Ecological risk assessment of cetaceans to Indian Ocean tuna fisheries

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Abstract

Bycatch, or the incidental capture in fishing gears, is the most significant threat to marine megafauna in the world's oceans. It is currently the main driver of the decline and extirpation of cetaceans (whales, dolphins and porpoises) in many regions around the globe, both in coastal and open-ocean ecosystems. However, the magnitude of bycatch remains poorly quantified in many regions and fisheries. Over the past decade, there has been increasing concerns about the extent of cetacean bycatch in the Indian Ocean, particularly in expanding drift gillnet fisheries. Here, an ecological risk assessment including a productivity-susceptibility analysis (PSA) designed for data-poor situations was adapted to investigate the vulnerability of cetaceans to bycatch in tuna fisheries, particularly in drift gillnets, pelagic longlines, and purse seines within the IOTC (Indian Ocean Tuna Commission) Area Of Competence. The PSA revealed that risk varies greatly between gears and species. Overall, risk is higher and for more species in drift gillnets than in pelagic longlines and purse seines. Species at higher risk include oceanic small delphinids, medium-sized delphinids, and, to a much lesser extent, baleen whales. For pelagic longline fisheries, risk was also relatively high for several large oceanic delphinids. Risk for purse seine fisheries was lower than for other gears, but was relatively high for some baleen whales (particularly *B. edeni*). Most species with high susceptibility to capture also had high vulnerability scores based on their life history traits. Overall, the highest vulnerability scores were for gillnets across all species, but particularly small oceanic dolphins. An assessment of the spatial overlap between cetacean occurrence generated by AquaMaps (https://www.aquamaps.org) and tuna fishing effort also allowed assessment of vulnerability of species groups for each gear. The spatial overlap between gillnet fisheries and baleen whales is limited to the northern portion of the Indian Ocean. Small and large oceanic dolphins exhibit similar patterns of overlap for all three gears, with high overlap in the northern Indian Ocean with gillnets, and with pelagic longlines and purse seines in the western tropical Indian Ocean. Large toothed whale distribution overlaps extensively with the three gears, including gillnets in the northern Indian Ocean and pelagic longlines in the southern and southwestern parts of the IOTC area. Overall, this study highlights the need to better quantify cetacean bycatch in Indian Ocean tuna fisheries, particularly in gillnet fisheries.

1. Introduction

Despite decades of research and assessments around the globe, the incidental capture (commonly defined as bycatch) of marine megafauna (sea turtles, marine mammals, sea turtles, seabirds, elasmobranchs) is the most significant threat to these long-lived species globally (Lewison *et al.* 2004, Dulvy *et al.* 2008, Wallace *et al.* 2010, Molina and Cooke 2012). It is particularly the case for cetaceans (whales, dolphins and porpoises) that interact with both commercial, artisanal and subsistence fisheries from coastal to open-ocean ecosystems (Read *et al.* 2006, Reeves *et al.* 2013, Brownell *et al.* 2019). However, there are still few empirical estimates of cetacean bycatch around the globe and mitigation measures have been tested and used for only a limited number of fisheries.

The first human-caused extinction of a cetacean in 2006 was the baiji (*Lipotes vexilifer*), endemic to the Yangtze River, which is attributed largely to bycatch (Turvey *et al.* 2007). In the northern Gulf of California, the vaquita (*Phocoena sinus*) could go extinct in the near future due to unsustainable bycatch levels in gillnets (Rojas-Bracho and Reeves 2013, Taylor *et al.* 2017). A recent assessment highlighted that 13 species, subspecies and populations of small cetaceans are currently assessed as Critically Endangered on the IUCN Red List of Threatened Species, and 11 of them have been declining due to bycatch, particularly in gillnets (Reeves *et al.* 2013, Brownell *et al.* 2019). Gillnets are relatively inexpensive to operate and can result in high catch rates for targeted and non-targeted species. Their numbers have also been increasing in some regions such as the northern Indian Ocean (Roberson *et al*. 2019), which is currently raising major concerns for some species, particularly cetaceans (Anderson *et al.* 2020, Kiszka *et al.* 2021, Roberson *et al.* 2022).

Indian Ocean fisheries produce 20% of global tuna catches (WWF 2020), the second-largest production in the world. Previous research suggests that bycatch is widespread issue in the main tuna fishing gears in the Indian Ocean, particularly in purse seines, pelagic longlines and gillnets for sea turtles (Bourjea *et al.* 2008, Wallace *et al.* 2013, Williams *et al.* 2018), elasmobranchs (Huang and Liu 2010, Amandè *et al.* 2012, Dulvy *et al.* 2014, Jabado *et al.* 2018), and cetaceans (Anderson *et al.* 2020, Kiszka *et al.* 2021, Roberson *et al.* 2022). While considerable research has been conducted to quantify bycatch of sea turtles and sharks in these fisheries, very little is known on the extent of cetacean bycatch in all Indian Ocean tuna fisheries. Published studies suggest that cetacean bycatch is relatively rare in Indian Ocean purse seine fisheries and that few mortalities have been recorded (Romanov 2002, Escalle *et al.* 2015), whereas they have caused the decline of pantropical spotted (*Stenella attenuata*) and spinner dolphins (*Stenella longirostris*) populations in the eastern tropical Pacific (Hall 1998, Gerrodette and Forcada 2005, Scott *et al.* 2012). The first accounts of interaction between purse seine fisheries and cetaceans in the Indian Ocean was documented by Robineau (1991) and Romanov (2002). Between 1986 and 1992, observer data were collected aboard Soviet purse seiners (494 sets), mostly around the Seychelles and to a lesser extent in the Mozambique Channel. A total of 45 sets were on baleen whales, possibly sei *Balaenoptera borealis* and fin whales *B. physalus* (although species identity remains uncertain; Romanov 2002). Escalle *et al.* (2015) later provided a detailed analysis of the interactions between French and Spanish purse seine fisheries in the tropical Atlantic and Indian Oceans using captain's logbooks (1980–2011) and reports from on-board scientific observers

(1995–2011). Despite a high level of co-occurrence between purse seine fisheries and cetaceans in the western tropical Indian Ocean, interactions were relatively rare and all sets where cetaceans were encircled survived (Escalle *et al.* 2015). The high apparent survival rates of cetaceans near, or directly involved in, fishing sets suggest that purse seine operations have little impact on cetacean populations in the region. However, a number of unverified factors could explain the lack of reports of cetacean mortality in the western tropical Indian Ocean, including changes of fishing practices in the presence of observers or the failure of captains to report mortality events in their logbooks when an observer is not present. Several species of baleen whales and small delphinids (especially *Stenella attenuata* and *S. longirostris*) have been observed associating with tuna schools (particularly yellowfin tuna *Thunnus albacares*; Anderson 2014) across the region and could therefore be captured in purse seines. However, the prevalence of these associations remains unknown and the impact of purse seining on cetacean populations in the region needs to be further investigated.

In global pelagic longline fisheries, cetaceans (and other species, particularly sharks) are well known to remove catches and baits, causing major economic losses, including in the Indian Ocean region (e.g., Petersen and Williams 2007, Poisson *et al.* 2007, Rabearisoa *et al.* 2007). However, the magnitude of cetacean bycatch in Indian Ocean pelagic longlines has been reported scarcely in the literature, and primarily involving species involved in depredation such as false killer whales (*Pseudorca crassidens*), short-finned pilot whales (*Globicephala macrorhynchus*), Risso's dolphins (*Grampus griseus*), and occasionally smaller delphinids (Poisson *et al.* 2001, Nishida and Shiba 2005, Nishida 2007, Kiszka *et al.* 2008, 2010). In other regions around the globe, pelagic longline fisheries are known to capture cetaceans. For instance, in the US pelagic longline fisheries operating in the central North Pacific, the bycatch of false killer whales exceeds allowable levels under the Marine Mammal Protection Act (e.g., Gilman *et al.* 2007, Forney *et al.* 2011). There are anecdotal reports of cetacean bycatch in Indian Ocean pelagic longline fisheries. Around the French island of Mayotte (northeastern Mozambique Channel), non-lethal injuries observed on the dorsal fins of several oceanic species such as short-finned pilot whales and melon-headed whales (*Peponocephala electra*) provide evidence that interactions with the longline fishery occur (Kiszka *et al.* 2008). Between 2009 and 2010, an observer program recorded only one cetacean capture - a false killer whale - in the Mayotte longline fishery; the animal was released alive (Kiszka *et al.* 2010). A Risso's dolphin was reported as bycatch in the longline fishery off La Réunion (Poisson *et al.* 2001). Around the Seychelles, incidental captures may occur in the semi-industrial pelagic longline fishery, where large delphinids (primarily pilot whales and false killer whales) have a major impact through depredation of catches (Rabearisoa *et al.* 2012, Romanov *et al.* 2013). Data are lacking although some have been reported to the Indian Ocean Tuna Commission (IOTC) since 2012 (total of 91 records; IOTC Secretariat). However, there is a critical need to further assess the spatial and temporal patterns of cetacean bycatch and depredation in pelagic longline fisheries in the IOTC area of competence.

Over the past two decades, there have been increasing concerns about cetacean bycatch in gillnets from inshore to the open-ocean waters of the Indian Ocean (Kiszka *et al.* 2009, Temple *et al.* 2018), primarily in bottom-set artisanal gillnets and in drift gillnets targeting tuna (Anderson 2014, Anderson *et al.* 2020, Kiszka *et al.* 2021, Roberson *et al.* 2022). In tuna drift gillnets, it was estimated that over 4 million cetaceans have been caught between 1950-2018, peaking at 100,000 cetaceans per year from 2004 to 2006 (Anderson *et al.* 2020). A study conducted off Pakistan from 2013 to 2017 estimated that 8,411 (SE=1.057) cetaceans are caught annually in tuna drift gillnets (Kiszka *et al.* 2021). Although data used to generate these estimates are probably incomplete, it is likely that the magnitude of cetacean bycatch in drift gillnets in the Indian Ocean is significant and possibly unsustainable, at least for some species. In addition, drift gillnet fleets are increasing in size in the IOTC area, particularly in the northern Indian Ocean, which could have major implications for the conservation of cetaceans and other vulnerable species (Roberson *et al.* 2019).

Two types of information are needed to assess the magnitude of bycatch: a measure of fishing effort and a bycatch rate (e.g., a number of individuals taken per unit of fishing effort; Moore *et al.* 2010). However, both data types are lacking for many fisheries, particularly those considered as artisanal such as drift gillnet fisheries occurring in the Indian Ocean (Roberson *et al.* 2019). Over the past decade, a popular approach in ecosystem-based management commonly referred as Ecological Risk Assessment for the Effects of Fishing (ERAEF) has been extensively used to identify species at risk from fishing. This is a hierarchical and precautionary approach that can contribute to management decisions by evaluating the risk of failing to meet objectives for ecosystem components, including targeted and non-targeted species (Hobday *et al.* 2011, Brown *et al.* 2013). As a component of the ERAEF, a productivity-susceptibility analysis is an approach to rapidly identify risk to species, habitats and communities (Milton *et al.* 2004). The PSA uses productivity and susceptibility scores that are used to estimate the relative vulnerability of a species to a fishery (Stobutzki *et al.* 2001). Productivity scores incorporate metrics that are used to assess the ability of a given species to recover from depletion, whereas susceptibility scores are used to measure the potential for capture and survival of a species to a given fishery (Patrick *et al.* 2010).

Here, the goal of this study was to undertake an ERAEF to assess the vulnerability of cetaceans to tuna fisheries using a PSA. In addition, an examination of the spatial overlap between cetaceans and tuna fisheries was attempted using IOTC catch data (2017-2019) and cetacean probabilities of occurrence generated by AquaMaps (https://www.aquamaps.org). The goal was to identify regions where interactions between each gear and species groups could potentially occur within the IOTC area.

2. Materials and methods

2.1 Productivity-susceptibility analysis

A productivity-susceptibility analysis (PSA) was used to compare risks to cetaceans across the three tuna fishing gears operating in the IOTC area of competence. This approach allows estimation of a species' or population's vulnerability to a fishing method (Hobday *et al.* 2011). The PSA quantifies species' vulnerability by incorporating its life history traits (productivity) and its exposure to a threat, such as a fishing gear (Hobday *et al.* 2007). Here, four life history traits were used to estimate productivity for each cetacean species included in the PSA (see Hobday *et al.* 2011, Brown *et al.* 2013, Breen *et al.* 2017). For each trait, there are three possible scores (1, 2 and 3) corresponding to low (1), medium (2) and high (3) productivity and susceptibility (Hobday *et al.* 2011; Table 1). When uncertainty occurred between two scores (e.g., between 1 and 2), a conservative approach was adopted. For instance, life history traits of certain species vary between sexes. Thus, for productivity scores, as females mature more slowly than males, the female attributes were used. The productivity score was the geometric mean of four parameters: age at sexual maturity (ASM), oldest reproductive female (ORF), calf survival (CS) and inter-calving interval (ICI; see Taylor *et al.* 2007 for details on estimating oldest reproductive female and calf survival), and following the approach adopted by Brown *et al.* (2013). Oldest reproductive female was included as some species such as sperm whales (*Physeter macrocephalus*), killer whales (*Orcinus orca*), or short-finned pilot whales (*Globicephala macrorhynchus*) experience reproductive senescence (Taylor *et al.* 2007). The scoring thresholds were adapted to reflect the distribution of cetacean life history parameters using a cluster analysis using Ward's method (Ward 1963), particularly to assign species to groups with similar life history traits, and to break the range of scores into high, moderate and low risk bins (Brown *et al.* 2013).

$$Productivity = \sqrt[4]{ASM \times ORF \times CS \times ICI}$$

In general, PSAs use a range of calculations for both productivity (*P*) and susceptibility (*S*) attributes, with the arithmetic mean used for *P* and the geometric mean for *S* (Cotter and Lart 2011). Geometric means are smaller than arithmetic means, which means that *S* is systematically down-weighted (Roberson *et al.* 2022). Therefore, in order to give equal weight to *P* and *S*, geometric means were used for both.

Table 1. Productivity attributes and scoring criteria/thresholds used in the PSA for cetaceans in IOTC tuna fisheries.

	High risk (score 3)	**Moderate risk (score 2)**	**Low risk (score 1)**
Attributes			
Mean sexual maturity	≥ 11 years	6 - 10 years	≤ 5 years
Oldest reproducing female	≥ 61 years	45 - 60 years	≤ 44 years
Calf survival (%)	≤ 0.76	0.77 - 0.89	⋝ 0.90
Inter-calving interval	3.5 years	2.6 - 3.5 years	≤ 2.5 years

Susceptibility of a species to a fishing gear was quantified using four parameters: availability, encounterability, selectivity and post-capture mortality (Hobday *et al.* 2007, 2011, Brown *et al.* 2013; Table 2). Susceptibility is a combination of the likelihood of capture and survival following the capture. Availability is the horizontal spatial overlap between the species and the fishing gear (longlines, purse seines and gillnets), and encounterability is the vertical overlap in the water column between habitat preferences of cetaceans and habitat where gears are typically used. Selectivity is the likelihood that a gear will entangle a given species and post-capture mortality is the outcome if the species is entangled (e.g., the animal's likelihood of dying or breaking free of the fishing gear).

$$Susceptibility = \sqrt[4]{Availability \times Encounterability \times Selectivity \ \times Post\ capture\ mortality}$$

Availability was calculated by combining a proxy for presence of a species with a proxy for presence of a fishing gear. The proxy for fishing effort was derived from IOTC catch data and a proxy for species' density was derived from species distribution maps from AquaMaps (see section 2.2 for more details). The two spatial layers were converted to raster files, then the value for the probability of occurrence for each species was multiplied by the scaled fishing effort value for each gear type in each grid cell. The resulting availability value represents the relative likelihood that a species and a fishing gear are both present in that cell.

$$Availability_{cell} = Probability\ of\ occurrence \times Fishing\ intensity$$

The availability of each species in each grid cell was calculated and values were summed across all cells in the IOTC area to obtain a relative measure of horizontal overlap between cetaceans and tuna fisheries.

$$Availability_{cumulative} = \sum_i^n A$$

Availability does not account for dial or seasonal variation in distribution, or possible ontogenetic shifts that might occur within species, which could potentially lead to both over- and underestimations of risk (Roberson *et al.* 2022).

Encounterability, as defined by Hobday *et al.* (2007), scores the potential for encounter between species and gears based on depth range in the water column relative to gear position (vertical overlap). Cetaceans are air-breathing organisms and therefore come to the surface to breath. Therefore, encounterability was instead defined as the potential overlap between cetacean habitat preferences and the habitat where gears are used in the IOTC area.

Table 2. Susceptibility attributes and scoring criteria/thresholds used in the PSA for cetaceans in IOTC tuna fisheries.

	High risk (score 3)	**Moderate risk (score 2)**	**Low risk (score 1)**
Attributes			
Availability (horizontal)	High overlap (> 66% of species' range in IOTC area)	Moderate overlap (34-66% of species' range in IOTC area)	Low overlap (<33% of species' range in IOTC area)
Encounterability	Complete overlap of habitat in relation to physiography and season	Moderate overlap of habitat in relation to physiography and season	Low overlap of habitat in relation to physiography and season
Selectivity	High potential for capture	Moderate potential for capture	Low potential for capture
Post-capture survival	Likely to be released dead	Likely to be released alive	Evidence of post-capture release and survival

Species were therefore classified as occupying inshore/coastal, shelf, shelf/insular breaks, and/or offshore habitats in the Indian Ocean region based on the literature. Habitat preferences of cetaceans was derived from several studies conducted throughout the Indian Ocean region (Ballance and Pitman 1998, Ersts and Rosenbaum 2003, Kreb 2005, Dolar *et al.* 2006, Jefferson *et al.* 2014, Mannocci *et al.* 2014, 2015, Cerchio *et al.* 2016, Condet and Dulau-Drouot 2016, Trudelle *et al.* 2016, Laran *et al.* 2017, Natoli *et al.* 2022).

Selectivity scores the potential of a gear to hook or entangle a species. There is limited empirical data as only a limited number of studies have quantified the likelihood of entanglement independent of species abundance/distribution and fishing effort. Here, data on all species included in this PSA was compiled from the peer-reviewed scientific and gray literature, particularly to group species according to life history traits that lead to a similar propensity for entanglement in fishing gears. Multiple factors were considered, including body size and shape, foraging behavior, swimming style, and attraction to fishing gears.

Post-capture mortality depends on a species' ability to escape the gear or to survive if released by the crew (Hobday *et al.* 2007, Roberson *et al.* 2022). Information on post-capture survival (and compliance with IOTC regulations for safe release) of cetaceans in the IOTC area of competence is very scarce. Gillnets, which are static gears and deployed overnight throughout most of the IOTC region, are likely to kill cetaceans in most cases. A few scattered reports mention that some larger species can sometimes survive. However, species caught in gillnets are not expected to survive (Kiszka *et al.* 2021). In pelagic longlines, survival seems to occur frequently for several species of cetaceans, particularly in the Indian Ocean (IOTC 2022). In purse seines, post-capture mortality data are too scarce, but large whales are usually expected to survive (e.g., Romanov 2002, Escalle *et al.* 2015).

The risk was assessed by plotting *P* and *S* scores graphically, with *P* on the *x* axis and *S* on the *y* axis. The overall vulnerability score for each species (Appendixes 1-3) is the Euclidian distance between *P* and *S* axes, used to assess the vulnerability of species for each gear:

$$\sqrt{Productivity^2 + Susceptibility^2}$$

This score was used to assess the relative vulnerability of each species for each gear.

2.2 Spatial patterns of risk in tuna purse seine, longline and gillnet fisheries

In order to create a spatially-explicit risk assessment, species distribution maps from AquaMaps (Kaschner *et al.* 2016) were used. A similar approach was carried out for the IOTC area and published recently (Roberson *et al.* 2022). AquaMaps model the occurrence of species in relation to several environmental variables, such as depth, sea surface temperature, or salinity (Ready *et al.* 2010). The model estimates a probability of occurrence for each species in 0.5° grid cells. AquaMaps were used as they provide a proxy of species occurrence and density, whereas other sources (e.g., IUCN range maps) usually provide information on species presence and absence. This is also the only source of information on the distribution and relative abundance of cetaceans in the Indian Ocean region that is available at the scale of the entire IOTC area, as limited dedicated surveys have been carried out to assess the distribution and relative abundance of cetaceans in the region (but see Laran *et al.* 2017, for the southwestern Indian Ocean). Probabilities of occurrence were selected for cetaceans occurring within the IOTC area of competence, covering the Indian Ocean to 45° and 55° South in the western and eastern Indian Ocean, respectively (Roberson *et al.* 2022).

Here, maps of overlap for each gear (purse seines, longlines and gillnets) were produced for five groups of ecologically similar and phylogenetically-close species. A total of 48 species of cetaceans are known to occur within the IOTC area of competence (Table 3; IOTC 2017), including 10 species of baleen whales (Mysticetes) and 38 species of toothed cetaceans (Odontocetes). Balaenidae, Neobalaenidae and Balaenopteridae were grouped as “baleen whales” (Table 3). Physeteridae, Kogiidae and Ziphiidae were grouped as “large toothed whales”. Large oceanic dolphins, defined as species larger than 2.5m and occurring mostly in shelf/insular break and oceanic waters, included seven species: Risso’s dolphin (*G. griseus*), melon-headed whale (*P. electra*), pygmy killer whale (*Feresa attenuata*), false killer whale (*P. crassidens*), killer whale (*O. orca*), short-finned pilot whale (*G. macrorhynchus*) and long-finned pilot whale (*Globicephala melas*). Inshore and estuarine species were grouped as “Inshore dolphins and porpoises”, and included the following species: the three species of humpback dolphins known to occur in the Indian Ocean (*Sousa plumbea*, *S. chinensis* and *S. sahulensis*), the Irrawaddy dolphin (*Orcaella brevirostris*), the Australian snubfin dolphin (*Orcaella heinsohni*), the Indo-Pacific bottlenose dolphin (*Tursiops aduncus*) and the Indo-Pacific finless porpoise (*Neophocaena phocaenoides*). All these species occur close to shore, usually less than 5 km from shore throughout most of the Indian Ocean region (Jefferson *et al.* 2018). Lastly, oceanic dolphins include several species of small delphinids (less than 3m long) occurring on shelf, but mostly in shelf break and oceanic habitat: rough-tooted dolphin (*Steno bredanensis*), common bottlenose dolphin (*Tursiops truncatus*), spinner dolphin (*Stenella longirostris*), pantropical spotted dolphin (*Stenella attenuata*), striped dolphin (*Stenella coeruleoalba*), common dolphin (*Delphinus delphis*) and Fraser's dolphin (*Lagenodelphis hosei*). The complete list of cetacean species included in this analysis is provided in Table 3.

Table 3. List of cetacean species occurring in the IOTC area of competence and their IUCN Red List status (accessed on August 9th, 2023).

Family	Common name	Scientific name	IUCN Red List status
Balaenidae	Southern right whale	*Eubalaena australis*	LC
Neobalaenidae	Pygmy right whale	*Caperea marginata*	LC
Balaenopteridae	Common minke whale	*Balaenoptera acutorostrata*	LC
	Antarctic Minke whale	*Balaenoptera bonaerensis*	NT
	Sei whale	*Balaenoptera borealis*	EN
	Bryde's whale	*Balaenoptera edeni*	LC
	Blue whale	*Balaenoptera musculus*	EN
	Fin whale	*Balaenoptera physalus*	VU
	Omura's whale	*Balaenoptera omurai*	DD
	Humpback whale	*Megaptera novaeangliae*	LC
Physeteridae	Sperm whale	*Physeter macrocephalus*	VU
Kogiidae	Pygmy sperm whale	*Kogia breviceps*	LC
	Dwarf sperm whale	*Kogia sima*	LC
Ziphiidae	Arnoux's beaked whale	*Berardius arnouxii*	LC
	Southern bottlenose whale	*Hyperoodon planifrons*	LC
	Longman's beaked whale	*Indopacetus pacificus*	LC
	Andrew's beaked whale	*Mesoplodon bowdoini*	DD
	Blainville's beaked whale	*Mesoplodon densirostris*	LC
	Ramari's beaked whale	*Mesoplodon eueu*	DD
	Gray's beaked whale	*Mesoplodon grayi*	LC
	Hector's beaked whale	*Mesoplodon hectori*	DD
	Deraniyagala's beaked whale	*Mesoplodon hotola*	DD
	Layard's beaked whale	*Mesoplodon layardii*	LC
	Spade-toothed whale	*Mesoplodon traversii*	DD
	Shepherd's beaked whale	*Tasmacetus shepherdi*	DD
	Cuvier's beaked whale	*Ziphius cavirostris*	LC
Delphinidae	Common dolphin	*Delphinus delphis*	LC
	Pygmy killer whale	*Feresa attenuata*	LC
	Short-finned pilot whale	*Globicephala macrorhynchus*	LC
	Long-finned pilot whale	*Globicephala melas*	LC
	Risso's dolphin	*Grampus griseus*	LC
	Fraser's dolphin	*Lagenodelphis hosei*	LC
	Irrawaddy dolphin	*Orcaella brevirostris*	EN
	Australian snubfin dolphin	*Orcaella heinsohni*	VU
	Killer whale	*Orcinus orca*	DD
	Melon-headed whale	*Peponocephala electra*	LC

	False killer whale	*Pseudorca crassidens*	NT
	Indo-Pacific humpback dolphin	*Sousa chinensis*	VU
	Indian Ocean humpback dolphin	*Sousa plumbea*	EN
	Australian humpback dolphin	*Sousa sahulensis*	VU
	Pantropical spotted dolphin	*Stenella attenuata*	LC
	Striped dolphin	*Stenella coeruleoalba*	LC
	Spinner dolphin	*Stenella longirostris*	LC
	Rough-toothed dolphin	*Steno bredanensis*	LC
	Indo-Pacific bottlenose dolphin	*Tursiops aduncus*	NT
	Common bottlenose dolphin	*Tursiops truncatus*	LC
Phocoenidae	Indo-Pacific finless porpoise	*Neophocaena phocaenoides*	VU

Catch and effort data reported to the IOTC are not consistent across fisheries, particularly as reporting requirements vary significantly. Catch and fishing effort data are especially limited for gillnets in the region. Therefore, to infer fishing effort in the IOTC area of competence we used nominal catch (in tons) for targeted species, including tuna and tuna-like species. Catches from purse seines are required to be reported at a maximum spatial aggregation of 1° x 1°, whereas longlines can be reported at 5° x 5°. Since gillnet fisheries are not categorized or managed as industrial sectors fisheries in the Indian Ocean, catches are reported in an irregular manner and the dataset contains reported catches at spatial aggregations of 1° x 1° and 5° x 5°. To standardize the spatial resolution of fishing data, nominal catches for each gear were reaggregated to 0.5° x 0.5° grid cells to match the resolution of the species distribution data described above.

Reported catch weight was used as a proxy for fishing effort instead of the reported effort due to inconsistencies of measurement within gears and between gears. For instance, the effort for purse seines could be reported as fishing hours, days, trips or sets which cannot be standardized with the information provided. In contrast, catches were all reported in tons so we were able to use catch weight as the best available proxy for effort as data was consistent within and between gears. Using catch as a proxy for effort assumes that areas with higher catch are indicative of high effort. However, this approach has some limitations. Fishery catch does not provide an indication as to how much gear was deployed in a given area or the length of its soak time. These are important variables to consider when estimating the effect of a particular gear on a species inhabiting the area (Stewart *et al*. 2010). However, due to the limited availability and quality of effort data in the Indian Ocean, using the actual reported catches of vessels fishing should provide a sufficient representation of fishing effort for the purpose of this work. Data spanning from 2017 to 2019 were selected with the intention of providing an assessment relevant to current fishing patterns, whilst excluding the impact of COVID-19 that might misrepresent "regular" fishing activity. Extreme spatial skewness was corrected by adjusting outlier cells to the 90th percentile and then log-transforming the values. The catch data remained highly skewed, which is assumed to be indicative of real patterns in fishing effort. Catch data were then scaled between 0-1 across all gears to provide a relative measure of fishing intensity across all three gears within the IOTC area of competence.

3. Results

3.1 Species vulnerability to bycatch

We considered 48 species of cetaceans known to occur within the IOTC Area Of Competence (the three humpback dolphin species occurring in the IOTC area were merged as *Sousa* sp.). We **identified 26 species or families that potentially interact with gillnets** (4 inshore dolphins and porpoises, 3 baleen whales, 6 large oceanic dolphins, 6 large toothed whales, and 7 small oceanic delphinids), **27 in pelagic longlines** (7 baleen whales, 7 large oceanic dolphins, 6 large toothed whales, and 7 small oceanic delphinids), and 24 in purse seines (5 baleen whales, 6 large oceanic dolphins, 6 large toothed whales, and 7 small oceanic delphinids).

All productivity, susceptibility and vulnerability scores for each gear are presented in Appendixes 1-3. The output of the PSA (Fig. 1) shows that risk varies greatly between gears and species. Overall risk is higher in gillnets than in any other gear, and the largest number of species are potentially at risk with this gear. Species at higher risk in gillnets are small oceanic delphinids. Risk to inshore delphinids and porpoises is low as the spatial overlap between gillnet fishing and these species is low. Risk is also high with baleen whales, such as Bryde's whales (*Balaenoptera edeni*) and humpback whales, particularly the Arabian Sea population (Critically Endangered species, IUCN Red List of Threatened Species) occurring in the north-northwestern Indian Ocean. For pelagic longline fisheries, risk is also relatively high for large oceanic delphinids (e.g., Risso's dolphin, false killer whale or short-finned pilot whale). Risk for purse seine fisheries was lower than for other gears, except for some baleen whale species such as *B. edeni*, also one of the most abundant non-migratory baleen whales in the tropical Indian Ocean.

Most species with high susceptibility to catch in fishing gears also had high vulnerability scores when considering their productivity traits (Fig. 2). The resulting vulnerability scores were also the highest for gillnets and for all species, but particularly small oceanic dolphins. Thus, 8 cetacean species had a vulnerability score higher than 3 (highest risk) in gillnets, including 6 species of delphinids, the sperm whale *Physeter macrocephalus* and the Bryde's whale *Balaenoptera edeni*. Vulnerability scores were only higher than 3 for the sperm whale in both pelagic longlines and purse seines (Fig. 2).

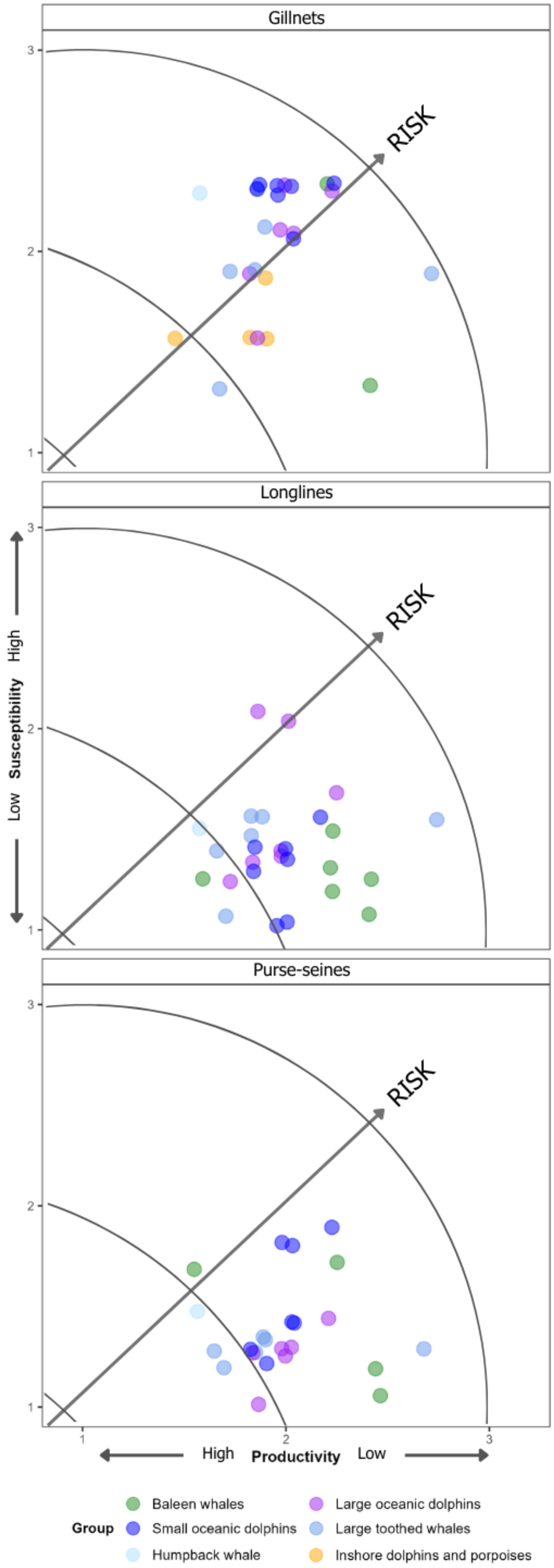

Figure 1. PSA plots showing the productivity of cetacean species and their susceptibility to and potential risk from tuna fisheries (gillnets, pelagic longlines and purse seines) in the IOTC area.

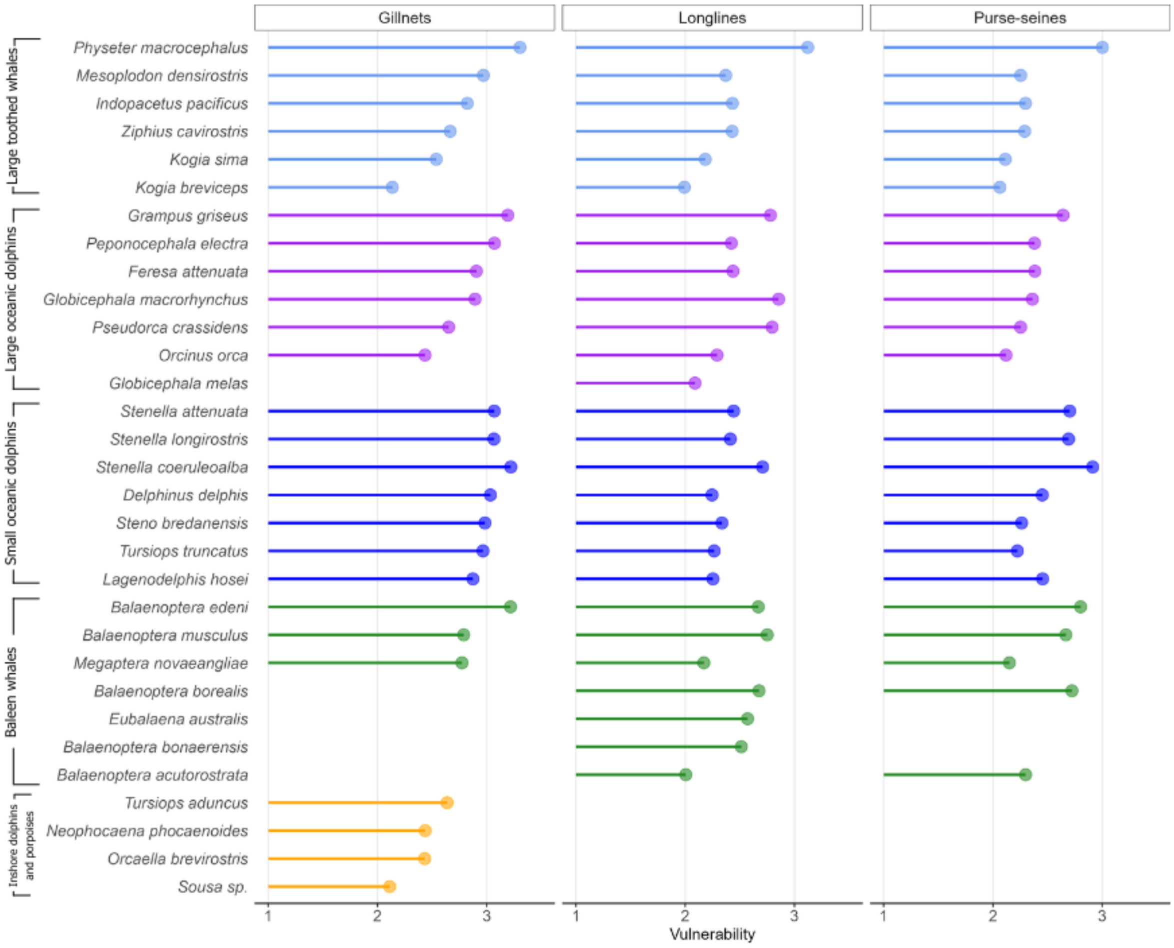

Figure 2. Vulnerability scores for cetaceans in tuna gears in the IOTC area.

3.2 Spatial overlap between tuna fisheries and cetacean distribution

IOTC catch data from 2017 to 2019 were used as a proxy of fishing effort. Pelagic longline fishing is widespread throughout the IOTC area, whereas gillnet fishing primarily occurs in the northern Indian Ocean and usually within EEZs, and purse seining primarily occurs in the western tropical Indian Ocean (Fig. 3). Overlap maps between IOTC catches and cetacean probabilities of occurrence are presented in Figs. 4 to 8. The spatial overlap between gillnets fisheries and baleen whales is limited to the northern portion of the Indian Ocean, particularly around Sri Lanka and in some parts of the East African coast (Fig. 4).

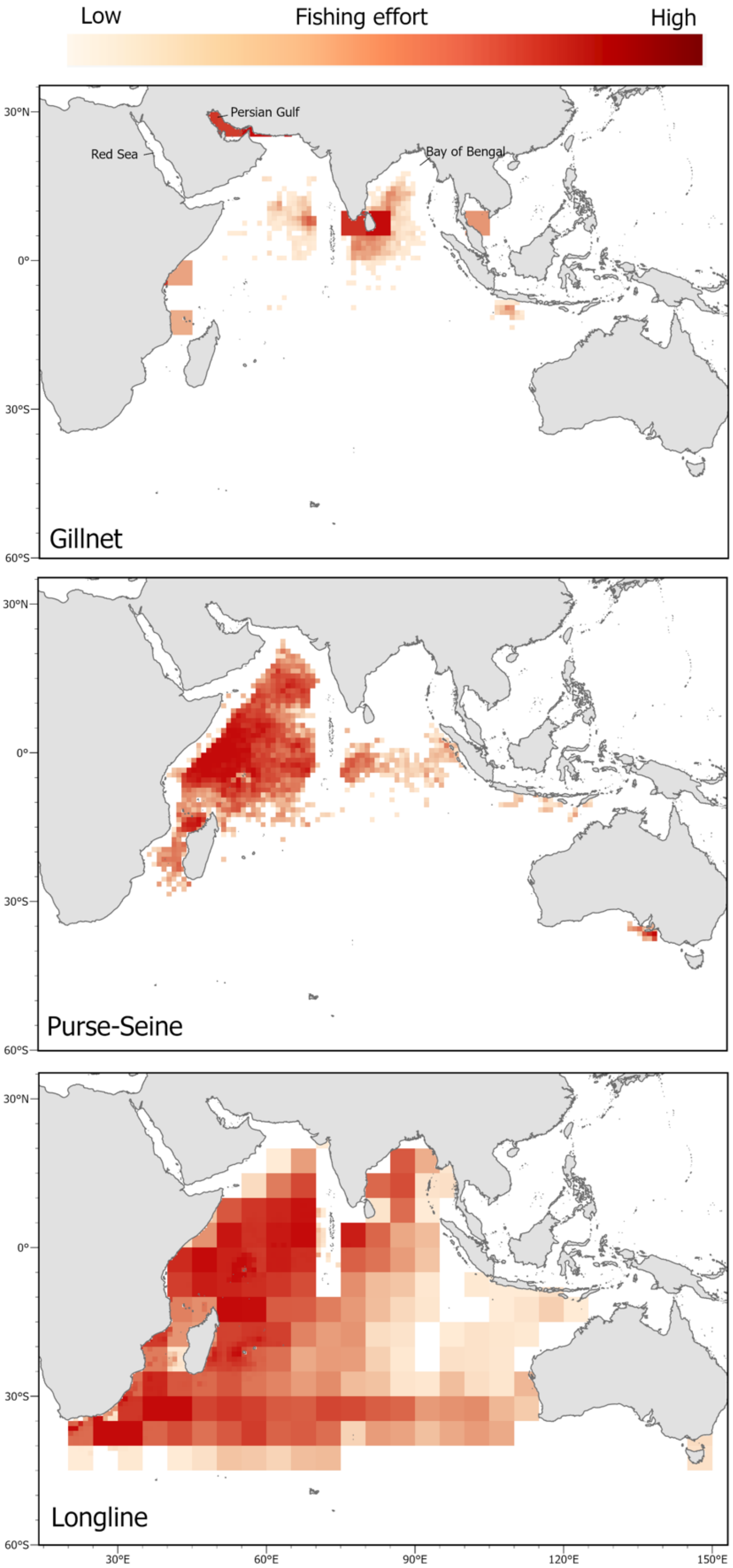

Figure 3. Distribution of tuna and tuna-like catches in gillnet (top), purse seine (middle) and pelagic longlines (bottom) as a proxy of fishing effort between 2017 and 2019 in the IOTC area.

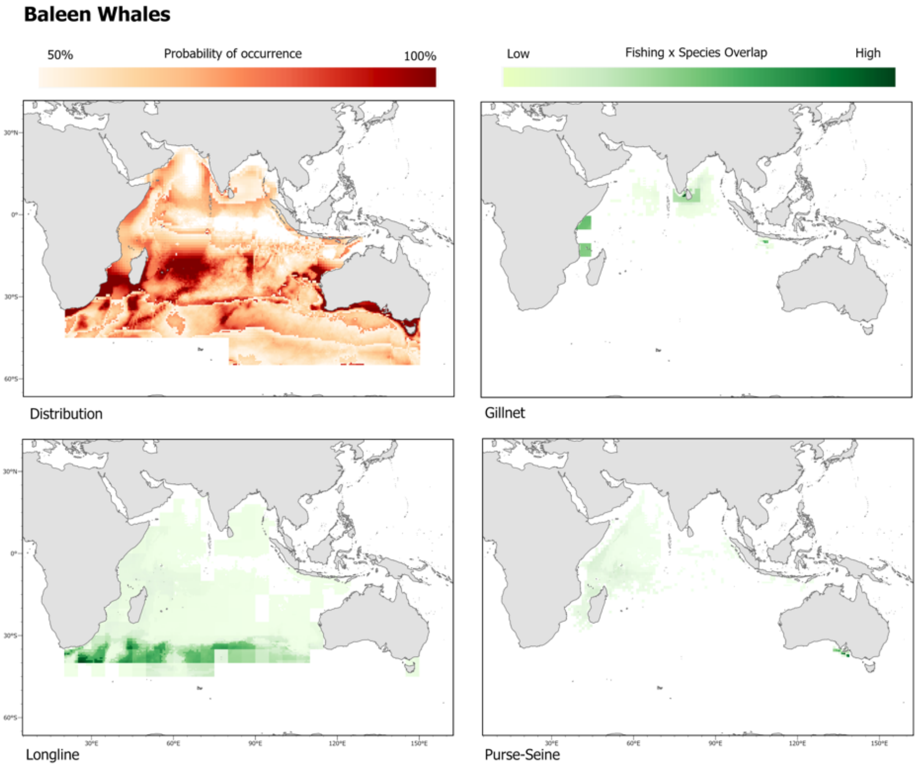

Figure 4. Spatial overlap between baleen whales and tuna fisheries (gillnets, longlines and purse seines) in the IOTC area.

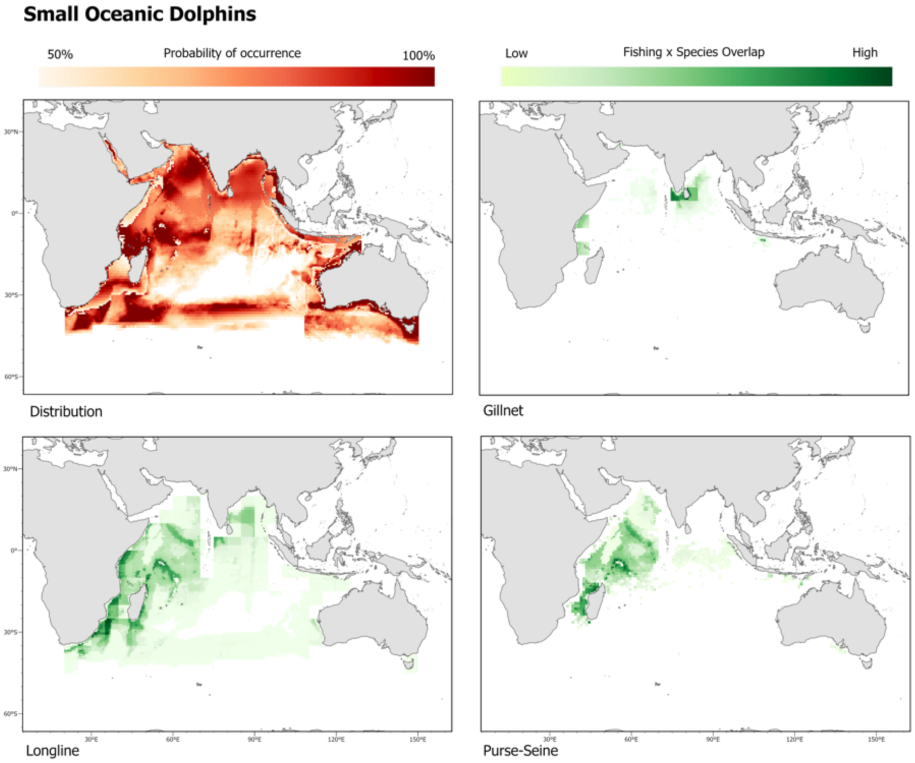

Figure 5. Spatial overlap between small oceanic dolphins and tuna fisheries (gillnets, longlines and purse seines) in the IOTC area.

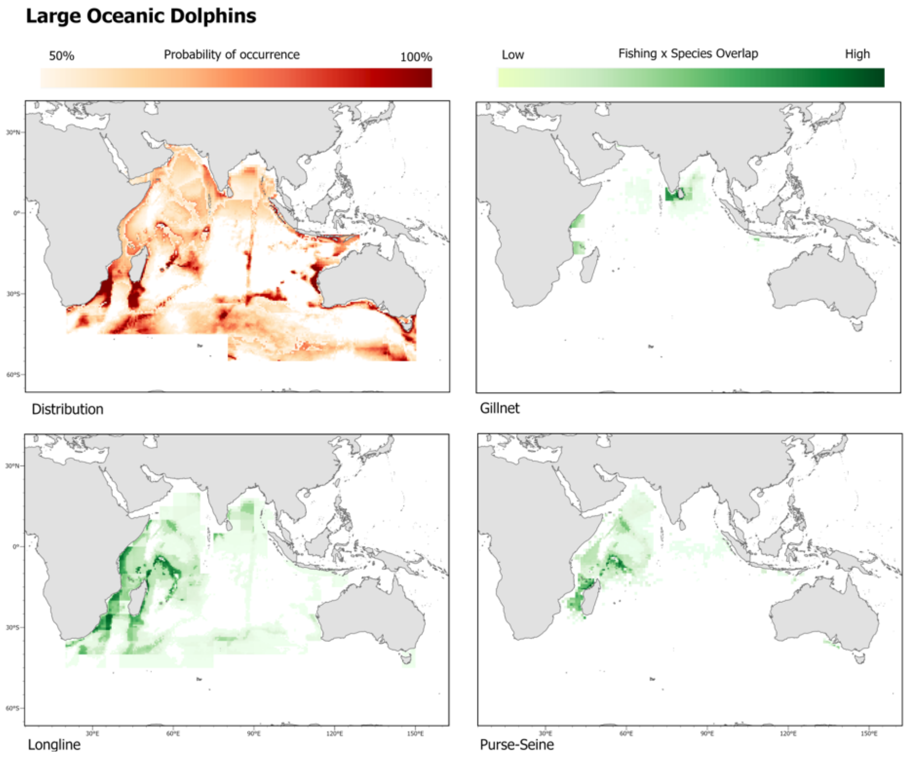

Figure 6. Spatial overlap between large oceanic dolphins and tuna fisheries (gillnets, longlines and purse seines) in the IOTC area.

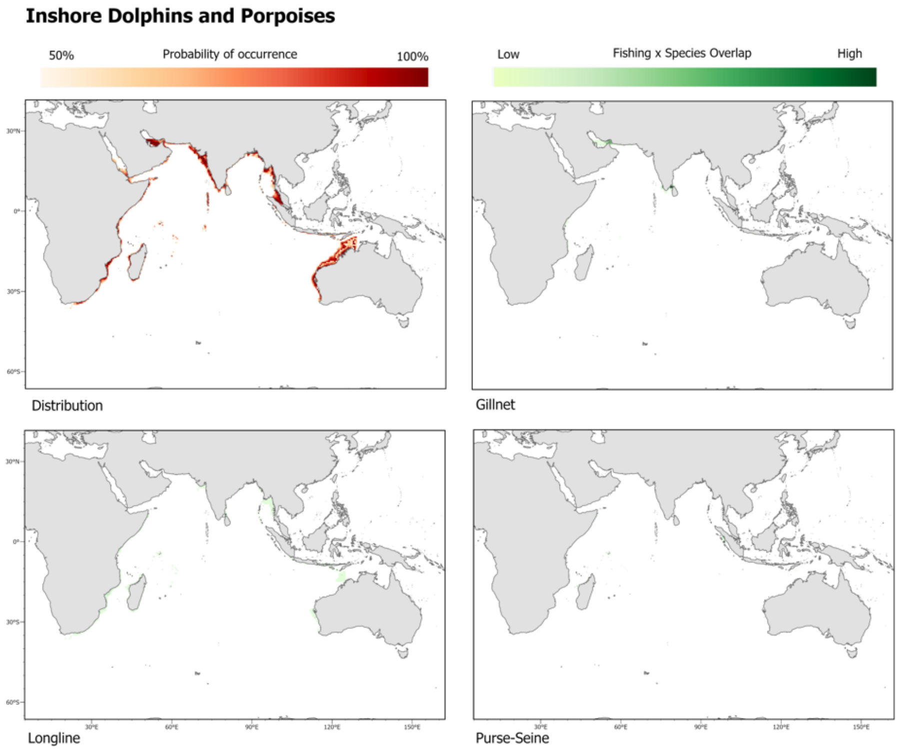

Figure 7. Spatial overlap between inshore dolphins and porpoises and tuna fisheries (gillnets, longlines and purse seines) in the IOTC area.

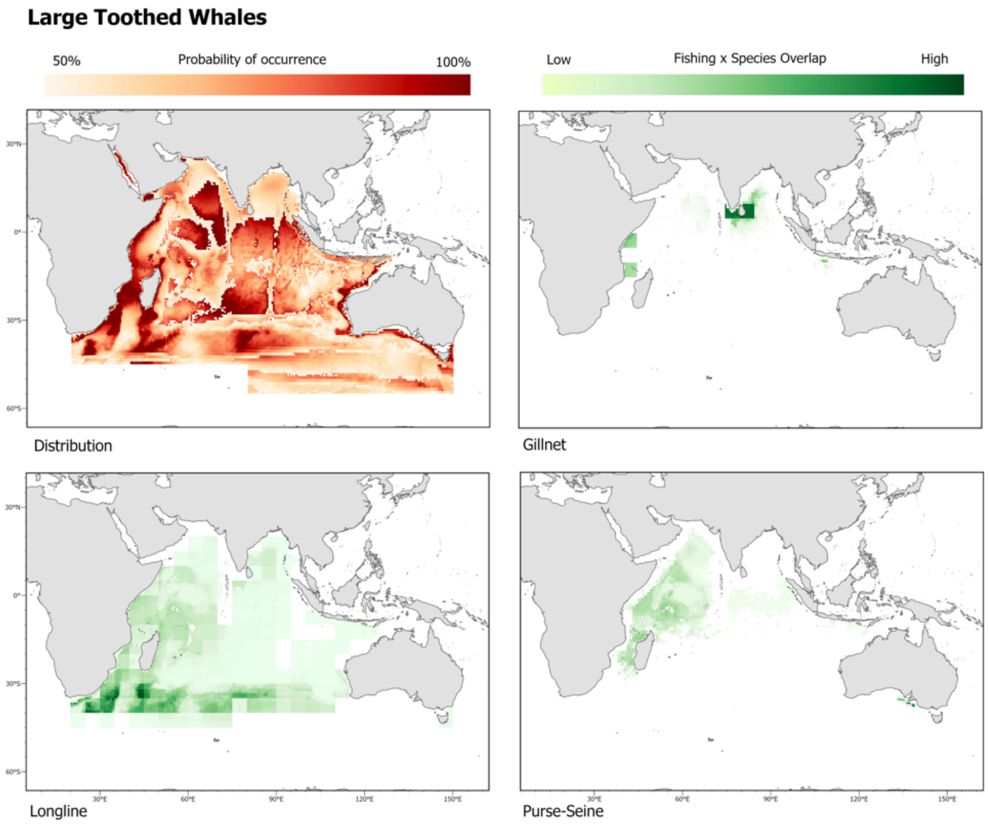

Figure 8. Spatial overlap between large toothed whales and tuna fisheries (gillnets, longlines and purse seines) in the IOTC area.

The spatial overlap between baleen whales and pelagic longline fisheries has an opposite pattern, with a higher overlap occurring in the southern and southwestern portion of the IOTC area of competence. The spatial overlap between baleen whales and purse seine fisheries is limited to the western tropical Indian Ocean, but appeared to be low (Fig. 4). Small and large oceanic dolphins exhibit similar patterns of overlap for all three gears, with high overlap in the northern Indian Ocean with gillnets (particularly around India and Sri Lanka), and with pelagic longlines and purse seines in the western tropical Indian Ocean (Fig. 5 and 6). The spatial overlap between coastal dolphins and porpoises is, for the most part, negligible (Fig. 7). Lastly, large toothed whales overlap extensively with the three gears (Fig. 8), including gillnets in the northern Indian Ocean and in eastern Africa and pelagic longlines in the southern and southwestern parts of the IOTC area, particularly off southeastern Africa and southern Madagascar. Overlap with purse seines is also limited to the western tropical Indian Ocean (Fig. 8).

4. Discussion

This is the first comprehensive risk assessment for interactions between cetaceans and tuna fisheries in the IOTC area. Here, we combined a holistic approach to evaluate risk using an ERAEF framework (Hobday *et al.* 2007, 2011). In addition, we evaluated the spatial overlap between tuna fisheries and cetacean occurrence using AquaMaps, as distribution and density data of cetaceans are unavailable for the vast majority of the IOTC area. Overall, the results suggest that a wide range of cetacean species are vulnerable to all tuna fisheries, particularly gillnets where small oceanic dolphins seem to be the most at risk from this gear. Risk was estimated to be lower in pelagic longline and purse seine fisheries. These results are fairly consistent with the literature on cetacean bycatch in pelagic longline and purse seine tuna fisheries in the IOTC area of competence (e.g., Romanov 2002, Huang and Liu 2010, Escalle *et al.* 2015, Kiszka 2015), where few occurrences of cetacean bycatch have been documented. On the other hand, drift gillnet fisheries represent the most significant threat to cetaceans in the Indian Ocean, as highlighted by several authors in the recent years, both globally (Read *et al.* 2006, Reeves *et al.* 2013, Brownell *et al.* 2019) and in the Indian Ocean region (Kiszka *et al.* 2009, Anderson 2014, Anderson *et al.* 2020, Kiszka *et al.* 2021, Roberson *et al.* 2022).

Overall, it is important to also acknowledge that the ERAEF framework used for this study has a number of limitations. The PSA approach is highly conservative and tends to overestimate the risk for many species, particularly those having low productivity and with a high degree of spatial overlap with gears. This is an issue that has been commonly reported in the literature (Brown *et al.* 2013, Roberson *et al.* 2022). For example, most baleen whale species included in the PSA and for which vulnerability scores were high, are unlikely to be at significant risk in pelagic longline fisheries, as indicated by rare bycatch and mortality events documented (Gilman *et al.* 2006, Hamer *et al.* 2012, Passadore *et al.* 2015). Similarly, large toothed whales and large oceanic delphinids (e.g., pilot whales, false killer whales) are unlikely to be vulnerable to purse seine fisheries, particularly in the Indian Ocean where no such occurrences have been previously reported (Romanov 2002, Escalle *et al.* 2015). Within the PSA, the data used to estimate productivity can be imprecise, as information from closely related species had to be used, or because a value can be attributed based on the opinion of an expert (Hobday *et al.* 2007, Brown *et al.* 2013). Life history data are lacking for many species of cetaceans occurring in the IOTC area (Taylor *et al.* 2007). Although efforts were made to use the best available information, productivity scores (and ultimately the output of the PSA and vulnerability score calculations) can therefore be affected by uncertainty and data quality. Scores used also may not be representative of Indian Ocean population(s), as there are sources of bias associated with determining life history traits of cetaceans (Mannocci *et al.* 2012). Differences in life history parameters can also occur, and using data from populations outside of the study area can also generate errors in productivity and therefore risk (Brown *et al.* 2013). For most cetacean species in the Indian Ocean, there is a lack of information on the occurrence, distribution, behavior, and life history. In order to further understand the potential impacts of fisheries bycatch on cetacean populations, it will be critical to develop international collaborative networks to collect biological samples and empirical data on cetaceans in the IOTC area, particularly on cetaceans caught in fisheries, and through existing stranding networks that operate in the region (e.g., IndoCet, the Indian Ocean Network for Cetacean Research, https://indocet.org/en/home/). The PSA and the vulnerability scores should therefore be taken with caution, particularly since there might also be subjectivity in the interpretation of the results obtained. The methods implies that productivity and susceptibility scores are equally important to estimate species vulnerability, which is not the case, as pointed out by other authors (e.g., Hordyk and Carruthers 2018). Rescaling the relationship between productivity and susceptibility or weighting productivity and susceptibility attributes should be considered, at least in some cases (Nel *et al.* 2013).

Assessing risk in space and time can be complex but is critical for management, particularly in dynamic and data-poor areas such as the Indian Ocean. It requires a detailed understanding of spatiotemporal dynamics of fishing effort and cetacean populations, which are both lacking in the region (Roberson *et al.* 2022). Our assessment of the spatial overlap between IOTC gillnet, pelagic longline and purse seine fisheries also has major limitations. It is well understood that catch data do not provide an accurate measure of fishing effort (Stewart *et al.* 2010). However, this was the only available source of data from the IOTC Secretariat that included the three major gear types. A first attempt to produce a spatially explicit assessment of risk of marine megafauna (including elasmobranchs, cetaceans and sea turtles) combined AquaMaps and a global model of fishing effort that estimates effort in terms of engine power across the three gear types and fishing days (Roberson *et al.* 2022). The model uses data from FAO and reports from countries to divide country's vessels into classes and associate effort with a corresponding catch (Rousseau 2020, Rousseau *et al.* 2019). The results of this study confirmed that cetaceans are more vulnerable to drift gillnets more than any other gear, particularly in the coastal waters of the northern Indian Ocean (Roberson *et al.* 2022). The authors found that susceptibility to tuna fisheries was concentrated in a relatively small portion of the IOTC area and along certain coastlines, whereas the present study (based on IOTC catch data) was more conservative and included more oceanic regions. With regards to drift gillnets, Roberson *et al.* (2022) identified high susceptibility of marine megafauna bycatch from the southern Red Sea to Indonesia. Those differences between the two studies highlight the need to incorporate fishing effort data for the three gears provided by fishing nations, including observer/logbook data, automatic ship identification systems (AIS), vessel monitoring systems (VMS), or remote electronic monitoring (Suuronen and Gilman 2020). The development of very high resolution (VHR) satellite-based remote sensing will also enable to better quantify the spatial and temporal dynamics of fishing effort (Toonen and Bush 2020), including Indian Ocean tuna fisheries.

Data used to characterize cetacean distributions and relative abundances also have major limitations, including the spatial representation of data used in the model or the lack of information on temporal (seasonal) changes in distribution of species (Kaschner *et al.* 2016). However, this approach is replicable and accessible, and was based on the most extensive data available on cetacean distribution in the Indian Ocean region. More efforts will be needed in the future to further investigate the distribution, abundance, and habitat preferences of cetaceans in the Indian Ocean to refine estimates on the co-occurrence of these species with tuna (and other) fisheries.

5. Conclusions

Vulnerability analyses of cetaceans to Indian Ocean tuna fisheries highlights that there are major data gaps in the region. However, the ERAEF framework used is repeatable, transparent, and does not require data on the occurrence and magnitude of bycatch. However, while data on the interaction between cetaceans and purse seine fisheries still needs to be collected to eventually detect potential changes that might occur as a result of climate change, there is a critical need to quantify the magnitude and spatiotemporal dynamics of cetacean bycatch in drift gillnet fisheries. Recent studies have clearly emphasized this need, particularly throughout the northern Indian Ocean (Temple *et al.* 2018, Anderson *et al.* 2020, Kiszka *et al.* 2021, Roberson *et al.*

2022). As many cetacean species are threatened by bycatch in gillnets, it also becomes urgent to expand mitigation trials to reduce cetacean interactions in the first place, as existing conservation and management measures in the Indian Ocean focus on safe release practices. A recent study suggests that cetacean bycatch in drift gillnets can be reduced significantly (78.5%) by using subsurface gillnets (Kiszka *et al.* 2021). This work was based on data collected by captains on a small number of vessels, and therefore has a number of limitations. However, it produced encouraging results that should promote further studies using the same mitigation methods in the region, which could also have positive impacts on the reduction of bycatch of other taxa, particularly sharks and sea turtles (WWF-Pakistan/J. Kiszka, unpublished data). While effort, catch and bycatch data are critically needed in gillnets, an analysis of bycatch rates based on existing data available at the IOTC-Secretariat in pelagic longlines should also be carried out. This assessment could be combined with a specific-specific analysis of the spatial interaction between pelagic longlines and species that are at higher risk of interactions, particularly large delphinids such as short-finned pilot whales, Risso's dolphins, false killer whales, and killer whales.

It is difficult to measure outcomes for animals after an interaction with fishing gear, but post-release survival is an important component of vulnerability. There is Survival post-capture is expected to be very low in gillnets, based on empirical and anecdotal information. However, it needs to be further assessed in other fishing gears such as pelagic longlines, where data are also lacking. Bycatch in gillnet vessels that are under 24 meters long should also be monitored, as their cumulative potential for bycatch is substantial. These vessels most likely overlap with the range of more coastal and endangered cetacean species within exclusive economic zones, and should be encouraged to report effort, catch and bycatch data.

There is, although insufficient, progress in the IOTC area to address the cetacean bycatch issue, particularly as FAO has developed voluntary bycatch reduction guidelines (FAO 2021). There has also been increasing initiatives to address the cetacean bycatch issue by IOTC and the WPEB (Working Party on Ecosystems and Bycatch) in collaboration with the International Whaling Commission's Bycatch Mitigation Initiative (BMI), and was endorsed in an agreement to foster bycatch reduction initiatives (IOTC-IWC 2021). The Import Provisions under the US Marine Mammal Protection Act (MMPA), expected to take effect by 2024, will require several members of the IOTC to demonstrate that their marine mammal bycatch regulatory programs are comparable to those in the United States. Although the impacts of the Import Provisions are unknown, it becomes urgent for Indian Ocean nations exporting to the US to comply and, if necessary, improve their monitoring and mitigation strategies to quantify and mitigate cetacean bycatch, including in tuna fisheries.

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Appendix 1. Attribute scores (productivity, susceptibility and vulnerability) for 26 species of cetaceans potentially interacting with gillnets in the Indian Ocean.

Family	Common name	Scientific name	Productivity	Susceptibility	Vulnerability
Balaenopteridae	Bryde's whale	*Balaenoptera edeni*	2.21	2.34	3.22
	Blue whale	*Balaenoptera musculus*	2.44	1.33	2.79
	Humpback whale	*Megaptera novaeangliae*	1.56	2.29	2.77
Physeteridae	Sperm whale	*Physeter macrocephalus*	2	1.89	3.30
Kogiidae	Pygmy sperm whale	*Kogia breviceps*	1.68	1.32	2.14
	Dwarf sperm whale	*Kogia sima*	1.68	1.90	2.54
Ziphiidae	Longman's beaked whale	*Indopacetus pacificus*	1.86	2.12	2.82
	Blainville's beaked whale	*Mesoplodon densirostris*	1.86	2.31	2.97
	Cuvier's beaked whale	*Ziphius cavirostris*	1.86	1.91	2.67
Delphinidae	Common dolphin	*Delphinus delphis*	2	2.28	3.03
	Pygmy killer whale	*Feresa attenuata*	2	2.11	2.91
	Short-finned pilot whale	*Globicephala macrorhynchus*	2	2.09	2.89
	Risso's dolphin	*Grampus griseus*	2.21	2.30	3.19
	Fraser's dolphin	*Lagenodelphis hosei*	2	2.06	2.87
	Irrawaddy dolphin	*Orcaella brevirostris*	1.86	1.57	2.43
	Killer whale	*Orcinus orca*	1.86	1.57	2.43
	Melon-headed whale	*Peponocephala electra*	2	2.33	3.07
	False killer whale	*Pseudorca crassidens*	1.86	1.89	2.65
	Humpback dolphins	*Sousa* sp.	1.41	1.57	2.11
	Pantropical spotted dolphin	*Stenella attenuata*	2	2.33	3.07
	Striped dolphin	*Stenella coeruleoalba*	2.21	2.34	3.22
	Spinner dolphin	*Stenella longirostris*	2	2.32	3.07
	Rough-toothed dolphin	*Steno bredanensis*	1.86	2.33	2.98
	Indo-Pacific bottlenose dolphin	*Tursiops aduncus*	1.86	1.87	2.64
	Common bottlenose dolphin	*Tursiops truncatus*	1.86	2.31	2.97
Phocoenidae	Indo-Pacific finless porpoise	*Neophocaena phocaenoides*	1.86	1.57	2.44

Appendix 2. Attribute scores (productivity, susceptibility and vulnerability) for 26 species of cetaceans potentially interacting with pelagic longlines in the Indian Ocean.

Family	Common name	Scientific name	Productivity	Susceptibility	Vulnerability
Balaenopteridae	Common minke whale	*Balaenoptera acutorostrata*	1.57	1.25	2.01
	Antarctic Minke whale	*Balaenoptera bonaerensis*	2.21	1.19	2.51
	Sei whale	*Balaenoptera borealis*	2.45	1.08	2.68
	Bryde's whale	*Balaenoptera edeni*	2.21	1.49	2.67
	Blue whale	*Balaenoptera musculus*	2.45	1.25	2.75
	Humpback whale	*Megaptera novaeangliae*	1.57	1.50	2.17
Physeteridae	Sperm whale	*Physeter macrocephalus*	2.71	1.55	3.12
Kogiidae	Pygmy sperm whale	*Kogia breviceps*	1.68	1.07	1.99
	Dwarf sperm whale	*Kogia sima*	1.68	1.39	2.18
Ziphiidae	Longman's beaked whale	*Indopacetus pacificus*	1.86	1.57	2.43
	Blainville's beaked whale	*Mesoplodon densirostris*	1.86	1.47	2.37
	Cuvier's beaked whale	*Ziphius cavirostris*	1.86	1.56	2.43
Delphinidae	Common dolphin	*Delphinus delphis*	2.00	1.02	2.25
	Pygmy killer whale	*Feresa attenuata*	2.00	1.39	2.44
	Short-finned pilot whale	*Globicephala macrorhynchus*	2.00	2.04	2.85
	Long-finned pilot whale	*Globicephala melas*	1.68	1.24	2.09
	Risso's dolphin	*Grampus griseus*	2.21	1.68	2.78
	Fraser's dolphin	*Lagenodelphis hosei*	2.00	1.04	2.25
	Killer whale	*Orcinus orca*	1.86	1.34	2.29
	Melon-headed whale	*Peponocephala electra*	2.00	1.37	2.42
	False killer whale	*Pseudorca crassidens*	1.86	2.09	2.80
	Pantropical spotted dolphin	*Stenella attenuata*	2.00	1.40	2.44
	Striped dolphin	*Stenella coeruleoalba*	2.21	1.56	2.71
	Spinner dolphin	*Stenella longirostris*	2.00	1.35	2.41
	Rough-toothed dolphin	*Steno bredanensis*	1.86	1.41	2.34
	Common bottlenose dolphin	*Tursiops truncatus*	1.86	1.29	2.26

Appendix 3. Attribute scores (productivity, susceptibility and vulnerability) for 24 species of cetaceans potentially interacting with purse seines in the Indian Ocean.

Family	Common name	Scientific name	Productivity	Susceptibility	Vulnerability
Balaenopteridae	Common minke whale	*Balaenoptera acutorostrata*	1.57	1.68	2.30
	Sei whale	*Balaenoptera borealis*	2.45	1.19	2.72
	Bryde's whale	*Balaenoptera edeni*	2.21	1.72	2.80
	Blue whale	*Balaenoptera musculus*	2.45	1.06	2.67
	Humpback whale	*Megaptera novaeangliae*	1.57	1.48	2.15
Physeteridae	Sperm whale	*Physeter macrocephalus*	2.71	1.29	3.00
Kogiidae	Pygmy sperm whale	*Kogia breviceps*	1.68	1.20	2.06
	Dwarf sperm whale	*Kogia sima*	1.68	1.28	2.11
Ziphiidae	Longman's beaked whale	*Indopacetus pacificus*	1.86	1.35	2.30
	Blainville's beaked whale	*Mesoplodon densirostris*	1.86	1.27	2.25
	Cuvier's beaked whale	*Ziphius cavirostris*	1.86	1.33	2.29
Delphinidae	Common dolphin	*Delphinus delphis*	2.00	1.42	2.45
	Pygmy killer whale	*Feresa attenuata*	2.00	1.30	2.38
	Short-finned pilot whale	*Globicephala macrorhynchus*	2.00	1.25	2.36
	Risso's dolphin	*Grampus griseus*	2.21	1.44	2.64
	Fraser's dolphin	*Lagenodelphis hosei*	2.00	1.42	2.45
	Killer whale	*Orcinus orca*	1.86	1.01	2.12
	Melon-headed whale	*Peponocephala electra*	2.00	1.29	2.38
	False killer whale	*Pseudorca crassidens*	1.86	1.27	2.25
	Pantropical spotted dolphin	*Stenella attenuata*	2.00	1.82	2.70
	Striped dolphin	*Stenella coeruleoalba*	2.21	1.89	2.91
	Spinner dolphin	*Stenella longirostris*	2.00	1.80	2.69
	Rough-toothed dolphin	*Steno bredanensis*	1.86	1.29	2.26
	Common bottlenose dolphin	*Tursiops truncatus*	1.86	1.22	2.22