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GHOTI

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By-catch risk for toothed whales in global small-scale fisheries

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Abstract

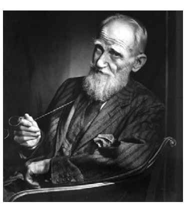
Fisheries by-catch poses the single greatest threat to cetacean (whales, dolphins and porpoises) populations. Despite this, by-catch of cetaceans does not receive proportionate levels of research or management effort. The contribution of small-scale fisheries to cetacean by-catch is generally overlooked because of the extreme data paucity in these fisheries. Here, we assess the likely geographic distribution of by-catch risk posed to the odontocetes (toothed whales) at the global scale. We combine species' occurrence and estimates of fisheries susceptibility for all 72 marine toothed whale species with estimates of small-scale fisheries' gillnet fishing pressure across 163 marine fishing nations. We show that the by-catch risk from small-scale fisheries is likely greatest in low- and middle-income regions, generally in the tropics and sub-tropics. Our findings highlight a "wicked problem", that the highest by-catch risks primarily occur in regions with lowest fisheries management efficacy. Addressing by-catch in these priority regions is fraught with potentially damaging consequences for the survival of vulnerable human coastal communities. Yet, immediate management and conservation actions are required to prevent species extirpation and extinction through the reduction of small-scale fisheries by-catch. To be successful, these actions will likely require multilateral cooperation and must carefully balance both species and human needs.

KEYWORDS

artisanal, cetacean, extinction, gillnet, marine mammal, subsistence

1 | INTRODUCTION

Gillnet fisheries pose the single greatest threat to cetacean (whales, dolphins, and porpoises) populations (Nelms et al. 2021; Read et al. 2006). This is the result of widespread and largely unintentional catches by fisheries (by-catch), coupled with the low annual reproductive potential of cetaceans. Despite the threat posed, by-catch assessment and mitigation does not attract proportionate levels of research effort, practical implementation, nor the political will to make measurable and effective progress (Brownell et al. 2019;



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Etymology of Ghoti

George Bernard Shaw (1856–1950), polymath, playwright, Nobel prize winner, and the most prolific letter writer in history, was an advocate of English spelling reform. He was reportedly fond of pointing out its absurdities by proving that 'fish' could be spelt 'ghoti'. That is: 'gh' as in 'rough', 'o' as in 'women' and 'ti' as in palatial.

Dolman et al. 2021). The majority of by-catch research to date is restricted to the large-scale commercial fisheries of high-income nations, in both their own waters and elsewhere (Lewison et al. 2014). This bias is subsequently reflected in global assessments of both the volume and distribution of cetacean by-catch (Lewison et al. 2014; Read et al. 2006) and therefore overlooks the contribution of small-scale fisheries (SSF).

Cetacean by-catch in SSF may be as important, if not more so, as by-catch in large-scale fisheries; but there is a general lack of data with which to test this hypothesis. While catch rates per vessel may be lower on average, SSF are far more numerous than their industrial counterparts (FAO, 2020) and their catch rates, at least in some instances, may be substantial (e.g. Bordino et al. 2002; Mangel et al. 2010). Additionally, SSF are generally concentrated over the continental shelf in waters between 0 and 200 m depth. SFF therefore pose a specific threat to coastal and neritic cetaceans, which represent the species most at-risk of extinction/extirpation and with little or no refuge from SSF pressure (Brownell et al. 2019). Further, currently available by-catch mitigation technologies (e.g. acoustic alarms "pingers" and lights), which to date are only sparingly implemented in large-scale fisheries (Dolman et al. 2021; Rogan et al. 2021), are expensive and therefore largely unfeasible for SSF. Here, we assess the geographic distribution of the relative by-catch risk posed by SSF to toothed whales (odontocetes).

2 | METHODS

Species' vulnerability to fisheries is a function of their biological resilience to fisheries exploitation and their exposure to fisheries. Species' biological resilience to fisheries exploitation is primarily dictated by population growth rates, which are broadly similar across toothed whale species at 2%–8% per year (Reilly & Barlow, 1986; Wade, 1998). Fisheries exposure is primarily a function of a species' susceptibility to being caught, fishing pressure and fishing power (i.e. the area of gear coverage and the gear efficiency). To create the first assessment of the geographic distribution of by-catch risk posed by SSF to toothed whales, we leveraged low-resolution metrics for species' susceptibility and fishing pressure at the national scale. Fishing power was not included in our analyses because its relationship with toothed whale by-catch rates is unknown. Fishing power in the context of toothed whale by-catch may vary with gear specification (e.g. mesh size and tension) and measures taken to reduce by-catch (e.g. mitigation devices). A better understanding of fishing power's relationship with toothed whale by-catch may improve the accuracy and interpretation of future estimates. Estimates of species' susceptibility were included for all 72 toothed whale species with a marine distribution. Estimates of fishing pressure were included for 163 fishing nations. Susceptibility and fishing pressure data at national levels were combined at Large Marine Ecoregion (LME) Realm scales, using weighted means across the constituent nations, to assess relative by-catch risk. We assessed the relative by-catch risk as the Euclidean distance in a 2-D plot where fishing pressure risk and species' susceptibility risk represent the axes; a flow diagram of the methodology is provided (Supplementary Figure S1). Analyses and visualisations were carried out in R Statistical Software v3.6.3 and QGIS v3.1 (QGIS, 2021; R Core Team, 2020).

Risk scores associated with toothed whale fisheries susceptibility were calculated as a combination of the presence and estimated susceptibility for each given species. A total of 72 species were considered, including all species with a marine distribution from the families Delphinidae (oceanic dolphins), Kogiidae (dwarf and pygmy sperm whales), Monodontidae (beluga and narwhal), Phocoenidae (porpoises), Physeteridae (sperm whale), Pontoporiidae (Franciscana dolphin), and Ziphiidae (beaked whales). Species found exclusively in freshwater were not included in our analyses, that is the Amazon river dolphin (*Inia geoffrensis*, Iniidae), the Tucuxi (*Sotaila fluviatilis*, Delphinidae), and the recently revised South Asian river dolphins (*Platanista gangetica*, *Platanista minor*, Platanistidae) (Braulik et al. 2021). The taxonomy of species follows that set out by the Society of Marine Mammalogy and IUCN Red List. Species' presence or absence in a given nation was assigned using the IUCN Red List (IUCN, 2020). We assume that the risk posed by SSF to species increases exponentially with decreasing maximum water depth. This assumption is based on the combination of increasing SSF pressure in shallower waters, relative to deeper waters, and the more limited areas of refuge from SSF pressure available for shallow water restricted species than for those in deeper waters. As a result, shallow water restricted species face a multiplicative problem of being both more likely to encounter SSF and having less refuge from them. We therefore calculated individual species risks as the natural log of the maximum water depth of their distribution, normalised these between lowest (0) and highest (1), and subsequently inverted this value (Supplementary Table S1). The natural log transformation reflects our assumption that the susceptibility of a species to SSF increases exponentially with decreasing maximum depth. Our assumption implies that species with the greatest maximum water depths are at negligible risk of by-catch in SSF, though by-catch may still occur in rare cases or in other fisheries types (e.g. high seas fisheries). The maximum water depth of species distribution was extracted from the IUCN Red List, which provides the only standardised global classifications of this type (IUCN, 2020). Where a specific value was not given, species were assigned as Marine Coastal/Supratidal/Intertidal (50 m), Marine Neritic (100 m), Epipelagic (200 m), Mesopelagic (1,000 m), or Bathypelagic (4,000 m) based on their IUCN Red List Habitat Classification Scheme designation. A cumulative total of individual species risk scores was calculated at the national level for each LME Realm. A weighted (by continental shelf area) mean was calculated for each LME Realm and subsequently normalised between the lowest (0) and highest (1) to produce an overall species risk score.

Risk scores associated with fishing pressure were calculated as the estimated SSF gillnet vessel density per km^2 of coastal shelf (≤200 m water depth) for each of the 163 nations. Where nations fell into multiple LME Realms, vessels were divided between LME Realms based on coastline length (Supplementary Table S2). SSF

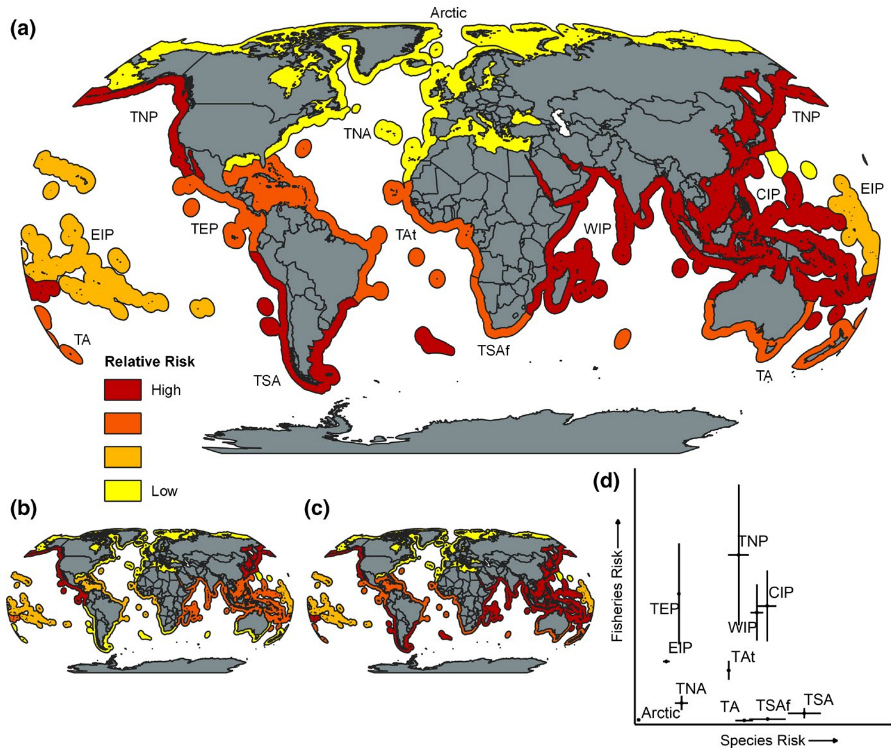

FIGURE 1 Global risk assessment of toothed whale by-catch in small-scale fisheries by Large Marine Ecoregion (LME) Realms. (a) Relative risk scores by LME Realm, calculated as the Euclidean distance with fisheries pressure risk and species susceptibility risk as axes. (b) Fisheries pressure relative risk score by LME Realm. (c) Species susceptibility relative risk score by LME Realm. (d) Relative risk scores by LME Realm with associated weighted mean standard errors displayed. LME Realms = Arctic, Central Indo-Pacific (CIP), Eastern Indo-Pacific (EIP), Temperate Australasia (TA), Temperate Northern Atlantic (TNA), Temperate Northern Pacific (TNP), Temperate South America (TSA), Temperate Southern Africa (TSAf), Tropical Atlantic (TAt), Tropical Eastern Pacific (TEP) and Western Indo-Pacific (WIP). Figure appears in color in the online version only

gillnet vessel numbers were estimated from FAO fishing vessel data (FAO, 2020). Fishing nations for which there was no vessel data available (e.g. North Korea) or for which an Economic Exclusive Zone could not be directly assigned (e.g. Channel Islands, Cook Islands, Curaçao) were excluded from the analysis. There was substantial variability among nations in the breakdown of gear types provided and likely also in the accuracy of vessel numbers reported. Variability in the accuracy of gear type and vessel number reporting will inevitably impact the estimates of gillnet fisheries pressure used in this study. On a nation-by-nation basis this may lead to either under- or overestimation of gillnet vessel numbers and therefore also the associated risk score. All vessels of "unknown" length or with a length <12 m were assumed to be SSF vessels for the purpose of these analyses. To estimate the total number of vessels which operate with gillnets, we used the gear-type breakdown from those nations where gear type was declared (ignoring the categories "Multipurpose Vessels" and "Other fishing vessels" as both represent a mixture of gears, including gillnets). The mean proportion of gillnets relative to other declared gear types was calculated across nations grouped by their Continent and Human Development Index (HDI) (Supplemental Table S3). We then estimated the total number of gillnets per nation by assigning a percentage of "Multipurpose Vessels" and "Other fishing vessels" as gillnets according to the Continent/HDI matrix of mean gillnet proportions and adding these to the number of gillnets originally declared. Our estimate is based on the assumption that nations in similar geographic areas and under similar economic circumstances are likely to be more similar in terms of fishing practices than the global average. The only exceptions in our methodology were for Kiribati (Micronesia), Papua New Guinea (Melanesia), and Vanuatu (Melanesia), whose estimated gillnet numbers were assigned based on their United Nations Statistics Division (UNSD) Region because no other nations with declared gear types fit into the same Continent/HDI matrix category. Gillnet estimates are intended as representations of the relative differences in gillnet numbers between nations and should not be considered as an estimate of the absolute number of gillnets. Gillnet vessel density was calculated per km^2 of coastal shelf area (≤200 m water depth) per nation per LME Realm. A weighted (by continental shelf area) mean was calculated for each LME Realm and subsequently normalised between the lowest (0) and highest (1) gillnet density to produce an overall fisheries risk score.

3 | RESULTS AND DISCUSSION

Our results (Figure 1, Supplementary Table S4) show a clear pattern of high toothed whale SSF by-catch risk in predominantly tropical and sub-tropical regions dominated by low- and middle-income nations.

By-catch risk was highest in the Central Indo-Pacific; Temperate Northern Pacific (driven partly by high SSF vessel numbers in China); Temperate South America (driven primarily by the large number of high-risk species); and the Western Indo-Pacific. This was followed by the Tropical Eastern Pacific; Tropical Atlantic; and Temperate Southern Africa.

Of the species assessed, those estimated to be most susceptible to fisheries by-catch were all four species of humpback dolphins (*Sousa chinensis*, *Sousa plumbea*, *Sousa sahulensis*, *Sousa teuszii*, Delphinidae), both Irrawaddy and Australian snubfin dolphins (*Orcaella brevirostris*, *Orcaella heinsohni*, Delphinidae), the Fanciscana dolphin (*Pontoporia blainvillei*, Pontoporiidae), the Guiana dolphin (*Sotalia guianensis*, Delphinidae), the Indo-Pacific finless porpoise (*Neophocaena phocaenoides*, Phocoenidae), and the likely soon to be extinct vaquita (*Phocoena sinus*, Phocoenidae). Of these ten species the IUCN Red List currently designates two as critically endangered, two as endangered and five as vulnerable. All ten species appear in the LME Realms identified as highest risk. Additionally, most of the critically endangered marine toothed whales reviewed by Brownell et al. (2019) occur in the regions we estimate as having either high or relatively high risk of toothed whale SSF by-catch. These include the vaquita and Atlantic humpback dolphin, as well as various subpopulations of Irrawaddy, harbour porpoise (*Phocoena phocoena*, Phocoenidae), common bottlenose dolphin (*Tursiops truncates*, Delphinidae), beluga (*Delphinapterus leucas*, Monodontidae), and the Māui dolphin subspecies (*Cephalorhynchus hectori maui*, Delphinidae). Beyond the aforementioned species, others of particular concern (i.e. those species not yet mentioned and which have a maximum depth of ≤100 m) are Peale's dolphins (*Lagenorhynchus australis*, Delphinidae) and Chilean dolphins (*Cephalorhynchus eutropia*, Delphinidae) in Temperate South America, and Hector's dolphin (*Cephalorhynchus hectori*, Delphinidae) in Temperate Australasia. Across much of their ranges, the status of populations for many of these high-risk species are poorly understood but there are often known or suspected high by-catch rates.

Our results highlight a “wicked problem” for toothed whale by-catch in SSF. This wicked problem results from a set of contradictory issues with which fisheries managers must contest. SSF are vital to the food, nutritional and economic security of many low- and middle-income nations (Béné, 2006; Hicks et al. 2019). Potential SSF management interventions to reduce by-catch in these nations are constrained by the need to protect the vulnerable human coastal communities that depend on these fisheries. Yet, it is low- and middle-income nations which predominantly compose the LME Realms identified in our analysis as having the highest by-catch risk for toothed whales, and so are most in need of management interventions. These contradictory needs are complicated further because by-catch and its resultant impacts on toothed whale populations are generally least well quantified in these regions (e.g. Temple et al. 2018). An additional layer of complexity is that, in at many cases, toothed whale catches in low- and middle-income nations may not even be considered as by-catch, rather they may often be of value for subsistence, as fishing bait, or for other traditional purposes (e.g. Castro et al. 2020; Porter et al. 2017). Lastly, gross domestic product is a powerful predictor of fisheries management and governance strength (Melnychuk et al. 2017). Taken together, this suggests that where the risks of toothed whale by-catch are highest and the complexity of managing it greatest, the capacity to effectively manage the fisheries which impact them are likely to be lowest.

Addressing the by-catch risk posed by SSF in the high-risk regions identified by our analysis is especially challenging and must be considered a global priority for toothed whale conservation. Given the risk posed to toothed whales by SSF and their role as meso- and apex predators supporting ecosystem stability and function (e.g. Heithaus et al. 2008), efforts to prevent localised extirpation and even extinction are required immediately. Toothed whale species and many of their constituent populations are often transboundary. In order to be effective, management interventions will therefore require multilateral cooperation among nations to ensure the long-term survival of toothed whale species. Yet, management interventions may be fraught with potential consequences for the vulnerable human coastal communities dependant on SSF. Conservation actions and management interventions must, therefore, be realistic; they will undoubtedly need to be tailored to specific local economic and social contexts, and must carefully balancing both species and human need.

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CONFLICTS OF INTEREST

The authors declare no conflict of interests.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are openly available from the FAO (https://doi.org/10.4060/cb1213t) and the IUCN (https://www.iucnredlist.org/).

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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