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An Ecological Risk Assessment (ERA) for marine mammals, sea turtles and elasmobranchs captured in artisanal fisheries of the SW Indian Ocean based on interview survey data*

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Abstract

The incidental catch of marine megafauna, including marine mammals, sea turtles and elasmobranchs, poses one of the main threats to these species at the global scale. The purpose of this study is to assess the magnitude of bycatch of vulnerable megafauna in the SWIO artisanal fisheries using interview survey data. A total of 961 interviews were conducted in the region, including in Mozambique, Tanzania, Kenya and Mauritius. At least 59 species were identified as bycatch or by-product species, including 5 species of sea turtles, 8 species of marine mammals and 46 species of elasmobranchs. A level-2 (Productivity-Susceptibility Analysis) Ecological Risk Assessment (ERA) emphasized that at least 17 species were particularly vulnerable to artisanal fisheries bycatch in the southwest Indian Ocean, including 5 species of sea turtles (loggerhead, green, hawksbill, olive Ridley and leatherback turtles), 4 species of marine mammals (dugong, Indo-Pacific bottlenose, humpback and spinner dolphins) and 8 species of elasmobranchs. Among elasmobranchs, highest risk was identified for Manta, spotted eagle rays, giant guitarfish and hammerhead sharks. Risk was higher in multifilament than in monofilament drift gillnets, for dolphins, sea turtles and elasmobranchs, and involved more species. Risk was lower in bottom set gillnets, but affected a greater number of species, especially benthic and demersal species. Line fisheries (longline and handline) have low risk scores for sea turtles and marine mammals. However, these fisheries have a significant impact on elasmobranchs. Beach seines were rated high risk for sea turtles, especially for the green turtle. This study clearly highlight that a diversity of oceanic large marine vertebrates interact with coastal artisanal fisheries. It also underlines the urgent need for integrated regional management of large and mobile marine vertebrates across large marine ecosystems, especially as wide-ranging species interact with both coastal artisanal and oceanic industrial fisheries.

Introduction

The incidental catch of marine megafauna, including marine mammals, sea turtles and elasmobranchs, poses one of the main threats to these species worldwide (Lewison *et al.*, 2004). These taxa are particularly vulnerable for biological reasons, such slow maturity and low reproductive rates. The bycatch issue has been primarily investigated in industrial fisheries while relatively little attention has been given to the extent of bycatch in artisanal fisheries. Artisanal fisheries account for more than 95% of fishers in the world (Pauly, 2006). Their impact on vulnerable megafauna may be significant, and the scope of the bycatch issue in artisanal fisheries may be significant (Moore *et al.*, 2010).

In the southwest Indian Ocean (SWIO) region (including east Africa from Mozambique to Kenya, Madagascar, the Seychelles, the Comoros and the Mascarenes), the bycatch issue in artisanal fisheries is poorly documented. However, of 254 recorded fisheries, 138 are artisanal (Everett *et al.*, 2011). Before the early 2000s, most information was anecdotal or unpublished. In response to increasing concern about incidental catch of vulnerable megafauna in the region, several initiatives were implemented to address this issue (e.g. FAO, 2006; Kiszka & Muir, 2007). These initial studies suggested that while sea turtles, dugongs, cetaceans and sharks are all impacted by fishing activities in the region, it is the dugong which is most severely threatened from gillnetting and habitat disturbance (Kiszka & Muir, 2007). Subsequently, several local and regional projects were conducted to assess the extent of bycatch on marine mammals and sea turtles in artisanal fisheries, such as in the Comoros (Poonian *et al.*, 2008), Mayotte (Kiszka *et al.*, 2007; Pusineri & Quillard, 2008); south-western Madagascar (Razafindrakoto *et al.*, 2008) and Zanzibar (Amir *et al.*, 2002; Amir, 2010). These studies highlighted that gillnet (both drift and bottom set) fisheries have the greatest impacts on these taxa. Knowledge on elasmobranch bycatch and exploitation in the SWIO is mostly available for industrial and semi-industrial fisheries, including purse seine, longline and shrimp/prawn trawl fisheries (e.g. Fennessy, 1994; Romanov, 2001, 2008; Huang & Liu, 2010). Information about catches of sharks and rays in artisanal fisheries is rare, not quantified, and is generally limited to targeted shark species (Marshall, 1997; Schaeffer, 2004; McVean *et al.*, 2006).

The flexibility of artisanal fisheries (broad range of targeted species, occurrence in multiple marine habitats and general absence of seasonality) make them very difficult to study, both in term of catch statistics and bycatch. Observer programs are very difficult (almost impossible) to implement, due to logistical constraints (small boat size, diffuse spatial arrangement of fishing communities, lack of regulatory management scheme). Therefore, in absence of data collected at sea on fishing vessels by observers, researchers have increasingly used social science methodology to better understand the interactions between artisanal fisheries and marine ecosystems (Johannes *et al.*, 2000; Close & Hall, 2006), and particularly marine mammals and sea turtles (Van Wearebeek *et al.*, 1997; Amir *et al.*, 2002; WWF EAME, 2004; Pusineri & Quillard, 2008; Moore *et al.*, 2010, Turvey *et al*., in press).

The purpose of this study is to assess bycatch and use of vulnerable megafauna (marine mammals, sea turtles and elasmobranchs) in the SWIO artisanal fisheries using interview surveys. More specifically, this study aims to identify those artisanal fisheries having the greatest impacts on marine mammals, sea turtles and elasmobranchs, and to identify the species most greatly affected. In order to achieve this goal and given the semi-quantitative value of interview-based data, we used an Ecological Risk Assessment for the Effects of Fishing approach (ERAEF, hereafter ERA). This framework involves a hierarchical approach that moves from a comprehensive but largely qualitative analysis of risk, through a more focused and semi-quantitative approach, to a highly focused and fully quantitative "model-based" approach (Hobday *et al.*, 2007, 2011). Here, we first used the Level 1 to select the most high risk fisheries and species, then used a Level-2 approach (Productivity-Susceptibility Analysis) on this subset, documenting for each species productivity and susceptibility to each gear type.

Materials and methods

Interview survey data

In order to spatially and quantitatively estimate fisheries bycatch, two types of information are needed: a measure of fishing effort and of bycatch rate (e.g. number of individuals caught per unit of effort). It is widely accepted that the most accurate method to assess bycatch rates is using independent fisheries observers on board fishing vessels (e.g. Alverson *et al.*, 1994). However, when observer data are unavailable or impossible to collect, the knowledge of fishermen can sometimes be obtained from structured questionnaire surveys (Johannes *et al.*, 2000). Despite limitations of social survey data (data are generally more qualitative than quantitative) this methodology may be useful for conducting an assessment of the relative impacts of different fisheries or in different areas on marine megafauna populations. Interview surveys have been extensively used to assess the distribution, relative abundance and threats to marine mammals and sea turtles, including in the western Indian Ocean region (Amir *et al.*, 2002; WWF EAME, 2004; Kiszka *et al.*, 2007; Pusineri & Quillard, 2008; Razafindrakoto *et al.*, 2008). These interviews have been rarely used to assess interactions between elasmobranchs and fisheries, except in the Comoros, Mayotte and northern Madagascar, where some investigations have provided some information on shark bycatch, exploitation and use (Maoulida *et al.*, 2009; Whitty *et al.*, 2010).

Rapid bycatch assessment (RBA), which forms the basis of this study, consists of in-person questionnaire surveys that were conducted in Mozambique, Tanzania (Zanzibar and Pemba), Kenya and Mauritius. A single questionnaire form was used, based on the methodology described by Moore *et al.* (2010). The questionnaire included mostly closed questions, as we were focused on collecting quantifiable and factual information (Gomm, 2004; White *et al.*, 2005). Each questionnaire was completed in-person with fishermen at landing sites (Fig. 1.1; Appendix 1). Questions asked about fishers' practices, gear use, boat type, targeted species, and bycatch of marine mammals, sea turtles and elasmobranchs (species, seasonality, number caught during the last year and use of caught animals by fishermen). Prior to each survey a statement explaining the purpose of the study and assuring confidence was made by the interviewer. Illustrations cards and identification guides were used to ensure proper bycatch species identification. A questionnaire was generally completed in 20-30 minutes. Port or landing site description was also completed (not with interviews) to record the number and types of boats in each fishing community, gear types used and general description of the area. A unique questionnaire form has been designed with national coordinators during a workshop held at Albion Fisheries Research Center, in Mauritius. For each country, a national coordinator was designated. He/she led training activities, supervised interviewers and collated data to fill in the national database (Excel table). National coordinators were permanent citizens/residents of the study countries and were experienced working with fishing communities and bycatch issues (except for 50 interviews conducted by a UK-based NGO, Global Vision International). Interviewers were staff members of local fisheries institutes or national environmental agencies (Kenya Marine Fisheries Research Institute, Institute of Marine Sciences Zanzibar, Instituto Nacional do Investigação Pesqueira in Mozambique, Tanzanian Fisheries Research Institute, MOI University, Department of Fisheries and Aquatic Sciences in Kenya, Albion Fisheries Research Center in Mauritius). Training of the interviewers included explaining the purpose of the study, survey protocol and design.

Ecological Risk Assessment
The Ecological Risk Assessment for the Effects of Fishing (ERAEF, hereafter ERA) framework involves a hierarchical approach that moves from a comprehensive but largely qualitative analysis of risk, through a more focused and semi-quantitative approach, to a highly focused and fully quantitative "model-based" approach (Hobday *et al.*, 2007, 2011 ; Fig. 1). Three levels of ERA have been identified: Level 1 analysis (Scale Intensity Consequence Analysis, SICA) is designed to identify hazards to species and systems using qualitative data and expert opinion; Level 2 (Productivity-Susceptibility Analysis, PSA) is based on the biological characteristics of species caught in the fishery concerned (Productivity), and the degree of interaction between that fishery and those species (Susceptibility). The Level 2 methodology considered to be the most appropriate and robust for fisheries ERA is termed Productivity-Susceptibility Analysis (PSA) (Hobday *et al.*, 2011). Up to five general ecological components can be evaluated: a- target species; b- by-product and bycatch species, c- threatened, endangered and protected species (TEP), d- habitats and e- ecological communities (Hobday *et al.*, 2011; Williams *et al.*, 2011). Such analyses allow the targeting of more detailed monitoring, research, and caution to be applied in managing effects of fishing, where information is incomplete or uncertain. This ERA method examines the likely consequences of removals through accidental fishing mortality on populations (their susceptibility to population effects of fishing) and recognizes that the differing fecundity and life-history attributes of populations (their productivity) play a role in determining likely population responses.

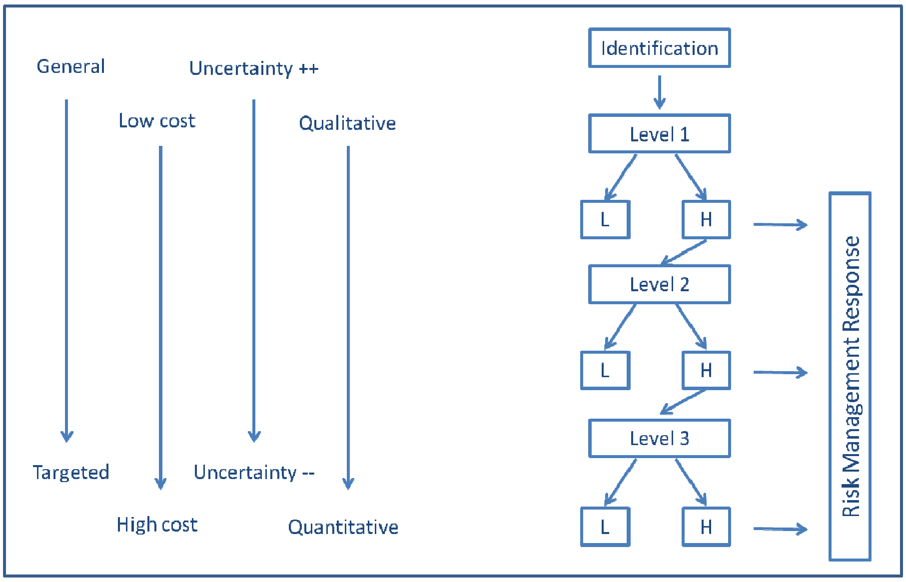

Fig. 1: ERAEF framework showing focus of analysis for each level (1 to 3; H: high risk, L: low risk). At leach level a risk management response is an alternative to proceeding to the next level (Smith *et al.*, 2007)

Level 1 (SICA) relies on expert judgment involving the stakeholders, and focus on the ecological component. An exposure-risk assessment approach is used at Level 1, and is only applied to the "worst case" unit. It involved scoring each fishing activity (hazard) for impact on the core objective for the component (Hobday *et al.*, 2011). The score and intensity of the activity are scored and the consequence score is selected from a component-specific set of scoring guidelines, e.g. from negligible (score 1) to extreme (score 6; Hobday *et al.*, 2007). Level 2 (PSA) documents, for each species, its resilience and exposure to gears/fisheries. This approach is particularly suitable in data-poor situations (including interview survey data). Each species is evaluated according to its life history characteristics (average age at maturity, maximum age, fecundity, maximum size, size at maturity, reproductive strategy, habitat characteristics and feeding strategies, i.e. productivity *P*) and exposure to gears/fisheries (overlap of species range with fishery, encounterability, post capture mortality and selectivity of the gear, Susceptibility *S* (Hobday *et al.*, 2011). A score is attributed for each attribute. There are several methods to calculate a global score for a given species, and the result is reported graphically (Fig. 2). A risk score is the Euclidian distance from the origin, which allows a single risk ranking. The *x*-axis score derives from attributes that influence the productivity of a unit, or its ability to recover after impact from fishing, while the *y*-axis score derives from attributes that influence the susceptibility of the unit to impacts from fishing. Combination of productivity and susceptibility determines the relative risk to a unit, i.e. units with high susceptibility and low productivity are at higher risk, and units with low susceptibility and high productivity are at lower risk (Fig. 2).

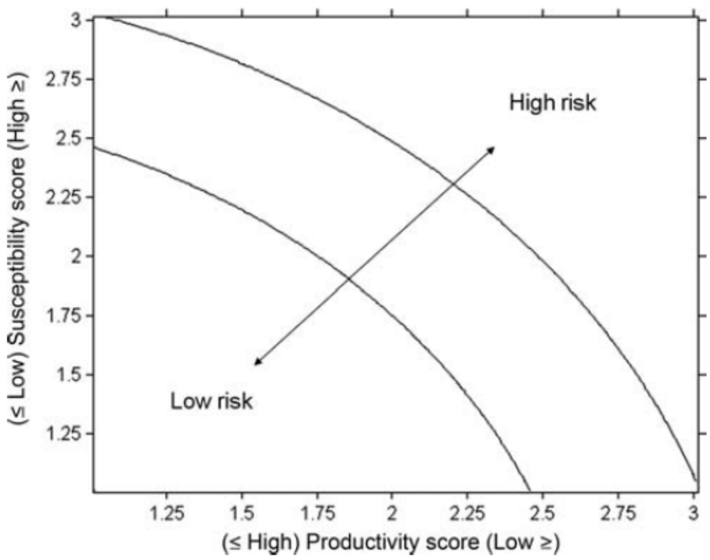

Fig. 2: Productivity-susceptibility analysis (PSA) plot used in semi-quantitative ecological risk assessments (Smith *et al*., 2007)

Based on interview survey data conducted in Mauritius, Kenya, Tanzania and Mozambique and the available literature for Madagascar and the Comoros (but only for gillnet fisheries), a PSA was conducted based on scoring methods provided by Hobday *et al.* (2011) and adapted for species of our interest and to use survey data.

First, Level 1 analysis (SICA) was undertaken to identify most impacting fisheries and species that are particularly involved in bycatch events. Fishery selection was based on the extent of survey effort conducted, its geographical/numerical extent (at the regional level) and overall bycatch levels of sea turtles, marine mammals and elasmobranchs. Selected species for the PSA (Level 2) was based on species IUCN status, regional range and occurrence as bycatch species. PSA scoring methods followed methodology described in Hobday *et al.* (2011) for productivity *P*. Productivity and susceptibility attributes are scored as 1 (low), 2 (medium) or 3 (high), and missing attributes are scored as a 3. A total of nine criteria were used to calculate *P*, including age at maturity, size at maturity, maximum age, fecundity, reproductive strategy, range (global and regional distributions), global population size, habitat characteristics and diet. The arithmetical mean of all criteria constituted *P*. Susceptibility (*S*) was calculated for each selected fishery and was based on bycatch incidence (N individuals/taxonomical group during the last year). However, as bycatch incidence was calculated for each main taxonomical group, species composition (proportion) was used to estimate a specific bycatch incidence for the species included in the PSA. In our case, *S* was calculated as the arithmetic mean of scores of five criteria, including mean regional bycatch incidence (mean of bycatch incidence for each surveyed country), commercial value, gear selectivity, habitat overlap between gear and bycatch species and post capture survival. Curved lines (thresholds) have been added graphically (at 2.5 and 3 scores), dividing the PSA plot into thirds, representing low, medium and high risk, and group units of similar risk levels (Hobday *et al.*, 2011).

Results

Sampling

A total of 961 interview surveys were conducted in the region, including in Kenya (n=330), Tanzania (n=276), Mozambique (n=296) and Mauritius (n=59; Fig. 3).

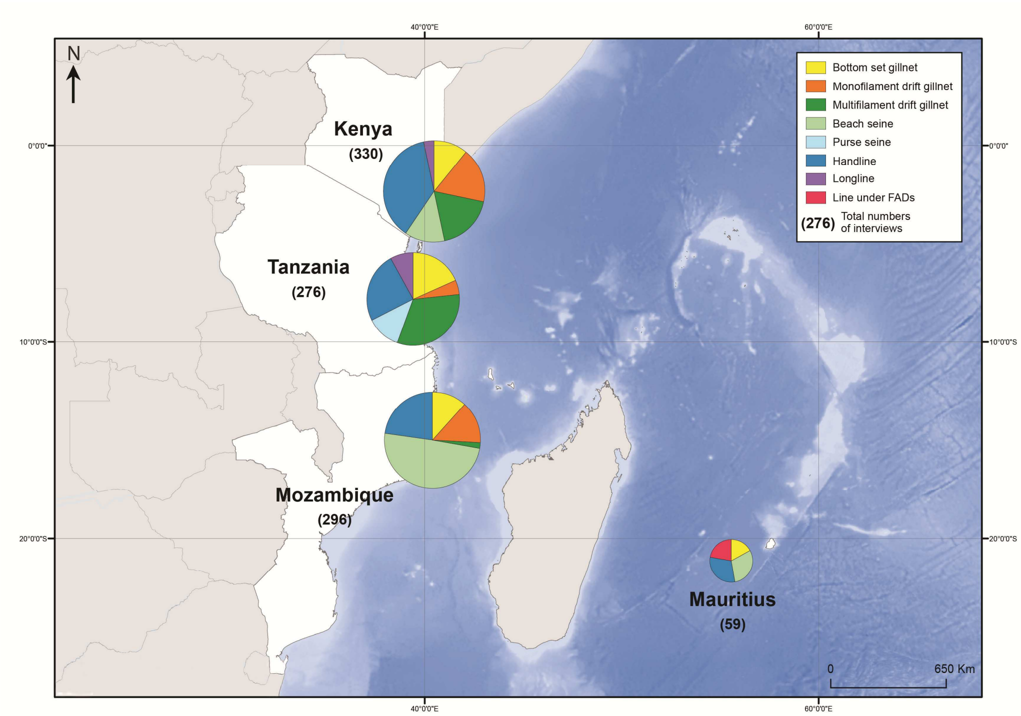

Fig. 3: Number of interview surveys conducted in each sampled countries (N = 961)

Throughout the region, eight artisanal fisheries (or gear-types) were sampled. These fisheries were the most likely involved in sea turtle, marine mammal and elasmobranch bycatch. A particular effort has been devoted to sample gillnet fisheries, previously documented as the major threat to large marine megafauna in the region (Bourjea *et al.*, 2008; Kiszka *et al.*, 2008). Some geographical variations of gear used were observed. Around Mauritius, hook-line fishing under fixed FADs is possible due to the proximity of deep oceanic waters (narrowness of shelf). Conversely, along the east coast of Africa, beach seining and gillnetting is intense due to the presence of a wide continental shelf and availability of coastal marine habitats.

Ecological Risk Assessment

Level 1 (SICA) of the ERA identified five gears/fisheries to be included in the PSA: multifilament drift gillnets, monofilament drift gillnets, bottom set gillnets, beach seines and handlines. The other fisheries provided few replicates (limited amount of data), or were geographically restricted (purse seines, longlines and lines under FADs). During RBA surveys, a total of 59 species were identified by fishermen as bycatch/by-product species, including 5 species of sea turtles, 8 species of marine mammals and 46 species of elasmobranchs. However, only 17 species were selected for the Productivity-Susceptibility Analysis. All other species were rarely recorded at the regional level. As previously mentioned, selected species for the PSA was also based on species IUCN status and their occurrence as bycatch species (bycatch incidence). All species of sea turtles, the most common marine mammal species and the most commonly bycaught elasmobranchs were included in the analysis (Table 1).

Table 1: Selected species for the Productivity-Susceptibility Analysis

	English name (abbreviation)	Latin name
Sea turtles		
	Green turtle (GNT)	*Chelonia mydas*
	Hawksbill turtle (HKS)	*Eretmochelys imbricata*
	Loggerhead turtle (LOG)	*Caretta caretta*
	Leatherback turtle (LET)	*Dermochelys coriacea*
	Olive Ridley turtle (OLI)	*Lepidochelys olivacea*
Marine Mammals		
	Dugong (DUG)	*Dugong dugon*
	IP bottlenose dolphin (BOT)	*Tursiops aduncus*
	IP humpback dolphin (HUM)	*Sousa chinensis*
	Spinner dolphin (SPI)	*Stenella longirostris*
Elasmobranchs		
	Manta ray (MAN)	*Manta* spp.
	Spotted eagle ray (NAR)	*Aetobatus narinari*
	Giant guitarfish (GIT)	*Rhynchobatus djiddensis*
	Black-spotted stingray (BLS)	*Taeniurops meyeni*
	Honeycomb stingray (HON)	*Himantura uarnak*
	Scall. hammerhead shark (SHH)	*Sphyrna lewini*
	Great hammerhead shark (GHH)	*Sphyrna mokarran*
	Whitetip reef shark (WTR)	*Triaenodon obesus*

PSA outputs are presented in Fig. 4. Patterns are relatively similar among the drift gillnets (mono- and multifilament), but higher risk is estimated for all species of sea turtles (especially for multifilament drift gillnets), coastal marine mammals (especially Indo-Pacific bottlenose dolphin), as well as three large elasmobranchs (*Manta* spp, *S. lewini* and *S. mokarran*). Two species (*Stenella longirostris* and *Aetobatus narinari*) face a medium risk. Benthic and coastal/demersal species of elasmobranchs face a low risk in drift gillnet fisheries.

The situation for bottom set gillnets is significantly different than in drift gillnets (Fig. 4c). Benthic and coastal/demersal elasmobranchs (including most rays) face a medium risk, while pelagic/oceanic species are less impacted by bottom set gillnets. Higher risk is estimated for most of sea turtle species (except *D. coriacea*), *Manta* spp, *Tursiops aduncus* and *Dugong dugon*. *Stenella longirostris* faces to low risk, primarily due to its preferential oceanic foraging habitat.

In beach seines, higher risk is estimated for *Chelonia mydas*, and other sea turtles (except *D. coriacea*; Fig. 4d). Coastal marine mammals are also potentially at risk in beach seines. Risk is medium for all elasmobranch species, while oceanic dolphins (*Stenella longirostris*) face a low risk in this fishery. In handlines (Fig. 4e), *Chelonia mydas* and *Eretmochelys imbricata* face to the higher risk. *Sphyrna lewini* is situated in the medium risk category. Overall, risk faced by vulnerable megafauna is relatively low at the regional level.

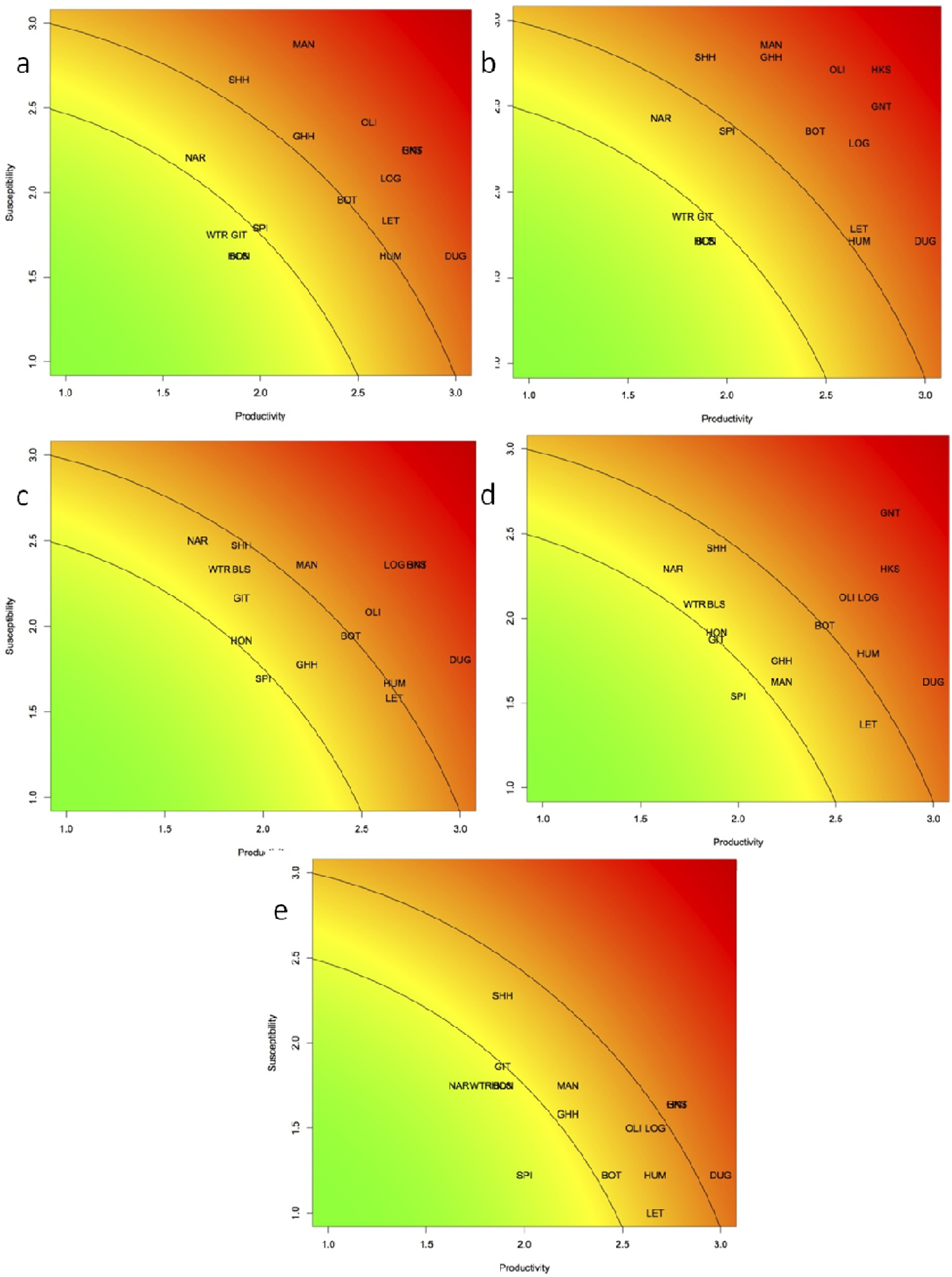

Fig. 4: Productivity-Susceptibility plots for a- monofilament drift gillnets, b- multifilament drift gillnets, c- bottom set gillnets, d- beach seines and e- handlines for all countries combined. Contour lines divide the risk plot into approximate thirds

Discussion

Major findings

This study investigated the extent of marine mammal, sea turtle and elasmobranch bycatch and use in the southwest Indian Ocean. It is based on a large number of interviews (nearly 1,000) undertaken in four countries, including Kenya, Tanzania, Mozambique and Mauritius, where very little was known on megafauna bycatch in artisanal fisheries. The extent of interview effort is currently one of the most ambitious ever conducted at the global scale and the most significant in the Indian Ocean. This is also the first study of marine mammal, sea turtle and elasmobranch bycatch and utilization in artisanal fisheries of Kenya, Mozambique and Mauritius. The major finding of this study is the high extent of large marine vertebrate bycatch in artisanal fisheries, especially in drift, bottom set gillnets and beach seines. At least 59 species were identified as bycatch and by-product species, including 5 species of sea turtles, 8 species of marine mammals and 46 species of elasmobranchs. The Ecological Risk Assessment identified at least 17 species were particularly vulnerable to artisanal fisheries bycatch in the southwest Indian Ocean, including all species of sea turtles (loggerhead, green, hawksbill, olive Ridley and leatherback turtles), 4 species of marine mammals (dugong, Indo-Pacific bottlenose, humpback and spinner dolphins) and 8 species of elasmobranchs. Among elasmobranchs, highest risk was identified for Manta, spotted eagle rays, giant guitarfish and hammerhead sharks (including scalloped and great hammerheads. Line fisheries (longline and handline) have a low impact on the survival of sea turtles and marine mammals. However, these fisheries have a significant impact on elasmobranchs. It was particularly clear for the artisanal longline fishery off Zanzibar, but this statement is only based on a relatively limited sample size (which explains exclusion of this fishery/gear from the PSA). Therefore, a future regional effort would be critical to conduct to characterize the extent of vulnerable megafauna' bycatch in artisanal longline fisheries.

As suggested in the PSA plots, there is a difference in the risk to vulnerable megafauna among gears. Risk was higher in multifilament than in monofilament drift gillnets, both for cetaceans (and small delphinids in particular), sea turtles and elasmobranchs, and involved more species. Sea turtles (especially green, hawksbill, olive Ridley and loggerhead turtles), manta rays, hammerhead sharks and Indo-Pacific bottlenose dolphins were the species at higher risk. Risk was lower for these species in bottom set gillnets (but they were still high for several species), but affected a greater number of species, especially benthic and demersal species (especially coastal rays and reef sharks).

However, the risk associated with bottom set gillnets was lower for all species (due to lower susceptibility). Beach seines were also high risk for sea turtles, especially for the green turtle, as this gear is frequently used very close to shore, over seagrass meadows (foraging habitats for this species). Other species of sea turtles were also at high risk including hawksbill, olive Ridley and loggerhead turtles and, surprisingly, coastal marine mammals. Risk was also high for inshore Indo-Pacific bottlenose dolphins, especially in Mozambique. The risk of beach seines on more pelagic and oceanic species was low, such as spinner dolphins (rarely observed in inshore waters), Manta rays, great hammerhead sharks and leatherback turtles. Finally, handlines have the lowest estimated risk for vulnerable megafauna.

The adverse effects of gillnets (including drift and bottom set gillnets) have already been highlighted in previous studies in the southwest Indian Ocean, such as off Zanzibar (Amir *et al.*, 2002), along the southwest coast of Madagascar (Razafindrakoto *et al.*, 2008), around

Mayotte and the Comoros (Kiszka *et al.*, 2007; Poonian *et al.*, 2008; Pusineri & Quillard, 2008) and in the region for particularly vulnerable species, such as the dugong (WWF EAME, 2004; Muir & Kiszka, 2012). In 1999, in 10 villages around Zanzibar, questionnaire survey of 101 gillnet vessel operators were made (Amir *et al.*, 2002). A total of 96 dolphins were reported to have been incidentally caught between 1995 and 1999; 43 Indo-Pacific bottlenose dolphins, 29 spinner dolphins, 5 Indo- Pacific humpback dolphins and 19 unidentified dolphins. In addition, 0.46 dolphins per year was the extrapolated bycatch rate per vessel. This ERA greatly complement these previous studies and confirm high risk for a diversity of large and vulnerable marine vertebrates. This study also highlighted new information regarding sea turtle bycatch in gillnets. High bycatch levels observed for loggerhead turtles in Mozambique and northern Tanzania should be linked to the presence of major feeding grounds for this species off these countries. In addition, even if leatherback turtle bycatch was relatively uncommon in drift gillnets, it should be taken into account as this species is seriously declining in the southwest Indian Ocean region (Bourjea *et al.*, 2008).

Data limitations

In this study, we used data from a high number of interviews (in comparison to most studies conducted; e.g. Moore *et al.*, 2010). Therefore, sample size is not a significant issue, especially for net fisheries. However, as longline bycatch is potentially a serious threat to a number of sea turtle and elasmobranch species (data collected in Tanzania), a larger sampling would be needed in a future assessment, both at the local (Zanzibar and Pemba) and regional scale (SW Indian Ocean). We can be also confident in our sampling, since some information collected during this study was consistent with empirical local knowledge and published information from the region (Amir *et al.*, 2002; Kiszka & Muir, 2007; Bourjea *et al.*, 2008; Kiszka *et al.*, 2008; Amir, 2010). However, for species that are difficult to identify (particularly in elasmobranchs, such as stingrays, a number of shark species as well as sea turtles), our analyses could have some limitations. However, bycatch incidence was calculated for main taxonomic groups and the most vulnerable species (especially those included in the PSA analysis) were the most easily identifiable species. Concerning bycatch incidence, it was based on fishermen's declarations, which were sometimes quite approximate. Nevertheless, PSA plots are probably the most accurate that could be produced for artisanal fisheries, as observer programs are almost impossible to implement (programs could be potentially implemented on the largest boats, such as longliners and large gillnet boats, as it was previously conducted in Zanzibar; Amir, 2010).

Implications for management

This study clearly highlights that a diversity of large and vulnerable marine vertebrates are at risk due to coastal artisanal fisheries bycatch in the southwest Indian Ocean. It also underlines that coastal artisanal fisheries are likely to have an impact on oceanic species (and vice versa), such as Manta rays and hammerhead sharks, which are also affected by industrial tuna fisheries. Consequently, large megafauna bycatch issues should be urgently managed in coastal fisheries of the southwest Indian Ocean. IOTC is strongly encouraged to take into account bycatch information from coastal artisanal fisheries for appropriate management measures of bycatch in the Indian Ocean.

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