	36	100	32
Antipodean albatross	0	0	0
Atlantic yellow-nosed albatross	0	0	6
Black-browed albatross	36	67	20
Grey-headed albatross	45	33	14
Grey petrel	27	0	8
Indian yellow-nosed albatross	18	67	10
Light-mantled albatross	36	0	0
Northern giant petrel	0	0	0
Northern royal albatross	36	0	16
Sooty albatross	36	33	2
Southern giant petrel	55	67	26
Tristan albatross	45	0	14
Wandering albatross	45	67	30
White-capped albatross	45	33	22
White-chinned petrel	45	33	16

being set. Prior to the risk assessment SIOFA had adopted *CMM 2019/13 Conservation and Management Measure on mitigation of seabird bycatch in demersal longlines and other demersal fishing gears fisheries (Mitigation of Seabirds Bycatch)* in which it notes that ACAP has provided best practice seabird bycatch mitigation measures for demersal trawls and longlines. However, CMM 2019/13 makes no specific reference to pelagic longline gear despite this being the largest fishery in SIOFA, in terms of catch and number of vessels. This is also the method of fishing that poses some of the greatest risks to the incidental catch of high-risk seabird species, especially the critically endangered and endangered species of *Diomedea* albatrosses.

Data-limited approaches are becoming increasingly accepted as an integral part of a precautionary approach to fisheries management as they reduce the risks associated with waiting until there are sufficient data before management action can be taken. The tiered approach to ERA provides a framework in which the available data, however limited, can be used to advance management advice. This means that interpretation of, and especially the comparison between, risk scores should be approached with an awareness of the differences in the information available. For example, when considering the risk scores for Amsterdam albatross relative to other species it is important to recognize that while the population is increasing this remains an Endangered species, with a population of only circa 300 individuals (Rivalan et al., 2010; Centre d'Etudes Biologiques de Chizé CEBC-CNRS Marine Top Predator Team, unpublished data).

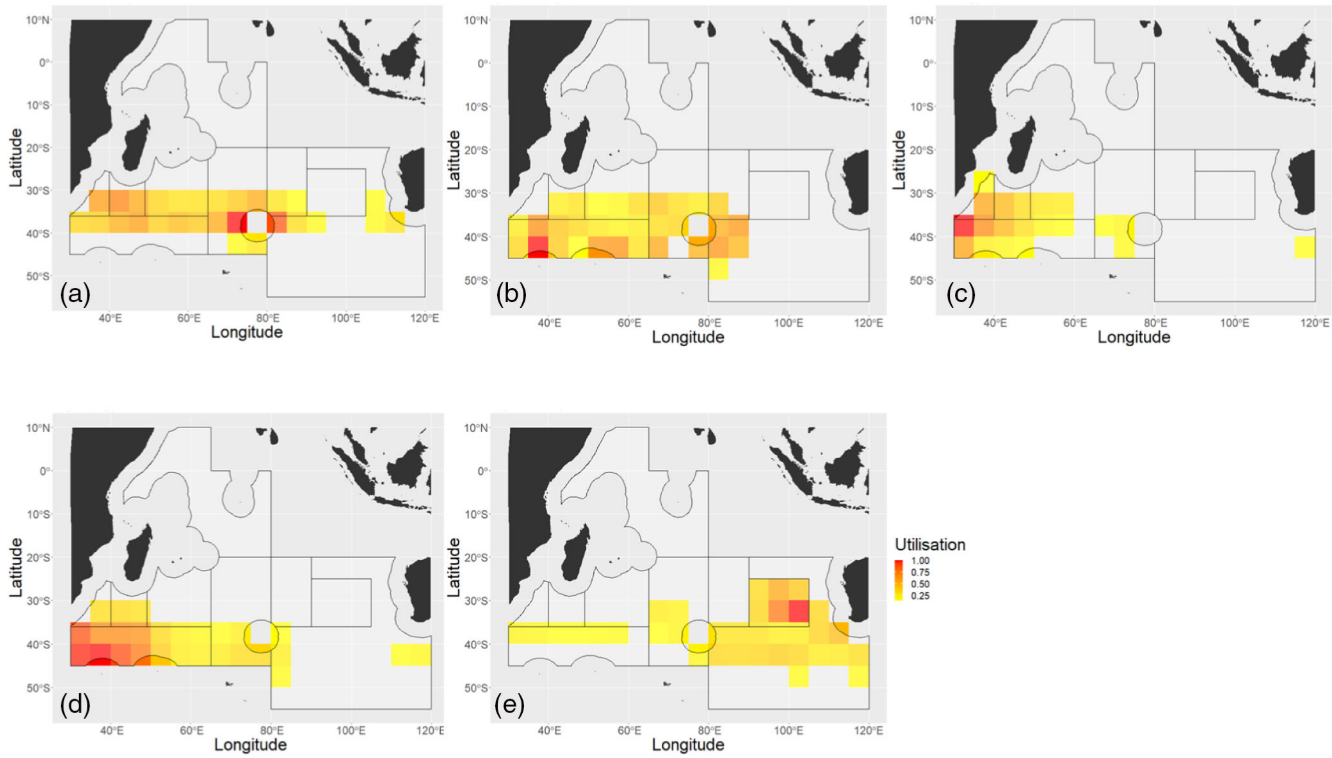

FIGURE 4 Relative proportion of utilization of 5° × 5° cells in the Southern Indian Ocean Fisheries Agreement Area (from Carneiro et al., 2020), the relative utilization is scaled individually for each of (a) Amsterdam albatross (tracked from Amsterdam Island), (b) sooty albatross (tracked from Marion Island), (c) Tristan albatross (tracked from Gough Island), (d) wandering albatross (tracked from South Georgia) and (e) white-capped albatross (tracked from Auckland Island).

4.2 | Management action

At the third meeting of SIOFA's Stock and Ecological Risk Assessment Working Group in 2021, France (Overseas Territories) led discussions on seabird distributions in the southern Indian Ocean and recommended that an ERA and overlap analysis be conducted to determine the risks to seabird in SIOFA fisheries (SIOFA, 2021a) this request was endorsed by the Sixth Meeting of the Scientific Committee of SIOFA (SIOFA, 2021b). The Seventh Meeting of the Scientific Committee of SIOFA (SC7) in 2022 considered the results of the ERA and overlap analysis included herein and recommended that pelagic longliners operating in the SIOFA Area follow Indian Ocean Tuna Commission (IOTC) *Resolution 12/06 On reducing the incidental bycatch of seabirds in longline fisheries* (SIOFA, 2022a). This Resolution requires all longline vessels fishing south of 25° S, to use at least two of the following three mitigation measures: night setting with minimum deck lighting; bird-scaring lines (tori lines); or line weighting.

At the Ninth Meeting of Parties to SIOFA France presented a proposal (France [Overseas Territories], 2022) to amend CMM 2019/13 on the mitigation of seabird bycatch to reflect the recommendation made by the SC7, which subsequently led to adoption of a revised CMM 2019/13 that now includes seabird mitigation requirements for pelagic longline vessels (SIOFA, 2022b).

The SIOFA Agreement covers fishery resources excluding highly migratory species, specifically the tuna and tuna-like species listed in Annex I of the United Nations Convention on the Law of the Sea (UNCLOS), as the latter fall under the management remit of the tuna Regional Fisheries Management Organizations (t-RFMOs), with the relevant t-RFMO for the Indian Ocean being the IOTC. For this reason, much of the discussion in SIOFA has focused on trawl and demersal longline fisheries and relatively little attention has been given to the pelagic longline fishery. However, oilfish (and escolar), while not included in Annex 1 of UNCLOS, are caught using the same pelagic longline gear as tuna; indeed, both species are frequently reported as bycatch in tuna fisheries and, conversely, tuna are the largest bycatch in the SIOFA oilfish fishery. In terms of the impact of fishing on seabirds, it is important to focus on the risks posed by particular gear types, irrespective of the target species, but also to recognize that the regulatory body responsible for implementing the required mitigation measures may be determined by the principal target species.

The challenge for SIOFA is now to monitor the implementation of the new requirements within its own compliance assessment processes to ensure that the mitigation measures achieve their objective of reducing the incidental mortality of at-risk seabirds. Scientific observers have played an important role in monitoring the implementation and effectiveness of seabird bycatch mitigation (Good et al., 2020). However, SIOFA currently has no requirement for observer coverage in the pelagic longline fishery, whereas SIOFA CMM 2021/2 requires 100% observer coverage in trawl fisheries and 20% coverage in all other demersal fisheries.

TABLE 3 Ecological risk assessment scores for seabirds interacting with SIOFA fisheries (see methods for description of risk scoring).

Species	IUCN	Pop trend	Overlap	Vulnerability	Life history	First breeding	S	P	Risk
Tristan albatross	3	2	3	3	3	3	2.75	3.00	4.07
Wandering albatross	1	2	3	3	3	3	2.25	3.00	3.75
Northern royal albatross	2	2	2	3	3	3	2.25	3.00	3.75
Grey-headed albatross	2	2	2	3	3	3	2.25	3.00	3.75
Antipodean albatross	2	2	1	3	3	3	2.00	3.00	3.61
Sooty albatross	2	2	3	1	3	3	2.00	3.00	3.61
Amsterdam albatross	2	0	2	3	3	3	1.75	3.00	3.47
Atlantic yellow-nosed albatross	2	2	1	3	2	3	2.00	2.50	3.20
Indian yellow-nosed albatross	2	2	1	3	2	3	2.00	2.50	3.20
White-capped albatross	0.5	2	2	3	3	2	1.88	2.50	3.13
Barau's petrel	2	2	2	1	3	2	1.75	2.50	3.05
White-chinned petrel	1	2	2	3	2	2	2.00	2.00	2.83
Black-browed albatross	0	0	2	3	2	3	1.25	2.50	2.80
Campbell albatross	1	0	1	3	2	3	1.25	2.50	2.80
White-headed petrel	0	2	2	1	3	2	1.25	2.50	2.80
Light-mantled albatross	0.5	2	1	1	3	2	1.13	2.50	2.74
Southern fulmar	0	1	1	1	2	3	0.75	2.50	2.61
Grey petrel	0.5	2	1	3	2	2	1.63	2.00	2.58
Sooty shearwater	0.5	2	1	3	2	2	1.63	2.00	2.58
Flesh-footed shearwater	0.5	2	1	3	2	2	1.63	2.00	2.58
Great-winged petrel	0	2	2	2	2	2	1.50	2.00	2.50
Short-tailed shearwater	0	2	1	3	2	2	1.50	2.00	2.50
Shy albatross	0.5	1	1	3	2	2	1.38	2.00	2.43
Wedge-tailed shearwater	0	2	2	1	2	2	1.25	2.00	2.36
Great shearwater	0	1	1	3	2	2	1.25	2.00	2.36
Southern giant petrel	0	0	2	1	2	2	0.75	2.00	2.14
Northern giant petrel	0	0	2	1	2	2	0.75	2.00	2.14
Cory's shearwater	0	1	1	1	2	2	0.75	2.00	2.14
Northern rockhopper penguin	2	2	1	1	2	1	1.50	1.50	2.12
Cape gannet	2	2	1	1	2	1	1.50	1.50	2.12
King penguin	0	0	1	1	3	1	0.50	2.00	2.06
Cape petrel	0	1	2	1	2	1	1.00	1.50	1.80

A key element in the rapid progression from the scientific process in the ERA to implementing a change in the management regulations was undoubtedly the availability of suitable regulations that had already been agreed to by the IOTC. This is an example of regulatory diffusion, where the adoption of regulation by one agency increases the likelihood of the adoption of that regulation by another agency (Nou & Nyarko, 2022). Indeed, when the IOTC agreed Resolution 12/06 it noted that the amendments to the existing seabird related measures would 'harmonise the measure' with that adopted by the International Commission for the Conservation of Atlantic Tunas in 2011. Regulatory diffusion is an important consideration in the development of policy across many disciplines (Nou & Nyarko, 2022). It is recognized as delivering efficiencies in relation to the drafting, negotiation and implementation of a new legal text; however, it can also act to retain outdated solutions at the expense of innovation. In the case of the pelagic longline mitigation measures agreed in SIOFA, regulatory diffusion made a positive contribution to the relatively rapid transition from the identification of the risk to the change in regulations to address those risks. It may also facilitate a positive approach for introducing a requirement for scientific observers in the pelagic longline fishery in SIOFA.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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