Vulnerability assessment of elasmobranch species to fisheries in coastal Kenya: implications for conservation and management policies

Benedict Kiilu[1,2, *], Boaz Kaunda-Arara[3], Gladys Okemwa[4], Remmy Oddenyo[5], Elizabeth Mueni[1], Bernerd Fulanda[2], Edward Kimani[4]

[1]Kenya Fisheries Service, P.O. Box 90423- 80100, Mombasa, Kenya

[2]Department of Biological Sciences, Pwani University, P.O Box 195-80108, Kilifi Kenya

[3]Department of Fisheries and Aquatic Sciences, University of Eldoret, P.O. Box 1125, Eldoret, Kenya

[4]Kenya Marine and Fisheries Research Institute (KMFRI), P.O. Box 81651-80100, Mombasa, Kenya

[5]Wildlife Conservation Society, P.O. Box 99470-80107, Mombasa, Kenya

Abstract

Ecological risk assessment (ERA) of species to fisheries is useful for making informed management decisions especially in data-scarce situations based on species relative vulnerabilities to fisheries. Understanding the vulnerability of species to fishing gears is important for targeted management measures especially for species known to have delicate life-history strategies such as the elasmobranchs. As part of a National Plan of Action for Sharks (NPOA-sharks) initiative, a three-day workshop was organized (in April 2022) involving various experts and stakeholders to analyze relative vulnerability risks of shark and ray species to fishing gears in Kenya's Exclusive Economic Zone (EEZ). The workshop applied a Productivity and Susceptibility Analysis (PSA) approach to estimate relative vulnerability of species to the fishing gears. A total of 30-shark and 29-ray species were used for analysis of relative vulnerability to artisanal fishing gears, prawn trawlers, and industrial pelagic longline fishery within Kenya's EEZ. Overall, results showed high species vulnerability to the prawn trawl fishery (35% for rays and, 65% for sharks and shark-like rays) and to the industrial longlines (100% for rays and, 46% for sharks and shark-like rays). There were variable but lower vulnerability ranges for species in the artisanal fishery gears. Thirty species, grouped as a High Vulnerability Species Assemblage (HVSA), were assessed to have High Relative Vulnerabilities to the gears calling for their targeted management strategies. Of the HVSA group, five species; *Sphryna lewini, Pseudoginglymostoma brevicaudatum, Rhina ancyclostoma, Rhynchobatus djiddensis, Rhynchobatus laevi* are classified as Critically Endangered (CR), while another five; *Carcharhinus plumbeus, Mobula birostris, Mobula eregoodoo, Stegostoma tigrinum, Rhinoptera jayakari* are Endangered (EN) according to the IUCN Red List assessment (www.iucnredlist.org, release 2022-1). The results suggest that a lower fishing-pressure threshold is required to predispose the prawn trawl bycatch species to High Vulnerabilities. Lastly, over 50% of the species evaluated as being of High Vulnerability also fell under the IUCN Threatened Category. A validation approach has been used to reduce uncertainty around PSA, however, the tool will require continuous updating to include more species and improve on its sensitivity. A precautionary Shark and Ray Management Plan (SRMP) that takes into account the outputs of the PSA is recommended for the management and conservation of the elasmobranch stocks within the framework of a NPOA-Sharks for Kenya.

Keywords: Productivity, susceptibility, overfishing, conservation, management, policy, Red List

1.0 Introduction

Sharks and rays (family elasmobranchs) are incidentally caught in various types of fisheries including artisanal, longlines fishing for tuna, and prawn trawlers (Carvalho *et al*., 2011). Bycatch increases the risk of extinction of several species of sharks and alters ecosystem structure and functions by removing these top predators (Myers and Baum, 2007). It is estimated that one-third of the chondrichthyans are globally threatened with extinction (Dulvy *et al*., 2021) with most of the threats emanating from fishing activities. Additionally, the global populations of oceanic sharks and rays are believed to have declined by about 70% since the 1970s with about three-quarter of these stocks being threatened with extinction, with a greater risk in the Western Indian Ocean (Pacoureau *et al*., 2021). The management of fish stocks in the Western Indian Ocean (WIO) faces challenges due to data scarcity emanating from low governance challenges (van der Elst *et al*., 2012) calling for more precautionary approaches in the management of marine resources. In such data-scarce scenarios, ecological risk assessment (ERA) approaches that provides a hierarchical framework for managing fisheries with different levels of data-quality have been applied (Milton, 2001; Stobutzki *et al*., 2001; Hobday *et al*., 2004; 2011). Productivity and Susceptibility Analysis (PSA) is one such ERA approach applied to data-scarce fisheries and that generates vulnerability levels of species to exploitation thereby allowing fisheries managers and stakeholders to make objective and transparent decisions on stocks. PSA is a semi-quantitative, species-level risk assessment method that requires limited data to evaluate the relative vulnerability of species to fishing activities (Hobday, 2004; 2007; Patrick *et al*., 2010).

PSA has been used to evaluate the vulnerability of different species to fisheries including chondrichthyans (Cortes *et al*., 2010; Patrick *et al*., 2010; Furlong-Estrada *et al*., 2017; McCully *et al*., 2013; Clarke *et al*., 2018) and other fish stocks (Okemwa *et al*., 2016; Faruk and Matsuda, 2021). The most general feature of PSA is that it compares the inherent recovery potential of species once depleted (i.e., productivity) with the attributes of susceptibility (i.e., the impact of the fishery on fish stock) to fishing activities in deriving overall vulnerability (Stobutzki *et al*., 2001; Hobday *et al*., 2011). Productivity attributes that measure the intrinsic rate of increase (r) are averaged with the susceptibility attributes that measure vulnerability to gear to provide a risk index to fishing effects. Often expert opinions and proxies are used in PSA analyses due to the paucity of data, mostly on biological attributes, thus creating levels of uncertainty in the vulnerability indices (Patrick *et al*., 2010). Nonetheless, PSA still remains a useful approach in evaluating risk levels that fishing poses to stocks.

In developing countries, wide latitudinal spread in fishing effort, a low level of surveillance and year-round fishing in small-scale artisanal fisheries has made it difficult to monitor the status of fisheries (Berg *et al*., 2002; van der Elst *et al*., 2012). While different approaches have been used to assess exploitation risk to teleost stocks in the WIO (van der Elst *et al*., 2012), to our knowledge, no stock or risk assessments have been conducted to evaluate how elasmobranch species respond to fishing pressure. The reasons for this disparity relates to lack of species-specific data on life-histories, catch data and to low governance priority on the elasmobranchs. It is estimated that about 3,100 artisanal fishing vessels operate in the territorial waters of Kenya (Kenya Marine Frame Survey Report, 2016), of which about 600 target inshore pelagic species and reef fish, with incidental catches of sharks. Considerable quantities of various shark and ray species are caught as target species in the artisanal fisheries and as bycatch in the semi-commercial prawn-trawl fishery on the north coast of Kenya (Fulanda *et al*., 2011; Munga *et al*., 2014). The lack of species-specific information has made it difficult to evaluate the effects of fisheries on species of sharks and rays in Kenya (Kiilu *et al*., 2019). In this study, we assess the vulnerability risk of 99 elasmobranch species to fishing pressure and provide a first step towards a robust and objective criterion for making management and policy decisions for sustainable management of the elasmobranchs in coastal Kenya.

2.0 Materials and Methods

2.1. Description of the fisheries in coastal Kenya

Information used in this study relates to three fishery categories (artisanal, prawn trawl and tuna longlines) operating within Kenya's EEZ (Figure 1). Artisanal fishers using gillnets, handlines, longlines, and ringnets mainly operate closer to the coastline at relatively shallower depths, usually extending 0-12 nm offshore, but ubiquitous from 0-5 nm. Industrial trawling targeting prawns is done in the inshore waters, at the Malindi-Ungwana Bay (Lat. 3°30'S and 2°30'S and Long. 40°00'N and 41°00'N) during the industrial prawn-trawl open season (April to November). Further, trawling for mixed demersal fish species is done off the bay, usually beyond 5nm from the baseline. This trawling is permitted all year round through a special licensing regime. Industrial longlining for tuna and tuna-like species is done far offshore beyond 12nm from the baseline, and sometimes is done as far off as the international waters.

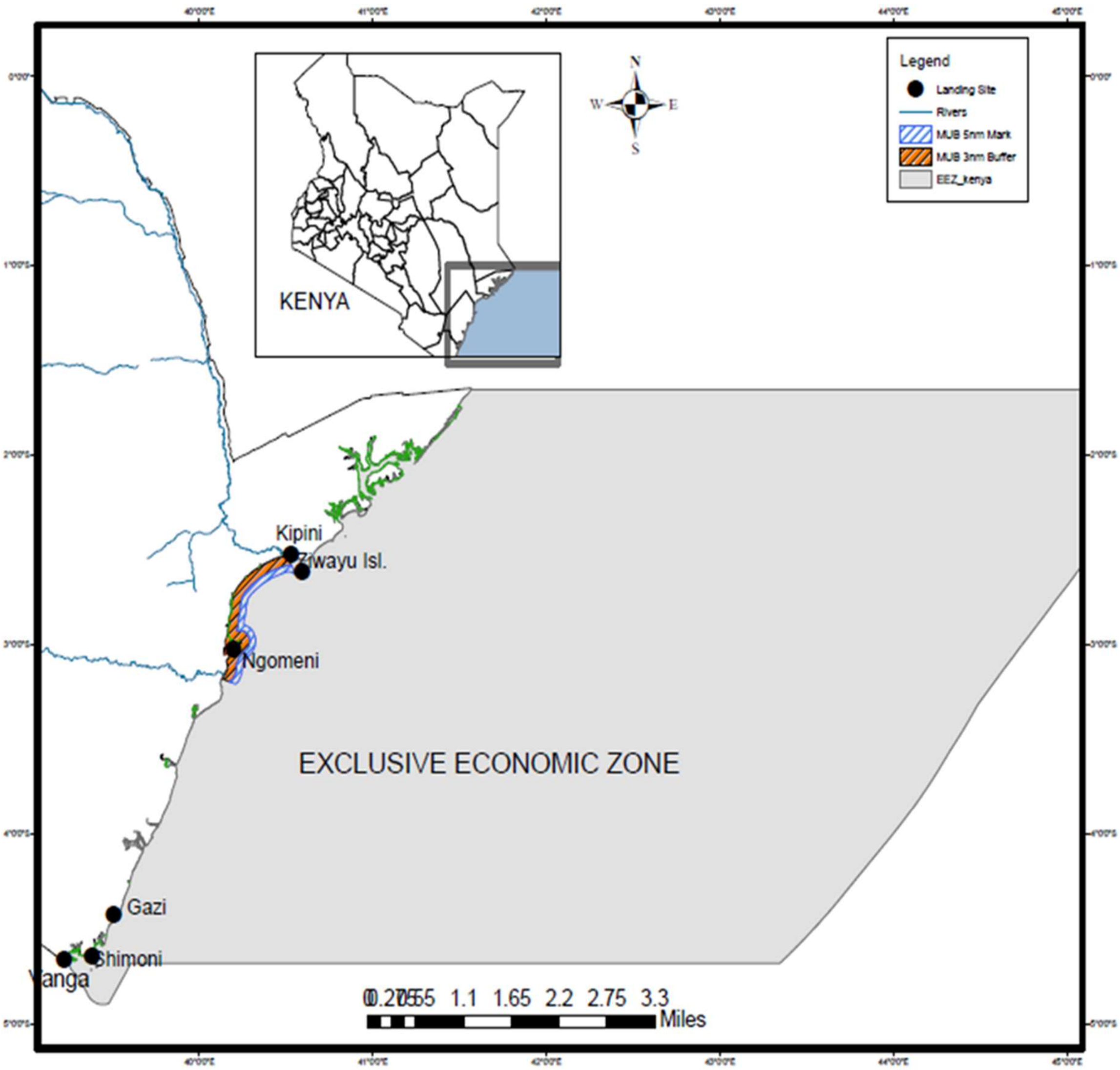


Figure 1: Map showing Kenya's EEZ, Malindi-Ungwana Bay (MUB) fishery zone (shaded) and artisanal fishery sampling areas (Vanga, Shimoni, Malindi-Ngomeni, and Kipini), and adjacent coastal settlement areas with overlapping fisheries.

2.2. Application of PSA to derive shark and ray species relative vulnerability to fisheries

2.2.1. Determination of species list for PSA

The species list of sharks and rays to be subjected to PSA was derived from available catch data from published literature (Kiilu *et al*., 2019; Remy *et al*., 2017; Bennett *et al*., 2020; Kaunda-Arara *et al*. 2017), catch monitoring databases (e.g., the Wildlife Conservation Society (WCS) shark and ray catch monitoring database), and the grey literature. The fishery and gear types used in the PSA as catching species were categorized as: artisanal (gillnets, handlines, longlines, ringnets, spearguns and traps), industrial longline, and the semi-industrial prawn trawl. Species occurrence in Kenyan waters was further validated using web-based databases (e.g. www.fao.org/geornetwork/srv/en/main.search, www.iucnredlist.org, www.fishbase.org) and consultations with experts on shark taxonomy (see acknowledgments). Species identified only to the genus level were left out of the analysis in order to minimize possible duplication of names leading to superfluous conclusions.

The process of species database formation identified a list of 99 species (57 of sharks and 42 of rays) reported to occur or likely to occur in Kenyan marine waters, and is presented in Tables S1 and S2. However, for this study, a total of 59 species (30 of sharks and 29 of rays and shark-like rays), for which information on life-history attributes could be found, were assessed as interacting with the fishing gears in Kenya's coastal waters and used in the PSA. The PSA was conducted during a three-days' workshop organized by the Kenya Fisheries Service (KeFS). Vulnerability risk indices were generated at the gear level to assess species-specific differences in relative vulnerabilities (Patrick *et al.*, 2010).

2.2.2. PSA Scoring Approach and Attribute selection

The PSA was applied by scoring Productivity and Susceptibility attributes to estimate relative potential vulnerability of species to fishing activities. The Productivity (P) attributes are assumed to influence the intrinsic rate of increase (r) of species, and the Susceptibility (S) attributes are assumed to influence catchability (q) of species (Hobday *et al.*, 2007; Georgeson and Emery, 2019). The Productivity and Susceptibility attributes used in this analysis were taken from Patrick *et al.*, (2010) and were selected based on; their likely influence on vulnerability of species to gears, attribute information availability from local studies or the region or in web-based databases (e.g. www.fishbase.org). The attribute scoring scheme was modified from that of Patrick *et al.*, (2010) to score risk levels associated with attribute values rather than scoring the levels of attributes themselves (Georgeson and Emery, 2019; Arrizabalaga *et al*., 2011).

Consequently, attributes (P and S) used in the PSA were scored on a scale of 1-3. The scores were assigned to attributes as: 1 (Low Vulnerability or Low risk), 2 (Medium Vulnerability or Medium risk) or 3 (High Vulnerability or High risk). Consequently, species with low productivity and with high susceptibility attribute scores to the gear are considered to be the most Vulnerable to the fishery or gear (High risk of overfishing), while species with high productivity and low susceptibility attribute scores are considered to be the least Vulnerable to the fishery or gear (Low risk of overfishing effects).

2.2.3. Data Quality Index, Weighting and Validation

A data quality index was assigned to the species P and S attributes as a measure of the uncertainty in the data. *et al*. Scoring data quality of an attribute provides an indication of levels of uncertainty in the information and an objective criterion for interpreting the relative vulnerability of a species (Patrick *et al*., 2010). The data quality score for an attribute ranged from a best data score of 1 to poorest quality data score of 5 when data were missing (Patrick *et al*., 2020). The data quality scores are aggregated for the attributes and an overall productivity and susceptibility score obtained by averaging the individual scores for a species. The definitions of data quality ranges (score 1-5) are provided in Table 1. We considered attribute scores < 3 to reflect good data quality following the thresholds in Cortés *et al*., (2010). As attributes contribute differently to the total relative Vulnerability scores (Cope *et al*., 2011; Carrunthers, 2016) each attribute was weighed differently on a scale of 1 (low) to 4 (high) based on their contribution to the total Productivity or Susceptibility scores of a species (Patrick *et al*., 2010).

A precautionary score of 3 (High Vulnerability and Low Productivity) is recommended for missing attributes (Hobday *et al*, 2011), however, in our case, missing attributes or ones with no data were not scored to avoid biasing of the Vulnerability scores to High risks (false positive) instead, data quality for such attributes were considered poor (score = 5) and reported separately to provide levels of uncertainty in the analysis (Swasey *et al*., 2016).

Due to the variability in the quality of data and the data gaps in PSA analyses, the Vulnerability scores often have associated uncertainties (Hobday *et al*., 2007; Cope *et al*., 2011) that may reduce the confidence level of the fisheries managers and stakeholders in using the PSA outputs. To enhance the confidence and transparency around the Vulnerability risk estimates in the PSA analysis, we correlated the Vulnerability scores to a fishing pressure indicator (F/M ratio). It is assumed that higher fishing pressure will lead to Higher Vulnerability of stocks to fishing mortality. Consequently, we performed a regression of Vulnerability scores on the fishing pressure indicator (F/M) for seven species from the prawn trawl fishery that had sufficient data for the F/M analysis.

Table 1: The five tiers of data quality used when evaluating the productivity and susceptibility of an individual stock (adopted from Patrick *et al*., 2010).

Data Quality Tier	**Description**	**Example**
1	**Best data**. Information is based on collected data for the stock and area of interest and is established and substantial.	Data-rich stock assessment; published literature documenting methods used.
2	**Adequate data**. Information is based on limited coverage and corroboration, or for some other reason is deemed not as reliable as tier-1 data	Limited temporal or spatial data; relatively old information.
3	**Limited data**. Estimates have high variation and limited confidence and may be based on studies of similar taxa or life history strategies.	Similar genus or family, etc.

4	**Very limited data**. Information is based on expert opinion or general literature reviews from a wide range of species, or outside of region.	General data not referenced or sourced from the grey literature.
5	**No data**. When there are no data on which to make even an expert opinion, the person using the PSA should give this attribute a "data quality" score of 5 and not provide a "productivity" or "susceptibility" score so as not to bias those index scores. When plotted, the susceptibility or productivity index score will be based on one less attribute and will be highlighted as such by its related quality score.	

2.2.4. Calculating relative vulnerability risk of species

The overall Productivity risk score of a species was calculated as the average of the risk scores associated with eight productivity attributes (*intrinsic growth rate r, average maximum age, von Bertalanffy growth coefficient K, natural mortality, fecundity, breeding strategy, size at maturity, mean trophic level*) as defined in Patrick *et al*., (2010). The attributes and scoring bins are shown in Table 2. Breeding strategy was modified to include number of times the species spawns per year to reflect monsoon spawning seasonality on the Kenyan coast, while fecundity was modified to reflect the number of pups in a uterus for the species as most of the sharks assessed are ovoviviparous.

Table 2: Productivity attributes used to score Vulnerability of shark and ray species to fisheries/gears in coastal Kenya. Attributes are weighed from 1 (Low) to 4 (High) depending on influence on productivity. Adapted from Patrick *et al*., (2010)

Productivity Attributes	Low Productivity (High risk level score = 3)	Moderate Productivity (Medium risk score= 2)	High Productivity (Low risk level score = 1)	Weight
Intrinsic growth rate, r	<0.16	0.16 - 0.5	>0.5	4
Average maximum age	>25 years	10 - 25 years	<10 years	1
Maximum size	>150 cm	60 -150 cm	< 60 cm	1
von Bertalanffy growth coefficient (K/yr)	< 0.15	0.15 - 0.25	> 0.25	2
Estimated natural mortality (M/yr)	< 0.20	0.20 - 0.40	> 0.40	3

Measured fecundity or Maximum uterine fecundity	<15 pups	15 - 30 pups	>30 pups	2
Breeding strategy	Biennual (every 2 years)	Annual (once a year)	Biannual (twice a year)	1
Size at first maturity (L_{50})	>100 cm	40 - 100 cm	<40 cm	3
Mean trophic level	>3.5	Between 2.5 and 3.5	< 2.5	1

The overall Susceptibility (S) score was calculated as the product of risks associated with six susceptibility attributes (*availability/ aereal overlap*, *encounterability/ Vertical overlap, catchability, post-capture mortality, desirability, management strategy*) as also defined in Patrick *et al*., (2010). The attributes, their descriptions and scoring bins are shown in Table 3. However, we replaced gear selectivity attribute (Patrick *et al*., 2010) with "catchability" as proxied by reported relative abundance of species, assuming higher species relative abundance and gear efficiency will yield high catchability (Cadrin *et al*., 2015). Desirability was measured by market value of the species as advised by fishers and from market values.

Table 3: Susceptibility attributes used to score Vulnerability of shark and ray species to different fisheries/gears in coastal Kenya. Adapted from Patrick *et al*., (2010).

Attributes	Attribute Description	High Susceptibility (Risk Level score= 3)	Medium Susceptibility (Risk Level score= 2)	Low Susceptibility (Risk Level score = 1)	weight
Availability	Geographical distribution	Restricted to WIO	Spread (Indo-Pacific)	Wide spread (Circumglobal)	2

Encounterability / Vertical	Depth distribution/ Behaviour (Artisanal/ Aquarium)	Readily not accessible to the gear (0-30m)	Accessible to the gear (30 - 60 m)	Limited accessibility to the gear >60m;	2
	Depth distribution/ Behaviour (Trawl)	0 - 40m	40 - 60 m	>60m	2
	Depth distribution/ Behaviour (Longline)	0 - 60m	60 - 150 m	>150m	2
Catchability	Relative abundance by number (%) in the catch (gear specific)	>20%	10% - 20%	> 10%	4
Post-Capture Mortality	Probability of survival of individuals of species that escape/are released/discarded AFTER being captured by gear especially trawlers and longlines	Mortality High (>60%)	Mortality significant, but <60%	Likely to be alive	4
Desirability	How much effort are fishers likely to deploy to try to capture the specie(s)	Very desirable/ High value. Fishers will go to great	Medium desirable/ Moderate valuable. Fishers will capture it in their regular	Not desirable / Low value	3

		lengths to capture it	activities but will not go to great lengths to capture it		
Management strategy	Management strategy	There is no regulation in effect for the species and no indirect measures	There are no specific regulations for the species, but there are some indirect measures	The species is currently subject to a number of conservation and management measures	3

After scoring the attributes for each of the species, the overall P and S risk scores were then calculated as the weighted average across all scored attributes. An x–y bi-plot was produced to visualize the scores in space, and overall risk or Vulnerability (V) was defined as the Euclidean distance from the origin of the x-y plot as described in Georgeson and Emery (2019) as:

$$V = (P^2 + S^2)^{1/2}$$

Species Vulnerability risk categories (High, Medium or Low) were subsequently assigned by dividing the 2-dimensional Euclidean distance into equal thirds, such that scores <2.64 are Low Vulnerability, between 2.64 and 3.18 are Medium Vulnerability, and >3.18 reflect High Vulnerability to overfishing (Georgeson and Emery, 2019).

Given the uncertainty inherent in the PSA process arising from data gaps, data quality and expert scoring opinions, vulnerability scores calculated for the species in each of the fisheries were validated as recommended in Patrick *et al*., (2010) by using two additional indicators of overfishing. This was deemed important as the subjectivity in scoring susceptibility attributes and data-gaps in the locally generated productivity attributes is likely to introduce uncertainty in the relative vulnerability estimates thereby requiring validation of the analysis to provide more confidence and transparency to fisheries managers and stakeholders (Patrick *et al*., 2010; Simpfendorfer *et al*., 2011).

As local species status assessments have not been done for elasmobranchs in Kenya, global Red List Assessments by the IUCN (www.iucnredlist.org) and relative fishing mortality (F/M) estimates were used for validation of the derived PSA Vulnerability categories. We assumed that Highly Vulnerable species according to the PSA outputs will tend to be those that that are threatened with extinction as per the IUCN Red List, and that species experiencing high fishing pressure including overfishing (F/M > 1, Gulland, 1971) will have High Vulnerability indices. The species relative vulnerability values derived from PSA were therefore correlated with F/M, a measure of fishing pressure. The mortality parameters (F – annual instantaneous fishing mortality, and M- annual instantaneous natural mortality) were derived from the Shepherds Method in FiSAT (Gayanilo *et al*., 1995) and Pauly's empirical formula (Pauly, 1980), respectively.

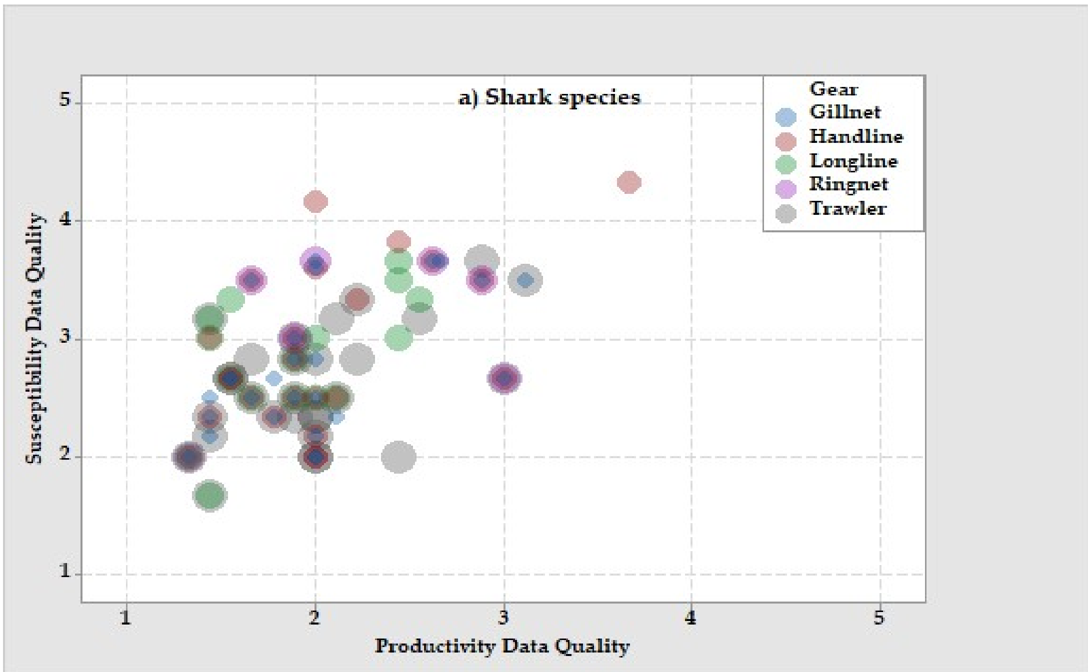
The global conservation status of the assessed species was determined using the International Union for Conservation of Nature (IUCN) (IUCN Red List, 2022) to assess the potential impact of fisheries in Kenya on species of concern. Conservation categories defined by IUCN were used and include Critically Endangered (CR), Endangered (EN), Vulnerable (VU), Near Threatened (NT), Least Concern (LC), and Data deficient (DD). Extinct in the Wild (EW) and Extinct (EX) were not considered in the assessment as they were deemed invalid for the study.

Selection and scoring of the attributes was done through consultative discussions and consensus building during a 3-day Kenya Fisheries Service (KeFS) organized workshop that comprised 12 participants including scientists, fisheries managers, policy makers and marine conservationists. Additionally, views of fisher representatives were sought, when necessary, via telephone communication.

3.0 Results

3.1. Data quality

The distribution of the productivity and susceptibility attribute data quality scores for the assessed species is shown in Figure 2. Among the shark species, majority (> 90%) had good data quality scores (< 3) for productivity attributes (Figure 2a). However, about 50% of the species had susceptibility attributes that had limited to very limited data quality indices (3-4) with a few stocks having poor data quality scores (4-5). For the ray species (Figure 2b), nearly all the species had good data quality (< 3) for the productivity attributes as also observed for the shark species. However, 50% of the ray species had susceptibility attributes that were of limited to very limited (3-4) data quality (Figure 2b) suggesting a greater uncertainty in the scoring of the susceptibility attributes for both groups.



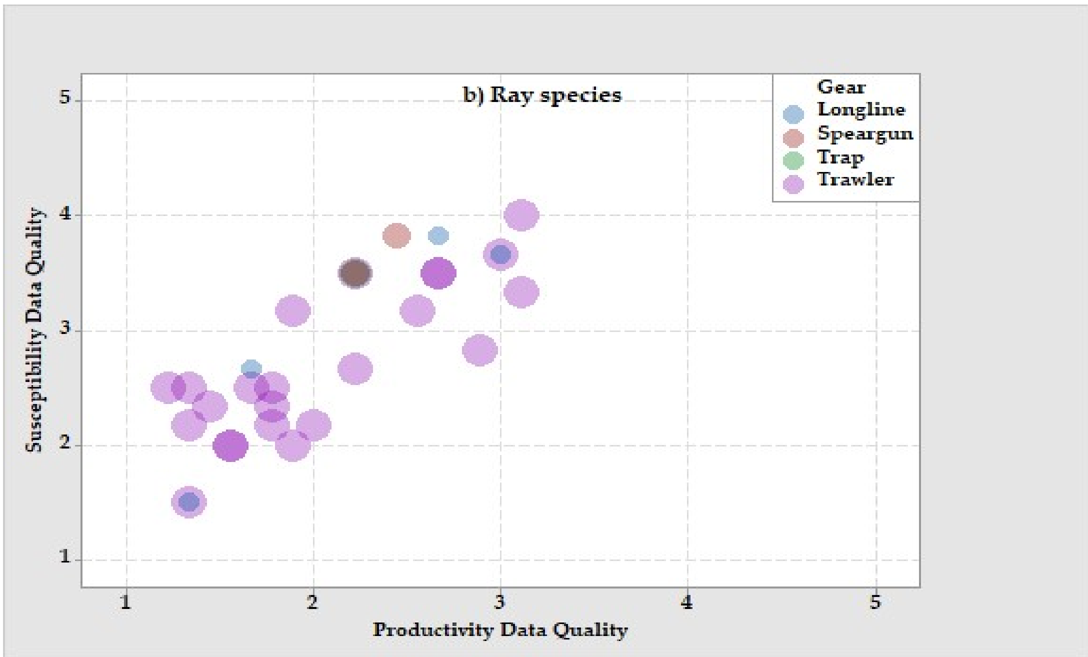


Figure 2: Data quality plots for the productivity and susceptibility attribute scores of a) shark and b) ray species caught by different gear-fishery in coastal Kenya. Score of ≤ 3 provides a threshold for good data quality. Bubbles represent species values.

3.2. Vulnerability to fishing gears

The prawn trawl fishery had the highest number of species in the highly vulnerable category for both rays (n = 6, 35%), and sharks and shark-like rays (n = 15, 65%), with no species of sharks and shark-like rays assessed as being of low relative vulnerability to the prawn trawlers (Figure 3). The industrial longline fishery has the second highest proportion of vulnerable species, with all four assessed species of rays being Highly Vulnerable, while six (46%) species of sharks and shark-like rays had High Vulnerability to the industrial longlines (Figure 3). The artisanal based gears (gillnets, longlines, handlines, traps, speargun) had no ray species assessed as being Highly Vulnerable to the gears, unlike for sharks and shark-like rays that had species Highly Vulnerable to gillnets and handlines.

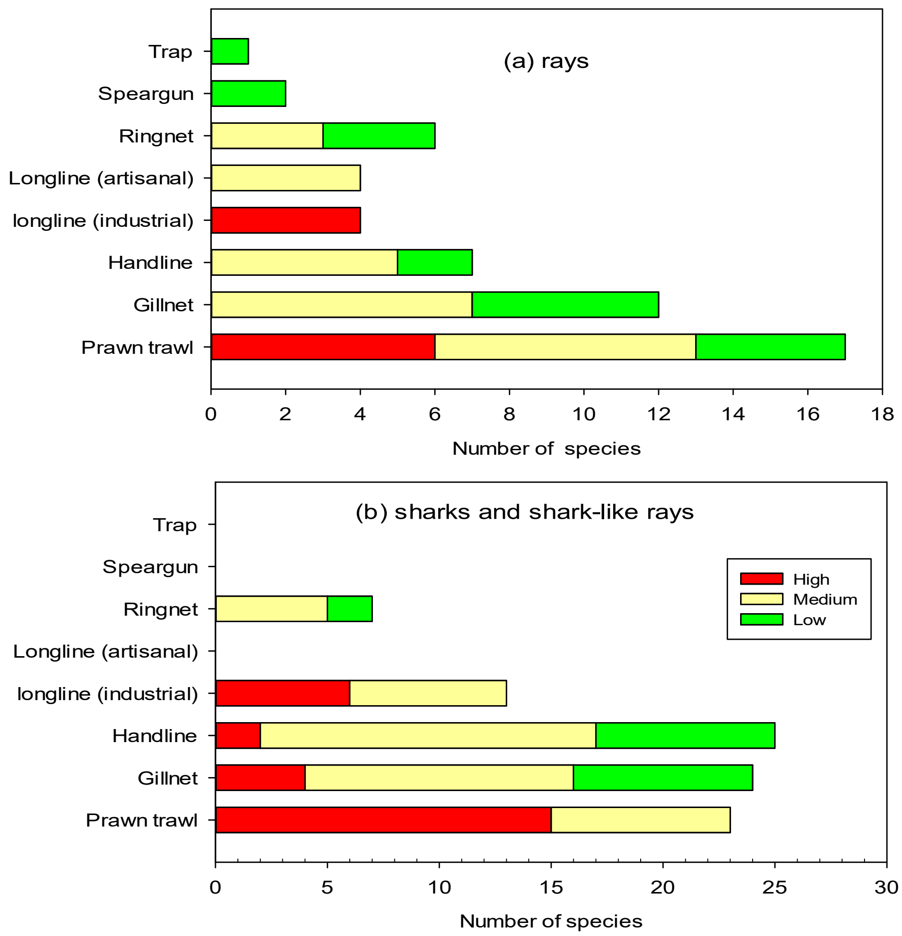


Figure 3: Numbers of species of sharks and shark-like rays, and rays evaluated in different vulnerability categories (low, medium, high) in the different gear-fisheries in coastal Kenya.

Higher proportions of ray species were of Medium and Low Vulnerability to the gillnets (Low; n= 5, 42%; Medium; n = 7, 58%) and Handline (Low; n = 2, 29%, Medium; n = 5, 71%) in the artisanal fishery (Figure 3a). The spearguns and traps used in the artisanal fishery had low numbers of potential/impacted species but were all assessed as being of low vulnerability (Figure 3a). For the sharks and shark-like rays caught in artisanal gears (Figure 3b); only the gillnets (n = 4, 16%) and handlines (n = 2, 8%) had a few species with High Relative Vulnerability to the fishery. Artisanal handlines had 15 species (60%) in the Medium Vulnerability category, while gillnets had 12 species (50%) in the same category (Figure 3b).

3.3. Species-specific vulnerability to fisheries

3.3.1. Artisanal fisheries

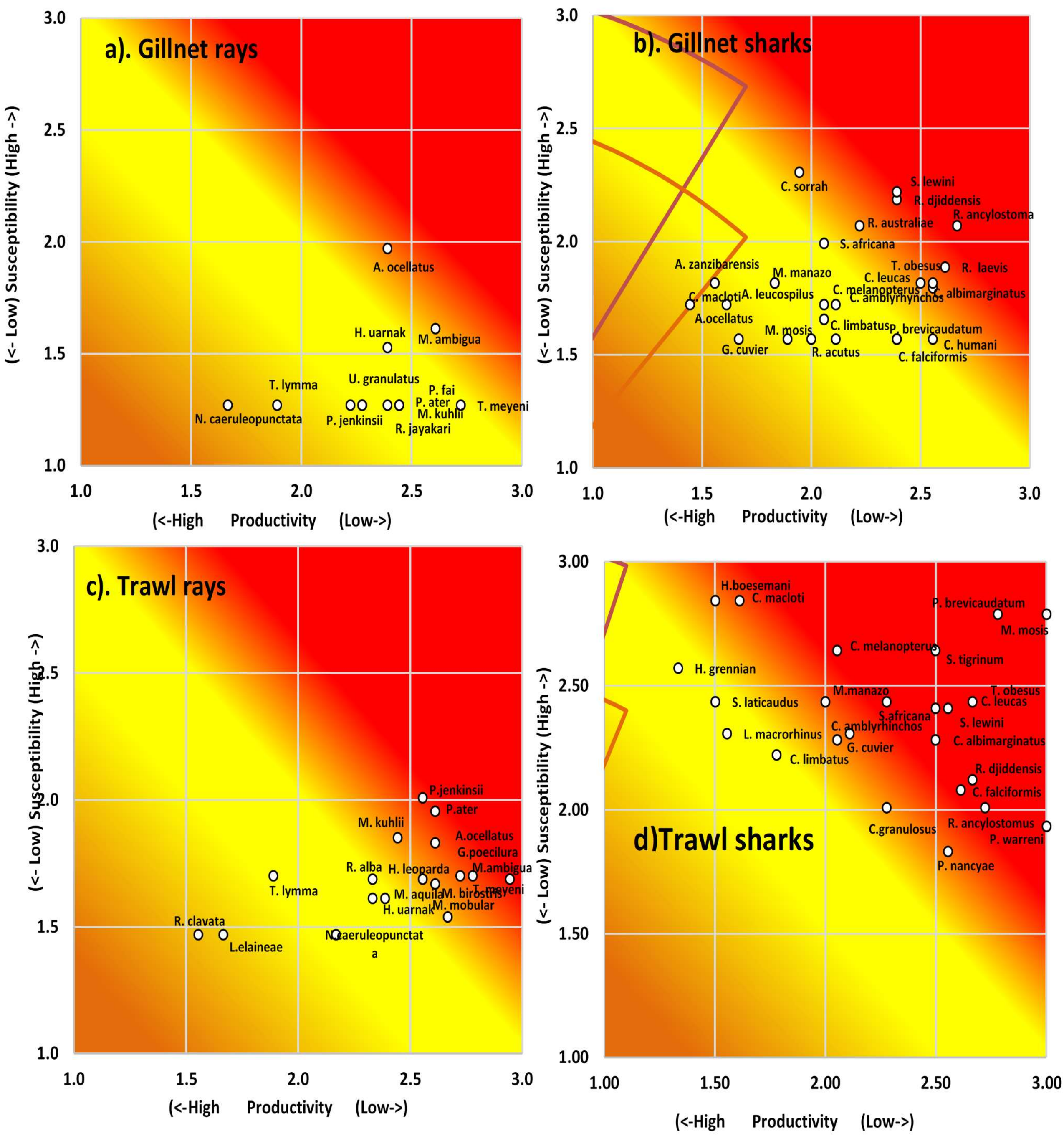
A total of 12 species of rays were assessed for vulnerability to the gillnets, with no species being assessed as of High Vulnerability (Figure 4a, Table S3). The twelve species of rays were assessed as being of Medium (n= 7) or Low (n =5) vulnerability to the gillnet fishery (Figure 4a). Of the assessed species, the Endangered *Himantura uarnak* and *Mobula kuhlii* are both evaluated as being of Medium Vulnerability to the gillnet fishery (Figure 4a, Table S3). The similarly Endangered *Rhinoptera jayakari,* and the Vulnerable (VU) *Pateobatis jenkinsii* are evaluated as being of Low Vulnerability to the gear. For the 24 species of sharks and shark-like rays evaluated for interaction with gillnets, four species; *Rhina ancylostoma, Rhynchobatus laevis, Sphyrna lewini,* and *Rhynchobatus djiddensis* were evaluated as being of High Vulnerability to the gillnet fishery (Figure 4b, Table S4). It is noteworthy that all the four species are classified as Critically Endangered (CR) in the IUCN Red List of Threatened Species. Twelve and Eight shark species were of Medium and Low Vulnerability to the gillnets, respectively (Figure 4b, Table S4). However, of these, a number of Vulnerable (VU) species according to the IUCN Red List (e.g., *Carcharhinus melanopterus, Carcharhinus limabatus, Carcharhinus leucas, Carcharhinus faciformis) and* a Critically Endangered species (e.g. *Pseudoginglymostoma brevicaudatum*) were assessed as being of Medium Vulnerability to the gillnet fishery (Figure 4b), while some Endangered species (e.g., *Acroteriobatus leucospilus)* and Near Threatened species (e.g., *Mustelus mosis*) were evaluated as being of Low Vulnerability risk (Figure 4b) likely indicating geographic variation in exploitation pressures on the species.

A total of 25 species of sharks were evaluated to potentially interact with the handline fishery (Figure 4e, Table S4). Two species, the Critically Endangered (CR) scalloped hammerhead shark (*Sphyrna lewini*) and the Vulnerable (VU) whitetip reef shark (*Triaenodon obesus*) were evaluated as being of High Vulnerability to the fishery, while 14 and 8 species were evaluated to be of Medium and Low Vulnerability to the handlines, respectively (Figure 4e). Of the 14 species evaluated as being of Medium Vulnerability to the handlines (Figure 4e, Table S4), four (*Alopias pelagicus, Carcharhinus amblyrhynchos , Carcharhinus plumbeus, Mustelus manazo)* are categorized as Endangered, while a further four species (*Alopias superciliosus*, *Carcharhinus albimarginatus*, *Carcharhinus falciformis, Carcharhinus leucas*) are Vulnerable (VU) to overfishing by the handline fishers. Of the eight species evaluated as being of Low Vulnerability to the handlines (Figure 4e, Table S4), one (*Mustelus manazo*) is Endangered, while the rest are either Vulnerable (*C. limbatus, Rhizoprionodon acutus)* or Near Threatened (e.g., *C. macloti, Galeocerdo cuvier, Hexanchus nakamurai, Loxodon macrorhinus, Scoliodon laticaudus*) (Figure 4e) indicating lowered local threats that are geographically different from those captured by the IUCN Red List but that will nonetheless require precautionary approach to management of these stocks.

For the rays, seven species were assessed for vulnerability to the handlines (Figure 4f, Table S3). None of the species had High Vulnerability risk to the handlines, while two (*Neotrygon caeruleopunctata, Taeniura lymma*) and five (*Aetobatus ocellatus, Himantura Uarnak, Maculabatis ambigua, Mobular mobular, Pateobatis fai*) species had Low and Medium Vulnerability risks, respectively (Figure 4f). Of the five species with Medium Vulnerability scores, two species (*P. fai* and *A. ocellatus*) are categorised as Vulnerable (VU) to extinction, while one species (Honeycomb sting ray, *H. uarnak*) is Endangered (EN) on a global scale. Both the two species assessed as being of Low Vulnerability to the handlines are of Least Concern (LC) indicating that they are not likely to fall to Threatened or NT IUCN Red list categories and consequently indirectly supporting our low vulnerability assessment.

3.3.2. Other artisanal gears

The other artisanal gears that interact with sharks and rays on the Kenyan coast, although at a lower scale, include; ringnets, spearguns and traditional traps. Six ray species (*Aetobatus ocellatus, Maculabatis ambigua, Neotrygon caeruleopunctata, Pateobatis jenkinsii, Rhinoptera jayakari, Taeniura lymma*) were assessed for vulnerability to the ringnets (Table S3), of which three (*A. ocellatus, R. jayakari* and *M. ambigua)* were of Medium Vulnerability, while the remaining three were of Low Vulnerability to the ringnet fishery. For the sharks and shark-like rays, seven species (*Acroteriobatus zanzibarensis, Carcharhinus humani, C. sorrah, Rhizoprionodon acutus, Rhynchobatus australiae, S. lewini*) interacted with the ringnets (Table S4), of which two (*A. zanzibarensis, C. humani*) had Low vulnerability to the nets, while the other five were of Medium Vulnerability to the gear. For the spearguns and traps, only two (*N. caeruleopunctata, T. lymma)* and one (*T. lymma*) ray species were found to have Low Vulnerability to the gears, respectively (Table 5, Table S3).


a). Gillnet rays
(<- Low) Susceptibility (High ->)
(<-High Productivity (Low->)
A. ocellatus
H. uarnak
M. ambigua
T. lymma
U. granulatus
P. fai
P. ater
M. kuhlii
T. meyeni
N. caeruleopunctata
P. jenkinsii
R. jayakari
b). Gillnet sharks
C. sorrah
S. lewini
R. djiddensis
R. ancylostoma
R. australiae
S. africana
A. zanzibarensis
M. manazo
T. obesus
R. laevis
C. leucas
C. melanopterus
C. amblyrhynchos
C. albimarginatus
C. macloti
A. leucospilus
A.ocellatus
M. mosis
C. limbatus
P. brevicaudatum
G. cuvier
R. acutus
C. humani
C. falciformis
c). Trawl rays
P.jenkinsii
P.ater
M. kuhlii
A.ocellatus
G.poecilura
R. alba
H. leopardа
M.ambigua
T. lymma
M. aquila
M. birostris
T. meyeni
H. uarnak
M. mobular
R. clavata
L.elaineae
N.caeruleopunctata
d)Trawl sharks
H.boesemani
C. macloti
P. brevicaudatum
M. mosis
C. melanopterus
S. tigrinum
H. grennian
M.manazo
T. obesus
S. laticaudus
C. leucas
S.africana
S. lewini
C. amblyrhinchos
L. macrorhinus
G. cuvier
C. albimarginatus
C. limbatus
R. djiddensis
C. falciformis
C.granulosus
R. ancylostomus
P. warreni
P. nancyae

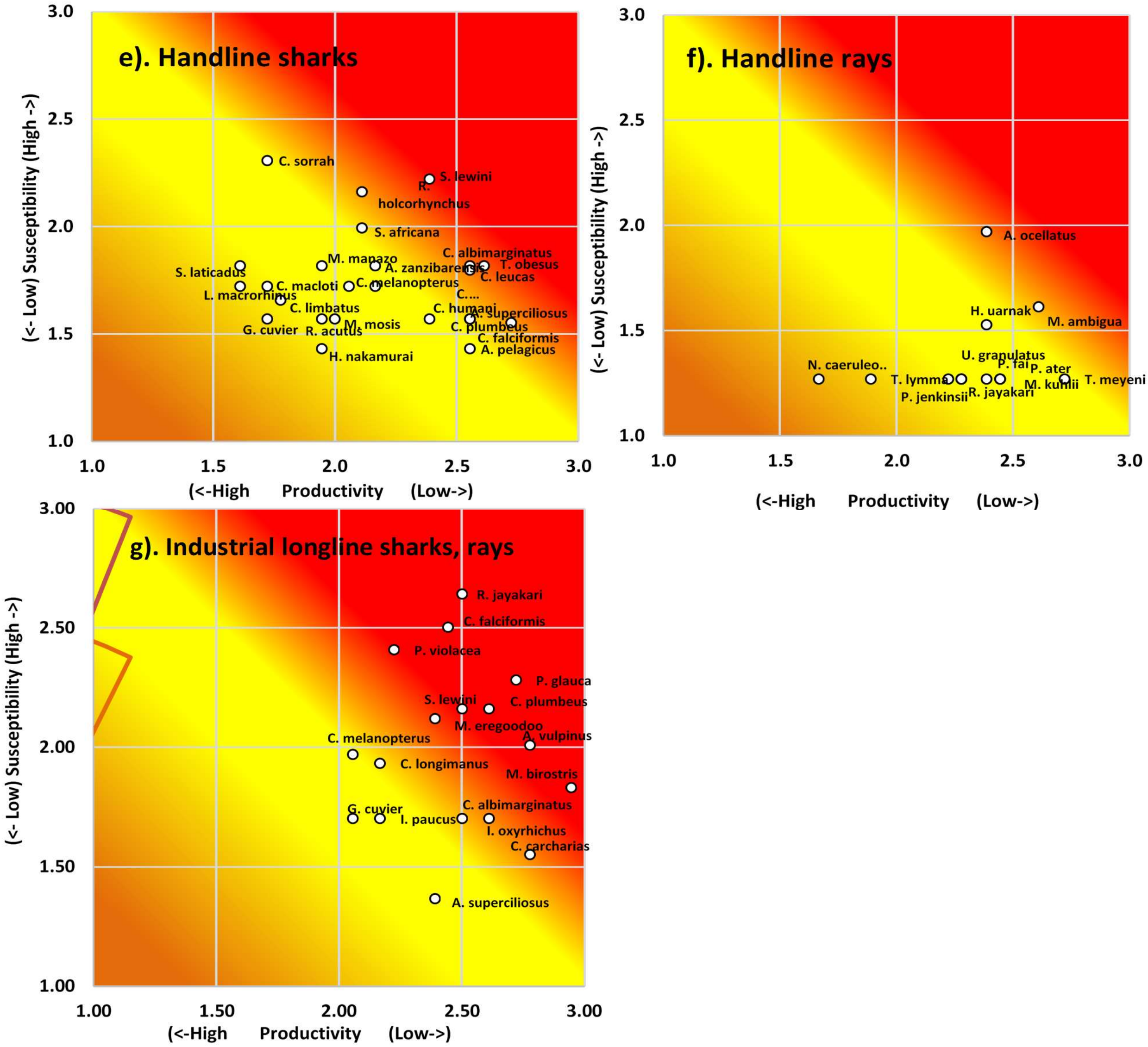


Figure 4: Vulnerability status of shark (and shark-like rays), and ray species to artisanal gears (gillnets and handlines), prawn trawlers and industrial pelagic longliners in Kenya's marine waters. Green, yellow and red colour shades represent low, medium and high vulnerability risks, respectively, to the gears. Species names are as contained in the text and Tables S1-S2

3.3.4. Prawn trawl fisheries

In total, 17 species of rays and 24 species of sharks and shark-like rays were evaluated for vulnerability to the prawn trawl fishery as bycatch through assessment of their Vulnerability indices (Figure 4c, Table S5). Of the 17 ray species, Six (*Aetobatus ocellatus, Gymnura poecilura, Pateobatus jenkinsii, Maculabatis ambigua, Pastinachus ater, Taenurops meyeni*) were evaluated as being of High Vulnerability risk in this fishery (Figure 4c, Table S5). Among the six, except for the Near Threatened (NT), *M. ambigua*, all the other five species are Vulnerable to Extinction according to global assessment by the IUCN Red List of Threatened Species. Of the evaluated ray species, seven were determined as being of Medium Vulnerability risk to the fishery (Figure 4c), while Four species (*Raja clavata, Leucoraja elaineae, Neotrygon caeruleopunctata and Taeniura lymma*) are of Low Vulnerability to the fishery (Figure 4c). Except for *R. clavata* that is of Near Threatened status, the remaining Low Vulnerability species are either Data Deficient (DD) or of Least Concern (LC) thus giving support to the Low Vulnerability assessment in this PSA.

For the sharks and shark-like rays, which are landed as bycatch in the prawn trawl fishery, 16 (67%) of the 24 evaluated species were Highly Vulnerable to the fishery (Figure 4d, Table S6). Of the 16 species with High Vulnerability risk to the fishery, two shark-like rays, the bowmouth guitarfish (*Rhina ancyclostoma*) and whitespotted wedgefish (*Rhynchobatus djiddensis*), and two shark species, scallopped hammmerhead (*Sphyrna lewini*), and shorttail nurse (*Pseudoginglymostoma brevicaudatum*) are also categorized as being Critically Endangered globally. Of the Eight species assessed as being of Medium Vulnerability to the fishery (Figure 4d), two species (*C. limbatus*, *Squalus acanthias*) are Vulnerable (VU), while the grey reef shark (*Carcharhinus amblyrhynchos*) is Endangered with extinction as per the IUCN Red List of

Threatened Species. It is noteworthy that no species of sharks or shark-like rays were evaluated as having Low Vulnerability to the prawn trawl fishery, indicating the high level of threat of the prawn trawlers to the elasmobranchs in Kenya.

3.3.5. Industrial longline fishery

Seventeen species consisting of sharks (n = 13) and rays (n = 4) were assessed for vulnerability to the pelagic industrial longlines targeting tuna. All the four assessed ray species had High Vulnerability to the industrial longlines (Figure 4g and Table S6). These included; the pelagic stingray (*Pteroplatytrygon violacea*), giant manta ray (*Mobula birostris)*, flapnose ray, *Rhinoptera jayakari*) and the longhorned mobula (*Mobula eregoodoo*) (Figure 3g). Of the four ray species, *P. violacea* is listed as of Least Concern (LC), while the remaining three are all listed as Endangered with extinction on a global scale and thereby aligning well with the High Vulnerability assessment. Of the 13 shark species, six (46%%) are assessed to have High Vulnerability to the longline fishery (Figure 4g, Table S6), including the Critically Endangered scalloped hammerhead shark (*S. lewini*), the Endangered sandbar shark (*C. plumbeus)*, the Vulnerable blue shark (*Prionace glauca)*, great white shark (*Carcharodon carcharias*), silky shark (*C. falciformis)* and common thresher shark (*Alopias vulpinus)* (Figure 4g). The remaining seven species were evaluated as being of Medium Vulnerability to the industrial longline fishery. None of the seventeen species assessed had Low Vulnerability to this fishery, indicating the high threat it has to the interacting species.

3.4. Validation of the Vulnerability Assessment

Validation assessment showed a moderately good correlation ($r^2 = 0.6$, $p < 0.05$, Figure 4) indicating a concordance between fishing pressure and vulnerability of the species, thereby providing a level of confidence in the Vulnerability estimates developed in this PSA. Species determined as being Highly Vulnerable to the trawlers (e.g. *S. lewini, P. warreni, M. ambigua* and *M. mosis,* (Figure 4c and d)) also tend to be on the higher fishing pressure (F/M > 0.5) and high vulnerability scales, while the 3 species (*R. alba, C. limbatus, L. elaneae*) that have been assessed as not being highly vulnerable to the prawn trawlers (Figure 4c and d) are below the vulnerability line (Figure 5). However, no species appear to be overfished if a fishing pressure threshold of F/M > 1 is taken to measure overfishing (Heymans *et al*, 2016; Gulland, 1971). The results, however, indicate a lower fishing pressure threshold is required to predispose the prawn trawl bycatch species to High Vulnerability (reduced production potential) on the Kenyan coast.

A complementary but indirect validation tool using IUCN Red List categories showed >50% of the species evaluated as being of High Vulnerability to also be globally Threatened with extinction (VU, EN and CR categories) further corroborating the PSA outputs. However, additional validation methods may be required to supplement the Fishing indicator method (F/M) especially as the IUCN Red List does not directly measure Vulnerability of species to fishing and may show variations between regions including underestimating local vulnerabilities.

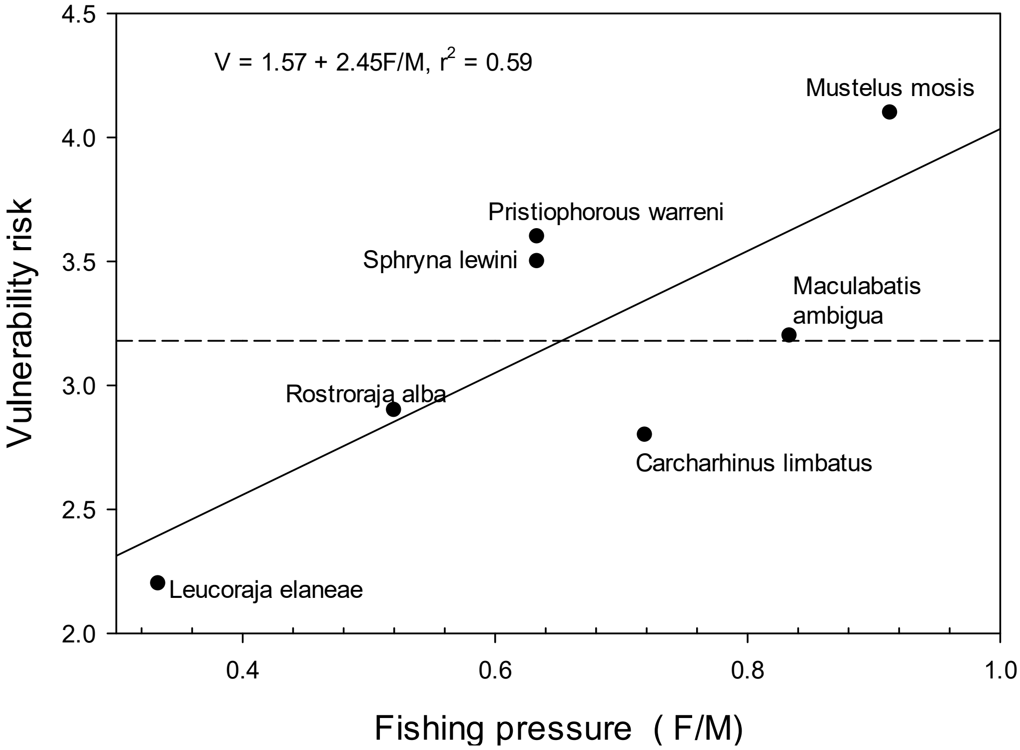


Figure 5: Relationship between Vulnerability risk (V) and fishing pressure index (F/M) for shark and ray species bycatch in the Malindi-Ungwana Bay prawn trawl fishery in Kenya. Horizontal dashed line indicates higher vulnerability threshold when V ≥ 3.18.

4.0 Discussion

Rapid assessment of vulnerability of stocks to fisheries is important for informing fisheries management especially in countries where rigorous stock assessment is not tenable and where fisheries are multi-gear and multi-species (Hobday *et al*., 2006; Cortes *et al*., 2010). In this study, we employed PSA as part of the ERA of the elasmobranchs, based on a scoring approach of productivity and susceptibility attributes that are believed to influence vulnerability of species to fisheries (Hobday *et al*, 2006, 2007). Species with low relative vulnerability to fishing may require lower priority for management actions, while a differed management action may be required for Medium Vulnerability species (Dulvy *et al*., 2004; Murua *et al*., 2018). However, species that are evaluated as being of High Vulnerability may require immediate changes in management strategies to avoid depletion of such stocks due to overfishing.

It is now estimated that one-third of the about 1200 shark and ray species are globally threatened with extinction (Dulvy *et al*., 2021) and that shark populations have significantly declined in many regions due to high fishery mortality and their typical vulnerability to high fishing pressure (Pacoureau *et al*., 2021). It is therefore important that rapid assessment methods such as PSA be used to guide their conservation and management especially in data-scarce countries with multi-gear fisheries such as in Kenya.

In this analysis, we found high vulnerability of species in the prawn trawl fishery (35% for rays and 65% for sharks and shark-like rays) and in the industrial pelagic longlines (100% for rays and 46% for sharks and shark-like rays) with variable vulnerability ranges for the artisanal gears. In multi-species stocks such as for sharks and rays in Kenya, management of species assemblages or complexes with similar Vulnerability profile may be more effective than management at the fishery unit such as gears (Swasey *et al*, 2016). Although it is important to estimate vulnerabilities at the fisheries unit level as different gears may have different effects on similar stocks (Patrick *et al*., 2010), management applications should consider the complex spatial structure of sharks and rays often showing population connectivity (Booth *et al*., 2019; Swasey *et al*., 2021). Species that belong to the same Vulnerability category or assemblage could receive different levels of priority in management actions. For example, in this study, the species that have been grouped under the High Vulnerability Species Assemblage (HVSA) could be prioritized for management actions within a Shark and Ray Management Plan (SRMP). Additionally, within the HVSA group, greater priority could be given to "indicator species" that have higher relative vulnerability to gears given such additional considerations as their exploitation rates and the IUCN Red List status.

Consequently, the Critically Endangered species such as the scalloped hammerhead shark (*Sphyrna lewini),* short-tail nurse shark *(Pseudoginglymostoma brevicaudatum),* bowmouth guitarfish *(Rhina ancylostoma),* whitespotted wedgefish (*Rhynchobatus djiddensis), and* smoothnose wedgefish *(Rhynchobatus laevis),* should form a high priority group in the HVSA to be considered for more targeted management actions that could lower their Vulnerability to fisheries. It is instructive that species of wedgefishes (e.g. *R. djiddensis)* and guitarfishes (*R. ancylostoma*) were found to be highly vulnerable to gears in this study, they are indeed considered to be among the most imperilled marine fish species (Bräutigam *et al*., 2015; Jabado, 2018). Management actions that could be considered for the HVSA group should include; area and time closures or restrictions, species bans, catch limits, excluder devices and size limits amongst other measures (Shiffman and Hammerschlag, 2016; Dulvy *et al*., 2017) that could be strengthened by enhanced MCS and observer programs. The species distribution areas within the prawn trawl areas (Kaunda-Arara *et al*, 2022), for example, could be used to manage the vulnerable bycatch species in the prawn trawl fishery through control of fishing effort or other effort control measures.

There is a need for a more precautionary approach in management of the elasmobranch species from the PSA outputs given the data uncertainties inherent in the susceptibility attribute scoring and productivity attribute datasets (Patrick *et al*., 2010). However, the Vulnerability indices reported here (for the prawn trawlers) showed a fairly good correlation with fishing pressure indicator (F/M) and corroborated most of the IUCN Red List categories for the species. Although these indicators provide some level of confidence in using the outputs of the PSA in this study, a precautionary approach in managing the gear-fisheries may be required within the context of the NPOA-sharks (FAO, 1999) or specific regulations.

Data quality analysis showed more satisfactory data for productivity attributes compared to the susceptibility attributes. Future efforts should be made to improve the data quality associated with the susceptibility attributes in addition to obtaining productivity attributes that relate to Kenyan or regional stocks. Nonetheless, improved data quality following more studies may not necessarily result in changes in Vulnerability status (Swasey *et al*., 2016) and hence a trade-off needs to be made between resource application for data quality improvements and use of prevailing vulnerability assessments especially in countries like Kenya where sharks are only beginning to get conservation recognition (Kaunda-Arara *et al*., 2022). Use of precautionary scoring for high vulnerability when there is no data (Hobday *et al*., 2007) as opposed to not scoring has its disadvantages, the former may cause false positives (higher vulnerabilities), we applied the later scenario as it is probably better than false positives from the point of precautionary management approach in a data-poor environment.

The present analysis has also shown the relative risk of overexploitation of the main species of elasmobranchs caught by artisanal, trawl and industrial longline fisheries. It appears, however, that the combination of low productivity and high susceptibility to pelagic longline gear places several species at high risk of overexploitation, most notably, the pelagic rays, the mako sharks and the IOTC protected species, such as the oceanic whitetip, thresher sharks and silky sharks. The pelagic stingray, common thresher and blue shark appear to have the lowest risk in the longlines.

5.0 Conclusions

In response to rising concerns on the impacts of target fisheries on bycatches and associated species, fishery scientists have sought to develop comprehensive risk assessment and management tools for all exploited fishery stocks. PSA is one such tool that can include a large number of exploited stocks in an assessment framework to evaluate the relative risk among species interacting with particular gear types. In the present study, we calculated the vulnerability for the 99 elamobranch species from coastal Kenya. Finally, our PSA outcomes were compared with the levels of protection accorded to the species at national and global levels (e.g. the IUCN Red List Assessments). This is information has the potential to contribute to policy development to protect sharks and rays in Kenya marine waters.

The International Plan of Action for the Conservation and Management of Sharks (IPOA-Sharks) that provides a framework for formulating NPOA-sharks, has long-term goals that include: mitigation of species extinctions, reduced incidental catches and maintenance of ecosystem function and services, amongst others (FAO 1999). The PSA tool provides a cost effective, easy to implement, and intuitive mechanism of identifying species and fisheries that require action within the framework of IPOA goals. This is particularly important for multi-species, multi-gear tropical fisheries as in Kenya, where knowledge of relative vulnerability of species to fisheries should help targeted management actions in view of limited resources. The outputs of PSA in this report therefore provide the Kenya Fisheries Service (KeFS) and other stakeholders with a first-step objective opportunity to prioritize conservation, management and research strategies in order to reduce effects of incidental catches of sharks and rays, within the framework of the NPOA-Sharks. The PSA used in this report has assessed the vulnerability of about 59.6% of the estimated 99 species of elasmobranchs estimated for Kenya's marine waters. The assessment will require continuous updating, as more resources and information on species becomes available. Additional future assessments may consider the cumulative effects of the gears on the vulnerability of the species (Micheli *et al*., 2014). This study becomes a pioneer application of a data-scarce method for evaluating stock status in the WIO region.

6.0 Acknowledgements

We wish to thank the Western Indian Ocean Marine Science Association (WIOMSA) for funding a significant part of data collection for this study. Further funding for PSA was provided by the Kenya Marine Fisheries Socioeconomic Development Project (KEMFSED) of the Kenya Fisheries Service (KeFS).

We also thank several institutions for sharing their shark databases and these included; the Kenya Marine and Fisheries Research Institute (KMFRI), Wildlife Conservation Society (WCS), CORDIO-East Africa and the Kenya Wildlife Service (KWS). A number of scientists helped with shark and ray taxonomy and we especially thank; Rhett Bennett, Dave van Beuningen, David Ebert and Simon Weigmann. Rhett Bennet and Dave van Beuningen further commented on a version of the manuscript as part of the Kenya shark assessment work.

Many thanks also to Geoffrey Odhiambo of CORDIO East Africa, Mombasa, Kenya for his assistance in generating the Map of Kenya's fish landing sites and EEZ used in this study.

7.0 References

Arrizabalaga H., Dufour F., Kell L., Merino G., Ibaibarriaga L., Chust G., *et al*. 2015. Global Habitat Preferences of Commercially Valuable Tuna. *Deep Sea Res. Part II: Top Stud. Oceanog.* 113, 102–112. doi: 10.1016/j.dsr2.2014.07.001

Astles K.L. 2008. A systematic approach to estimating ecological risks in marine fisheries. CABI Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources 3, 16.

Berg H, Francis J, Sourter P. 2002. Support to Marine Research for Sustainable Management of Marine and Coastal Resources in the Western Indian Ocean. *Ambio* 31: 597-601.

Biery, L. & Pauly, D. 2012. A global review of species-specific shark-fin-to-body-mass ratios and relevant legislation. *Journal of Fish Biology*, 80: 1643–1677.

Braccini, J. M., B. M. Gillanders, and T. I. Walker. 2006. Hierarchical approach to the assessment of fishing effects on non-target chondricthyans: case study of Squalus megalops in southeastern Australia. Can. J. Fish. Aquat. Sci. 63:2456–2466.

Bräutigam, A., Callow, M., Campbell, I.R., Camhi, M.D., Cornish, A.S., Dulvy, N.K., Fordham, S.V., Fowler, S.L., Hood, A.R., McClennen, C., Reuter, E.L., Sant, G., Simpfendorfer, C.A. and Welch, D.J. (2015). *Global Priorities for Conserving Sharks and Rays: A 2015–2025 Strategy*

Carruthers, T.R.; Kell, L.T.; Butterworth, D.D.S.; Maunder, M.N.; Geromont, H.F.; Walters, C.; McAllister, M.K.; Hillary, R.; Levontin, P.; Kitakado, T.; *et al*. 2016. Performance review of simple management procedures. *ICES J. Mar. Sci.*, *73*, 464–482, https://doi.org/10.1093/icesjms/fsv212.

Carvalho, F. C., Murie, D. J., Hazin, F. H. V., Hazin, H. G., Leite-Mourato, B., Travassos, P., Burgess, G. H. 2011. Catch rates and size composition of blue sharks (Prionace glauca) caught by the Brazilian pelagic longline fleet in the southwestern Atlantic Ocean. – Aquat. Living Resour. 23: 373-385.

Clarke, S.C., Magnussen, J.E., Abercrombie, D.L., McAllister, M.K. & Mahmood, S.S. 2006a. Identification of shark species composition. Proportion in the Hong Kong shark fin market based on molecular genetics and trade records. *Conservation Biology*, 20(1): 201–211.

Clarke, S.C., McAllister, M.K., Milner-Gulland, E.J., Kirkwood, G.P., Michielsens, C.G.J., Agnew, D.J., Pickitch, E.K., Nakano, H. & Mahmood, S.S. 2006b. Global estimates of shark catches using trade records from commercial markets. *Ecology Letters*, 9: 1115-1126.;

Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). 2015. Appendices I, II and III. In: *CITES* [online]. Valid from 5 February 2015. https://cites.org/eng/app/appendices.php

Convention on the Conservation of Migratory Species of Wild Animals (CMS). 2015. Appendices I and II (as amended by the Conference of the Parties in 1985, 1988, 1991, 1994, 1997, 1999, 2002, 2005, 2008, 2011 and 2014). In: *CMS* [online]. Effective 8 February 2015. [Cited 07 September 2015]. www.cms.int/en/species

Cope, J.M., Devore, J., Dick, E.J., Ames, K., Budrick, J., Erickson, D.L., Grebel, J., Hanshew, G., Jones, R., Mattes, L. 2011. An approach to defining stock complexes for U.S. west coast groundfishes using vulnerabilities and ecological distributions. *North Am. J. Fish. Manag. 31*, 589–604, https://doi.org/10.1080/02755947.2011.591264.

Cortés E., Brooks E.N., Shertzer K.W. 2015. Risk assessment of cartilaginous fish populations. ICES J Mar Sci 72:1057–1068. doi: 10.1093/icesjms/fsu157

Cortés, E., Arocha, F., Beerkircher, L., Carvalho, F., Domingo, A., Heupel, M., Holtzhausen, H., Santos, M. N., Ribera, M., Simpfendorfer, C. (2009). Ecological risk assessment of pelagic sharks caught in Atlantic pelagic longline fisheries. Aquatic Living Resources, 23, 25–34

Costello, C., Ovando, D., Hilborn, R., Gaines, S.D., Deschenes, O. and Lester, S.E. (2012). Status and solutions for the world's unassessed fisheries. *Science* 338 (6106):517–20. doi: 10.1126/science.1223389.

Costello, C., Ovando, D., Clavelle, T., Kent Strauss, C., Hilborn, R., Melnychuk, M.C., Branch, T.A., Gaines, S.D., Szuwalski, C.S., Cabral, R.B., *et al*. 2016**.** Global fishery prospects under contrasting management regimes. *Proc. Natl. Acad. Sci. USA*, *113*, 5125–5129, https://doi.org/10.1073/pnas.1520420113.

Costello, C., Ovando, D., Hilborn, R., Gaines, S.D., Deschenes, O., Lester, S.E. 2012. Status and solutions for the world's unassessed fisheries. *Science*, *338*, 517–520, https://doi.org/10.1126/science.1223389.

Dell'Apa, A., Smith, M.C. & Kaneshiro-Pineiro, M.Y. 2014. The influence of culture on the international management of shark finning. *Environmental management*, 54(2): 1–11.

Dulvy, N.K., Fowler, S.L., Musick, J.A., Cavanagh, R.D., Kyne, P.M., Harrison, L.R., Carlson, J.K., Davidson, L.N.K., Fordham, S.V., Francis, M.P., Pollock, C.M., Colin, A.S., Burgess, G.H., Carpenter, K.E., Compagno, L.J.V., Ebert, D.A., Gibson, C., Heupel, M.R., Livingstone, S.R., Sanciangco, J.C., Stevens, J.D., Valenti, S. & White, W.T. 2014. Extinction risk and conservation of the world's sharks and rays. *eLIFE*, 3: e00590. DOI: 10.7554/eLife.00590.

Dulvy, N.K., Simpfendorfer, C.A., Davidson, L.N.K., Fordham, S.V., Bräutigam, A., Sant, G., Welch, D. J. 2017. Challenges and Priorities in Shark and Ray Conservation. Current Biology, Volume 27, Issue 11.

Ebert, D. A., Khan, M., Ali, M., Akhilesh, K. V., and Jabado, R. W. 2017. *Rhinobatos punctifer*. The IUCN Red List of Threatened Species. Available online at: doi.org/10.2305/IUCN.UK.2017-2.RLTS.T161447A109904426.en (accessed December 6, 2019).

FAO. 1999. International Plan of Action for reducing incidental catch of seabirds in longline fisheries. International Plan of Action for the conservation and management of sharks. International Plan of Action for the management of fishing capacity. Rome, FAO. 1999. 26p.

FAO. 2009. *Signature of the Agreement on Port State Measures to Prevent, Deter and Eliminate Illegal, Unreported and Unregulated Fishing* [online]. [Cited 07 September 2015]. ftp://ftp.fao.org/FI/DOCUMENT/PSM/circular_lett_2009.pdf

FAO. 2020. *The State of World Fisheries and Aquaculture 2020 Sustainability in Action*; Food and Agriculture Organization: Rome, Italy, 2020.

FAO, Duke University and WorldFish. 2022. Small-scale fisheries and sustainable development: Key findings from the Illuminating Hidden Harvests report. Rome, FAO; Durham, USA, Duke University; Penang, Malaysia, WorldFish.

Faruque, H. and Matsuda, H. 2020. Assessing the vulnerability of bycatch species from Hilsa gillnet fishing using productivity susceptibility analysis: Insights from Bangladesh. *Fish. Res.*, *234*, 105808, https://doi.org/10.1016/j.fishres.2020.105808.

Faruque, H. and Matsuda, H. 2021. Conservative Scoring Approach in Productivity Susceptibility Analysis Leads to an Overestimation of Vulnerability: A Study from the Hilsa Gillnet Bycatch Stocks of Bangladesh. *Fishes*, *6*, 33. https://doi.org/10.3390/fishes6030033

Fischer, J., Erikstein, K., D'Offay, B., Guggisberg, S. & Barone, M. 2012. *Review of the Implementation of the International Plan of Action for the Conservation and Management of Sharks*. FAO Fisheries and Aquaculture Circular No. 1076. Rome, FAO. 120 pp. (also available at www.fao.org/docrep/017/i3036e/i3036e00.htm).

Fowler, S. & Seret, B. 2010. *Shark fins in Europe: Implications for reforming the EU finning ban*. European Elasmobranch Association and IUCN Shark Specialist Group. 42 pp.

Froese, R. and Binohlan, C. 2000. Empirical relationships to estimate asymptotic length, length at first maturity and length at maximum yield per recruit in fishes, with a simple method to evaluate length frequency data. *J. Fish Biol.*, *56*, 758–773, https://doi.org/10.1111/j.1095-8649.2000.tb00870.x.

Froese, R. and Pauly, D. 2021. World Wide Web Electronic Publication. Available online: www.fishbase.org

Fujita, R., Thornhill, D.J., Karr, K., Cooper, C.H. and Dee, L.E. 2014. Assessing and managing data-limited ornamental fisheries in coral reefs. *Fish Fish.*, *15*, 661–675, https://doi.org/10.1111/faf.12040.

Griffiths, S.P., Brewer D.T., Heales D.S., Milton D.A, and Stobutzki, I.C. 2006. Validating ecological risk assessments for fisheries: assessing the impacts of turtle excluder devices on elasmobranch bycatch populations in an Australian trawl fishery. Mar. Freshw. Res. 57:395–401.

Hareide, N.R., Carlson, J., Clarke, M., Clarke, S., Ellis, J., Fordham, S., Fowler, S., Pinho, M., Raymakers, C., Serena, F., Seret, B. & Polti, S. 2007. *European shark fisheries: a* *preliminary investigation into fisheries, conversion factors, trade products, markets and management measures*. European Elasmobranch Association. 61 pp.

Hepp, J. & Wilson, E.G. 2014. Shark conservation efforts: as diverse as sharks themselves. *In* E.J. Techera & N. Klein, eds. *Sharks: conservation, governance and management*, pp. 176-194. Routledge.

Hobday, A.J., Smith, A. and Stobutzki, I. 2004. Ecological risk assessment for Australian Commonwealth fisheries, 172 p. Report R01/0934 for the Australian Fisheries Management Authority, Canberra, Australia.

Hobday, A.J., Smith, A., Webb, H., Daley, R., Wayte, S., Bulman, C., Dowdney, J., Williams, A., Sporcic, M., Dambacher, J., Fuller, M. and Walker, T. 2007. Ecological risk assessment for the effects of fishing: methodology, 174 p. Report R04/1072 for the Australian Fisheries Management Authority, Canberra, Australia.

Hobday, A.J., Smith, A.D.M., Stobutzki, I.C., Bulman, C., Daley, R., Dambacher, J.M., Deng, R.A., Dowdney, J., Fuller, M., Furlani, D., *et al*. 2011. Ecological risk assessment for the effects of fishing. Fish. Res.108, 372–384, https://doi.org/10.1016/j.fishres.2011.01.013.

Hope B.K. 2006. An examination of ecological risk assessment and management practices. Env. Int. 32, 983-995.

IUCN Red List. 2022. The IUCN Red List of Threatened Species. *Version 2021-2.* Available online at: https://www.iucnredlist.org/en

Jennings, S., Reynolds, J.D. and Polunin, N.V. 1999. Predicting the vulnerability of tropical reef fishes to exploitation with phylogenies and life histories. *Conser. Biol.*, *13*, 1466–1475, https://doi.org/10.1046/j.1523-1739.1999.98324

Jensen, A.L. 1980. Beverton and Holt life history invariants result from optimal trade-off of reproduction and survival. *Can. J. Fish. Aquat. Sci.*, *53*, 820–822, https://doi.org/10.1139/f95-233.

Kaunda-Arara, B., Oddenyo, R. M., Mueni, E., Kiilu, B., Wambiji, N., Abunge, C., Kodia, M. A., Kosgei, J., Obota, C., Musembi, P., Muthiga, N. 2022. Kenyan shark baseline assessment report to support the national plan of action for the conservation and management of sharks. Kenya Fisheries Service, State Department of Fisheries and the Blue Economy, Nairobi

Kenya Marine Frame Survey Report 2016. State Department for Fisheries and the Blue Economy reports; Kenya Coastal Development Project (KCDP) (unpublished).

Kiilu, B., Kaunda-Arara, B., Oddenyo, R., Thoya, P. and Njiru J. 2019. Spatial distribution, seasonal abundance and exploitation status of shark species in Kenyan coastal waters, African Journal of Marine Science, 41:2, 191-201, DOI: 10.2989/1814232X.2019.1624614.

Klein, N. 2014. The existing global legal regime. *In* E.J. Techera & N. Klein, eds. *Sharks: Conservation, Governance and Management*, pp. 27–45. Routledge.

Lack, M. & Sant G. 2011. *The future of sharks: a review of action and inaction*. TRAFFIC International and the Pew Environment Group. 41 pp.

Lack, M., Sant, G., Burgener, M. & Okes, N. 2014. *Development of a Rapid Management- Risk Assessment Method for Fish Species through its Application to Sharks: Framework and Results.* Report to the Department of Environment, Food and Rural Affairs. Defra Contract No. MB0123. (Available at http://randd.defra.gov.uk/Document.aspx?Document=12003_MB0123FishandMEAsFINALreport24March2014.pdf).

Last, P., White, W., Carvalho, M., Seret, B., Stehmann, M. and Naylor, G. 2018. *Rays of the World, Peter Last, William White, Marcelo de Carvalho, Bernard Séret, Matthias Stehmann, Gavin Naylor, 9780643109131.* Available online at: https://www.publish.csiro.au/book/7053/

Leadbitter, D. 2013**.** A risk-based approach for promoting management regimes for trawl fisheries in South East Asia. *Asian Fish. Sci.*, *26*, 65–78, https://doi.org/10.33997/j.afs.2013.26.2.001.

Lin, C.Y., Wang, S.P., Chiang, W.C., Griffiths, S. and Yeh, H.M. 2020. Ecological risk assessment of species impacted by fisheries in waters off eastern Taiwan. Fish. Manag. Ecol., 27, 345–356, https://doi.org/10.1111/fme.12417.

Lucena-Frédou, F., Kell, L., Frédou, T., Gaertner, D., Potier, M., Bach, P., Travassos, P., Hazin, F. and Ménard, F. 2017. Vulnerability of teleosts caught by the pelagic Tuna longline fleets in South Atlantic and Western Indian Oceans. *Deep. Res. Part II Top. Stud. Oceanogr. 140*, 230–241, https://doi.org/10.1016/j.dsr2.2016.10.008.

Mace, P.M. 1994. Relationships between common biological reference points used as thresholds and targets of fisheries management strategies. *Can. J. Fish. Aquat. Sci.*, *51*, 110–122, https://doi.org/10.1139/f94-013.

Micheli, F., Leo, G., Butner, C., Martone, R.G., Shester G. 2014. A risk-based framework for assessing the cumulative impact of multiple fisheries, Biological Conservation, Volume 176, Pg 224-235.

Milton, D. A. 2001. Assessing the susceptibility to fishing of populations of rare trawl bycatch: sea snakes caught by Australia's Northern Prawn Fishery. Biol. Conserv. 101:281–290.

Munga, C., Fulanda, B., Manyala, J., Kimani, E., Ohtomi, J. and Vanreusel, A. 2012. Bottom shrimp trawling impacts on species distribution and fishery dynamics; Ungwana Bay fishery Kenya before and after the 2006 trawl ban. *Fisheries science* 78: 209-219.

Musick, J. A. 1999. Criteria to define extinction risk in marine fishes. Fisheries 24:6–14.

Myers, R. A. and Baum, J. K. 2007. Cascading effects of the loss of apex predatory sharks from a coastal ocean. – Science 315: 1850-1946.

Patrick, W.S., Spencer, P., Link, J., Cope, J., Field, J., Kobayashi, D., Lawson, P., Gedamke, T., Cortés, E., Ormseth, O., *et al*. 2010. Using productivity and susceptibility indices to assess the vulnerability of united states fish stocks to overfishing. *Fish. Bull.*, *108*, 305–322.

Patrick, W.S., Spencer, P., Ormseth, O., Cope, J., Field, J., Kobayashi, D., Gedamke, T., Cortés, E., Bigelow, K., Overholtz, W., *et al*. 2009. Use of Productivity and Susceptibly Indices to Determine Stock Vulnerability, with Example Applications to Six U.S. Fisheries; U.S. Department of Commerce: Washington, DC, USA, pp. 1–90.

Pauly, D. 1980. On the interrelationships between natural mortality, growth parameters, and mean environmental temperature in 175 fish stocks. *ICES J. Mar. Sci. 39*, 175–192, https://doi.org/10.1093/icesjms/39.2.175.

Pollerspöck, J. and Straube, N. 2021. Bibliography Database. *Version 2021.* Available online at: https://www.shark-references.com/

Reynolds, J.D., Jennings, S. and Dulvy, N.K. 2001. Life Histories of Fishes and Population Responses to Exploitation; Reynolds, J.D., Mace, G.M., Redford, K.H., Robinson, J.G., Eds.; Cambridge University Press: Cambridge, UK; pp. 147–168.

Roff, D.A. 1984. The evolution of life history parameters in teleosts. *Can. J. Fish. Aquat. Sci. 41*, 989–1000, https://doi.org/10.1139/f84-114.

Rosenberg, A., Agnew, D., Babcock, E., Cooper, A., Mogensen, C., O'Boyle, R., Powers, J., Stefansson, G. and Swasey, J. 2007. Setting annual catch limits for U.S. fisheries: An expert working group report, 36 p. MRAG Americas, Washington, D.C.

Scandol J.P., Ives M.C. and Lockett M. 2009. Development of national guidelines to improve the application of risk-based methods in the scope, implementation and interpretation of stock assessments for data-poor species (Final Draft). FRDC Project No. 2007/016, NSW Department of Primary Industries 182 pp.

Simpfendorfer, C.A., Heupel, M.R., White, W.T., & Dulvy, N.K. 2011. The importance of research and public opinion to conservation management of sharks and rays: a synthesis. *Marine and Freshwater Research*, 62(6): 518-527.Fischer *et al.*, 2012

Smith, A.D.M., Fulton, E.J., Hobday, A.J., Smith, D.C., and Shoulder, P. 2007. Scientific tools to support the practical implementation of ecosystem-based fisheries management. ICES J. Mar. Sci. 64:633–639.

Smith, S.J., Hunt, J.J. and Rivard, D. 1993. Risk Evaluation and Biological Reference Points for Fisheries Management. – Canadian Special Publication of Fisheries and Aquatic Sciences No. 120, Fisheries and Oceans Canada, Ottawa.

Stobutzki, I., Miller, M. and Brewer, D. 2001**.** Sustainability of fishery bycatch: A process for assessing highly diverse and numerous bycatch. *Environ. Conserv.*, *28*, 167–181, https://www.jstor.org/stable/44519886.

Stobutzki, I., Miller, M. and Brewer, D. 2001b. Sustainability of fishery bycatch: a process for assessing highly diverse and numerous bycatch. Environ. Conserv. 28:167–181.

Stobutzki, I.C., Miller, Jones, M.J.P. and Salini, J. P. 2001a. Bycatch diversity and variation in a tropical Australian penaeid fishery: the implications for monitoring. Fish. Res. 53:283–301.

Sumaila, U.R., Bellmann, C. and Tipping, A. 2016. Fishing for the future: An overview of challenges and opportunities. *Mar. Policy*, *69*, 173–180, https://doi.org/10.1016/j.marpol.2016.01.003.

Techera, E.J. & Klein, N. 2011. Fragmented governance: reconciling legal strategies for shark conservation and management. *Marine Policy*, 35(1): 73-78.

United Nations General Assembly (UNGA). 2010. *Resolution on Sustainable Fisheries, including through the 1995 Agreement for the Implementation of the Provisions of the United Nations Convention on the Law of the Sea of 10 December 1982 relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks, and related instruments, Sixty-fifth Session, 2010*. A/RES/65/38.

van der Elst R., Kiszka J., Jérôme B. and Ross W. 2012. Mainstreaming biodiversity in fisheries management: a retrospective analysis of existing data on vulnerable organisms in the South West Indian Ocean. *A specialist report prepared for the South West Indian Ocean Fisheries Project (SWIOFP).*

Zhou, S. and Griffiths, S.P. 2008. Sustainability assessments for fishing effects (SAFE): a new quantitative ecological risk assessment method and its application to elasmobranch bycatch in an Australian trawl fishery. Fish. Res. 91:56–68.

Mauricio Castrejón and Anthony Charles. 2013. Improving fisheries co-management through ecosystem-based spatial management: The Galapagos Marine Reserve, Marine Policy, Volume 38. Pages 235-245.

8.0 Supplementary material

Table S1: Numerical distribution of shark and shark-like rays (sharks) and ray species used in the Productivity and Susceptibility Analysis (PSA) of relative vulnerabilities of species to different fisheries-gears in coastal Kenya. (-) no information available.

Group	Handlines-artisanal	Longlines-industrial	Longlines-artisanal	Gillnets	Prawn Trawlers	Ringnets	Spearguns	Traps
Sharks	25	16	-	27	25	7	-	-
Rays	14	4	8	17	24	6	2	1

Table S1: Family and species names, gear-species interactions and conservation status of shark species occurring or thought to occur on the Kenyan coast. Information collated from different sources and expert consultations**.** IUCN conservation categories are as explained in Figure 1.

Family	**Species name**	**IUCN status**	**Fishery-gear interactions**
Alopiidae	*Alopias pelagicus*	EN	Trawl, Handline, Longline
Alopiidae	*Alopias superciliosus*	VU	Trawl, Longline, Handline
Alopiidae	*Alopias vulpinus*	VU	Longline
Carcharhinidae	*Carcharhinus albimarginatus*	VU	Trawl, Longline, Gillnet, Handline
Carcharhinidae	*Carcharhinus altimus*	NT	
Carcharhinidae	*Carcharhinus amblyrhynchos*	EN	Trawl, Gillnet, Handline, Longline
Carcharhinidae	*Carcharhinus amboinensis*	VU	Trawl
Carcharhinidae	*Carcharhinus falciformis*	VU	Trawl, Longline, Gillnet, Handline
Carcharhinidae	*Carcharhinus humani*	DD	Gillnet, Handline, Ringnet, Trawl
Carcharhinidae	*Carcharhinus leucas*	VU	Trawl, Gillnet, Handline
Carcharhinidae	*Carcharhinus limbatus*	VU	Trawl, Handline

Carcharhinidae	*Carcharhinus longimanus*	CR	Longline
Carcharhinidae	*Carcharhinus macloti*	NT	Trawl, Gillnet, Handline, Longline
Carcharhinidae	*Carcharhinus melanopterus*	VU	Trawl, Gillnet, Handline, Longline
Carcharhinidae	*Carcharhinus plumbeus*	EN	Handline
Carcharhinidae	*Carcharhinus sorrah*	NT	Gillnet, Handline, Ringnet
Carcharhinidae	*Loxodon macrorhinus*	NT	Trawl, Handline
Carcharhinidae	*Negaprion acutidens*	EN	
Carcharhinidae	*Prionace glauca*	NT	Trawl, Longline
Carcharhinidae	*Rhizoprionodon acutus*	VU	Trawl, Gillnet, Handline, Ringnet
Carcharhinidae	*Scoliodon laticaudus*	NT	
Carcharhinidae	*Triaenodon obesus*	VU	Gillnet, Handline, Ringnet
Odontaspididae	*Carcharias taurus*	CR	
Centrophoridae	*Centrophorus granulosus*	EN	Handline
Centrophoridae	*Centrophorus moluccensis*	VU	Trawl
Galeocerdidae	*Galeocerdo cuvier*	NT	Longline, Gillnet, Handline, Trawl
Ginglymostomatidae	*Nebrius ferrugineus*	VU	
Ginglymostomatidae	*Pseudoginglymostom a brevicaudatum*	CR	Trawl, Gillnet
Hemigaleidae	*Hemipristis elongata*	VU	Trawl
Hemigaleidae	*Paragaleus leucolomatus*	VU	
Heterodontidae	*Heterodontus ramalheira*	DD	Trawl
Hexanchidae	*Heptranchias perlo*	NT	Trawl
Hexanchidae	*Hexanchus nakamurai*	NT	Handline, Longline, Trawl, Handline
Lamnidae	*Carcharodon carcharias*	VU	Longline
Lamnidae	*Isurus oxyrinchus*	EN	Longline
Lamnidae	*Isurus paucus*	EN	Longline
Pentanchidae	*Bythaelurus hispidus*	NT	

Pentanchidae	*Halaelurus boesemani*	VU	
Pentanchidae	*Holohalaelurus grennian*	DD	Trawl
Pentanchidae	*Holohalaelurus melanostigma*	LC	Trawl
Pristiophoridae	*Pliotrema warreni*	DD	
Pristiophoridae	*Pristiophorus nancyae*	LC	Trawl
Proscyllidae	*Eridacnis radcliffei*	LC	
Proscyllidae	*Eridacnis sinuans*	LC	
Pseudocarchariidae	*Pseudocarcharias kamoharai*	LC	
Rhincodontidae	*Rhincodon typus*	EN	
Scyliorhinidae	*Cephaloscyllium sufflans*	NT	Trawl
Sphyrnidae	*Sphyrna lewini*	CR	Trawl, Longline, Gillnet, Handline, Ringnet
Sphyrnidae	*Sphyrna mokarran*	CR	
Squalidae	*Cirrhigaleus asper*	DD	Trawl
Squalidae	*Squalus mahia*	DD	
Squalidae	*Squalus bassi*	EN	Trawl
Squatinidae	*Squatina africana*	NT	Trawl, Gillnet, Handline
Stegostomatidae	*Stegostoma tigrinum*	EN	Trawl
Triakidae	*Hypogaleus hyugaensis*	LC	Longline
Triakidae	*Mustelus manazo*	EN	Gillnet, Handline
Triakidae	*Mustelus mosis*	NT	Gillnet, Handline

Table S2: Family and species names, gear-species interactions and conservation status of rays, shark-like rays and chimera species occurring or thought to occur on the Kenyan coast. Information collated from different sources and expert consultations**.** IUCN conservation categories are as explained in Figure 1.

Family	**Species name**	**IUCN status**	**Fishery-gear interactions**

Aetobatidae	*Aetobatus ocellatus*	VU	Gillnet, Handline, Longline, Ringnet, Trawl
Chimaeridae	*Hydrolagus africanus*	LC	
Dasyatidae	*Bathytoshia lata*	VU	Trawl, Longline
Dasyatidae	*Himantura leoparda*	VU	Longline
Dasyatidae	*Himantura uarnak*	EN	Trawl, Gillnet, Handline, Longline
Dasyatidae	*Maculabatis ambigua*	NT	Trawl, Gillnet, Handline, Longline, Ringnet
Dasyatidae	*Megatrygon microps*	DD	
Dasyatidae	*Neotrygon caeruleopunctata*	LC	Gillnet, Handline, Ringnet, Speargun
Dasyatidae	*Pastinachus ater*	VU	Gillnet
Dasyatidae	*Pateobatis fai*	VU	Gillnet, Handline
Dasyatidae	*Pateobatis jenkinsii*	VU	Gillnet, Ringnet
Dasyatidae	*Pteroplatytrygon violacea*	LC	Longline
Dasyatidae	*Taeniura lymma*	LC	Trawl, Gillnet, Handline, Ringnet, Speargun, Trap
Dasyatidae	*Taeniurops meyeni*	VU	Trawl, Gillnet
Dasyatidae	*Urogymnus asperrimus*	VU	

Dasyatidae	*Urogymnus granulatus*	VU	Gillnet
Glaucostegidae	*Glaucostegus halavi*	CR	Trawl
Gurgesiellidae	*Cruriraja parcomaculata*	LC	Trawl
Gymnuridae	*Gymnura poecilura*	VU	
Mobulidae	*Mobula birostris*	EN	Trawl
Mobulidae	*Mobula eregoodoo*	EN	
Mobulidae	*Mobula kuhlii*	EN	Trawl, Gillnet
Mobulidae	*Mobula mobular*	EN	Trawl, Handline
Myliobatidae	*Aetomylaeus vespertilio*	EN	
Myliobatidae	*Myliobatis aquila*	CR	Trawl
Narcinidae	*Narcine rierai*	DD	
Rajidae	*Dipturus springeri*	LC	Trawl
Rajidae	*Dipturus stenorhynchus*	DD	
Rajidae	*Leucoraja elaineae*	DD	
Rajidae	*Okamejei heemstrai*	LC	
Rajidae	*Raja clavata*	NT	Trawl

Rajidae	*Raja ocellifera*	EN	
Rajidae	*Rostroraja alba*	EN	
Rhinidae	*Rhina ancylostoma*	CR	Trawl, Gillnet
Rhinidae	*Rhynchobatus australiae*	CR	Ringnet, Gillnet
Rhinidae	*Rhynchobatus djiddensis*	CR	Trawl, Gillnet
Rhinobatidae	*Acroteriobatus leucospilus*	EN	Gillnet
Rhinobatidae	*Acroteriobatus ocellatus*	DD	Trawl
Rhinobatidae	*Acroteriobatus zanzibarensis*	NT	Gillnet, Handline
Rhinobatidae	*Rhinobatos holcorhynchus*	DD	Trawl, Handline
Rhinopteridae	*Rhinoptera jayakari*	EN	Gillnet, Ringnet, Handline, Longline
Torpedinidae	*Torpedo sinuspersici*	DD	Trawl

Table S3: Productivity (P), Susceptibility (S) and Overall vulnerability (V) risk and categories from results of PSA done on ray species potentially caught by different gears in the artisanal fishery in coastal Kenya.

Fishery/Gear	**Species**	**P-score**	**S-Score**	**V- risk value**	**Risk category**
Gillnet	*Aetobatus ocellatus*	2.39	1.97	3.097	Med
Gillnet	*Himantura uarnak*	2.39	1.53	2.836	Med
Gillnet	*Maculabatis ambigua*	2.61	1.61	3.069	Med
Gillnet	*Mobula kuhlii*	2.44	1.27	2.755	Med
Gillnet	*Neotrygon caeruleopunctata*	1.67	1.27	2.095	Low
Gillnet	*Pastinachus ater*	2.39	1.27	2.705	Med
Gillnet	*Pateobatis fai*	2.44	1.27	2.755	Med
Gillnet	*Pateobatis jenkinsii*	2.22	1.27	2.559	Low
Gillnet	*Rhinoptera jayakari*	2.28	1.27	2.608	Low
Gillnet	*Taeniura lymma*	1.89	1.27	2.276	Low
Gillnet	*Taeniurops meyeni*	2.72	1.27	3.004	Med
Gillnet	*Urogymnus granulatus*	2.28	1.27	2.608	Low
Handline	*Aetobatus ocellatus*	2.39	1.58	2.865	Med

Handline	*Himantura uarnak*	2.39	1.53	2.836	Med
Handline	*Maculabatis ambigua*	2.61	1.34	2.935	Med
Handline	*Mobula mobular*	2.67	1.54	3.079	Med
Handline	*Neotrygon caeruleopunctata*	1.67	1.27	2.095	Low
Handline	*Pateobatis fai*	2.44	1.27	2.755	Med
Handline	*Taeniura lymma*	1.89	1.27	2.276	Low
Longline	*Aetobatus ocellatus*	2.39	1.58	2.865	Med
Longline	*Himantura leoparda*	2.33	1.54	2.796	Med
Longline	*Himantura uarnak*	2.39	1.7	2.933	Med
Longline	*Maculabatis ambigua*	2.61	1.34	2.935	Med
Ringnet	*Aetobatus ocellatus*	2.39	1.58	2.865	Med
Ringnet	*Maculabatis ambigua*	2.61	1.61	3.069	Med
Ringnet	*Neotrygon caeruleopunctata*	1.67	1.27	2.095	Low
Ringnet	*Pateobatis jenkinsii*	2.22	1.27	2.559	Low
Ringnet	*Rhinoptera jayakari*	2.28	1.53	2.743	Med
Ringnet	*Taeniura lymma*	1.89	1.7	2.543	Low
Speargun	*Neotrygon caeruleopunctata*	1.67	1.7	2.382	Low

Speargun	*Taeniura lymma*	1.89	1.7	2.543	Low
Trap	*Taeniura lymma*	1.89	1.7	2.543	Low

Table S4: Productivity (P) and Susceptibility (S) scores, and Overall vulnerability (V) risk and categories from results of PSA Done on shark and shark-like ray species potentially caught by different gears in the artisanal fishery in coastal Kenya.

Gear	**Species**	**P-score**	**S-score**	**V- overall risk value**	**Risk category**
Gillnet	*Acroteriobatus ocellatus*	1.44	1.72	2.247	Low
Gillnet	*Acroteriobatus zanzibarensis*	1.56	1.82	2.392	Low
Gillnet	*Acroteriobatus leucospilus*	1.83	1.82	2.581	Low
Gillnet	*Carcharhinus albimarginatus*	2.5	1.82	3.091	Med
Gillnet	*Carcharhinus amblyrhynchos*	2.11	1.72	2.724	Med
Gillnet	*Carcharhinus falciformis*	2.56	1.57	2.999	Med
Gillnet	*Carcharhinus humani*	2.39	1.57	2.858	Med
Gillnet	*Carcharhinus leucas*	2.56	1.8	3.124	Med
Gillnet	*Carcharhinus limbatus*	2.06	1.66	2.64	Med
Gillnet	*Carcharhinus macloti*	1.61	1.72	2.358	Low

Gillnet	*Carcharhinus melanopterus*	2.06	1.72	2.681	Med
Gillnet	*Carcharhinus sorrah*	1.94	2.31	3.018	Med
Gillnet	*Galeocerdo cuvier*	1.67	1.57	2.289	Low
Gillnet	*Mustelus manazo*	1.83	1.82	2.581	Low
Gillnet	*Mustelus mosis*	1.89	1.57	2.456	Low
Gillnet	*Pseudoginglymostoma brevicaudatum*	2.39	1.57	2.858	Med
Gillnet	*Rhina ancylostoma*	2.67	2.07	3.376	High
Gillnet	*Rhizoprionodon acutus*	2	1.57	2.542	Low
Gillnet	*Rhynchobatus australiae*	2.22	2.07	3.038	Med
Gillnet	*Rhynchobatus djiddensis*	2.39	2.19	3.238	High
Gillnet	*Rhynchobatus laevis*	2.61	1.89	3.222	High
Gillnet	*Sphyrna lewini*	2.39	2.22	3.262	High
Gillnet	*Squatina africana*	2.06	1.99	2.863	Med
Gillnet	*Triaenodon obesus*	2.56	1.82	3.136	Med
Handline	*Acroteriobatus zanzibarensis*	2.17	1.82	2.828	Med
Handline	*Alopias pelagicus*	2.56	1.43	2.929	Med
Handline	*Alopias superciliosus*	2.72	1.55	3.133	Med

Handline	*Carcharhinus albimarginatus*	2.56	1.82	3.136	Med
Handline	*Carcharhinus amblyrhynchos*	2.17	1.72	2.767	Med
Handline	*Carcharhinus falciformis*	2.56	1.57	2.999	Med
Handline	*Carcharhinus humani*	2.39	1.57	2.858	Med
Handline	*Carcharhinus leucas*	2.56	1.8	3.124	Med
Handline	*Carcharhinus limbatus*	1.78	1.66	2.43	Low
Handline	*Carcharhinus macloti*	1.72	1.72	2.435	Low
Handline	*Carcharhinus melanopterus*	2.06	1.72	2.681	Med
Handline	*Carcharhinus plumbeus*	2.56	1.57	2.999	Med
Handline	*Carcharhinus sorrah*	1.72	2.31	2.879	Med
Handline	*Centrophorus sp.*	2.39	1.43	2.785	Med
Handline	*Galeocerdo cuvier*	1.72	1.57	2.33	Low
Handline	*Hexanchus nakamurai*	1.94	1.43	2.414	Low
Handline	*Loxodon macrorhinus*	1.61	1.72	2.358	Low
Handline	*Mustelus manazo*	1.94	1.82	2.661	Med
Handline	*Mustelus mustelus*	1.94	1.57	2.499	Low
Handline	*Rhizoprionodon acutus*	2	1.57	2.542	Low

Handline	*Rhinobatos holcorhynchus*	2.11	2.16	3.021	Med
Handline	*Scoliodon laticaudus*	1.61	1.82	2.428	Low
Handline	*Sphyrna lewini*	2.39	2.22	3.262	High
Handline	*Squatina africana*	2.11	1.99	2.903	Med
Handline	*Triaenodon obesus*	2.61	1.82	3.181	High
Ringnet	*Acroteriobatus zanzibarensis*	1.56	1.82	2.392	Low
Ringnet	*Carcharhinus humani*	1.89	1.57	2.456	Low
Ringnet	*Carcharhinus sorrah*	1.89	2.31	2.982	Med
Ringnet	*Rhizoprionodon acutus*	2.28	1.57	2.766	Med
Ringnet	*Rhynchobatus australiae*	2	2.07	2.879	Med
Ringnet	*Sphyrna lewini*	1.89	2.22	2.915	Med
Ringnet	*Triaenodon obesus*	2.44	1.82	3.046	Med

Table S5: Productivity (P) and Susceptibility (S) scores, and Overall vulnerability (V) risk values from results of PSA done on ray species potentially caught by prawn trawlers from Malindi-Ungwana Bay in coastal Kenya.

Species	**P- score**	**S- score**	**V- overall risk value**	**Overall risk category**
Aetobatus ocellatus	2.61	1.83	3.189	High

Gymnura poecilura	2.78	1.70	3.258	High
Pateobatus jenkinsii	2.56	2.01	3.251	High
Himantura leoparda	2.33	1.61	2.836	Med
Himantura uarnak	2.39	1.61	2.882	Med
Maculabatis ambigua	2.67	1.85	3.247	High
Mobula birostris	2.61	1.67	3.099	Med
Mobula mobular	2.67	1.54	3.079	Med
Mobula kuhlii	2.44	1.85	3.067	Med
Myliobatis aquila	2.56	1.69	3.063	Med
Raja clavata	1.56	1.47	2.140	Low
Lecoraja elaineae	1.67	1.47	2.222	Low
Rostroraja alba	2.33	1.69	2.880	Med
Neotrygon caeruleopunctata	2.17	1.47	2.618	Low
Pastinachus ater	2.61	1.96	3.262	High
Taeniura lymma	1.89	1.70	2.543	Low
Taeniurops meyeni	2.94	1.69	3.394	High

Table S6: Productivity (P) and Susceptibility (S) scores, and Overall vulnerability (V) risk and categories from results of PSA done on shark and shark-like ray species potentially caught by prawn trawlers from Malindi-Ungwana Bay in coastal Kenya.

Species – Scientific Name	**P-score**	**S-score**	**V-overall risk value**	**Risk category**
Carcharhinus limbatus	1.78	2.22	2.845	Med
Scoliodon laticaudus	1.50	2.44	2.860	Med
Centrophorus granulosus	2.28	2.01	3.037	Med
Squatina africana squatina	2.28	2.44	3.335	High
Halaelurus boesemani	1.50	2.84	3.214	High
Holohalaelurus grennian	1.33	2.57	2.896	Med
Loxodon macrorhinus	1.56	2.31	2.783	Med
Mustelus manazo	2.00	2.44	3.152	Med
Carcharhinus albimarginatus	2.50	2.28	3.385	High
Carcharhinus amblyrhynchos	2.11	2.31	3.127	Med
Carcharhinus leucas	2.56	2.41	3.511	High
Carcharhinus falciformis	2.61	2.08	3.338	High
Carcharhinus macloti	1.61	2.84	3.267	High

Carcharhinus melanopterus	2.06	2.64	3.347	High
Mustelus mosis	3.00	2.79	4.096	High
Galeocerdo cuvier	2.06	2.28	3.071	Med
Pseudoginglymostoma brevicaudatum	2.78	2.79	3.936	High
Sphyrna lewini	2.50	2.41	3.471	High
Squatina Africana	1.78	2.64	3.184	High
Stegostoma tigrinum	2.50	2.64	3.637	High
Triaenodon obesus	2.67	2.44	3.612	High
Pliotrema warren	3.00	1.93	3.569	High
Rhina ancylostoma	2.72	2.01	3.383	High
Rhynchobatus djiddensis	2.67	2.12	3.407	High