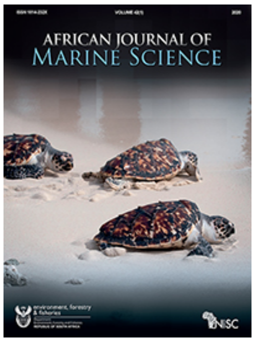

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Spatial patterns and environmental risks of ringnet fishing along the Kenyan coast

P Thoya[1,2]*, S Pérez-Jorge[3], GM Okemwa[1], H Mwamlavya[1], A Tuda[4], N Wambiji[1] and JM Maina[2]

[1] *Kenya Marine and Fisheries Research Institute, Mombasa, Kenya*
[2] *Department of Environmental Sciences, Macquarie University, Sydney, Australia*
[3] *Marine and Environmental Sciences Centre (MARE) and Institute of Marine Research (IMAR), University of the Azores, Horta, Portugal*
[4] *Kenya Wildlife Service, Nairobi, Kenya*
* *Corresponding author, e-mail: pascalthoya@gmail.com*

Ringnet fishing began in the early 20th century and is practised worldwide, mainly to target nearshore pelagic species. The method was introduced to Kenya's coastal waters by migrant fishers from Tanzania. However, the impacts of this fishing gear remain poorly assessed. We assessed the spatial distribution of ringnet fishing effort and its possible effects on ecosystem components, such as coral reefs, marine megafauna and marine protected areas, on the south coast of Kenya. We tracked 89 ringnet fishing trips made from December 2015 to January 2016 and used spatial multicriteria analysis to determine hotspots of possible environmental risks. The results showed that habitat type and bathymetric profile influenced the spatial distribution of ringnet fishing effort. Mixed seagrass and coral habitats had the highest concentration of the effort. Most of the habitats in the study area were moderately exposed to the impacts of the ringnet fishery. The study identifies high-risk areas that require spatial measures to minimise possible environmental risks of the gear both to habitats and to endangered sea turtles.

Keywords: coral reefs, habitat distribution, fishing pressure, marine spatial planning, risk assessment, sea turtles, spatial multicriteria analysis

Introduction

Coastal and marine ecosystems worldwide are experiencing immense pressure from overfishing, land-based pollution, habitat degradation and the increasing impacts of climate change (Pratchett et al. 2008; Teh et al. 2013). The effect of fishing has been a focus of research for many decades (Pauly et al. 2002; Porobic et al. 2019). Coastal fisheries have mainly been associated with a decline of critical ecosystems, such as coral reefs, mangroves and seagrass habitats (Jennings and Lock 1996). These impacts are significant in developing countries where fishing is concentrated in coastal waters, and where fishers use destructive low-cost gears (Wolff et al. 2015). Improved management using ecosystem-based approaches to fisheries, and local-based measures such as co-management and marine protected areas (MPAs), can help to mitigate these impacts and improve the governance system (Christie et al. 2007; Cinner et al. 2009; Ayers and Kittinger 2014).

Artisanal fishers dominate Kenya's marine capture fisheries where fishers operate in nearshore areas within the lagoon reefs (McClanahan and Mangi 2004; Alidina 2005). The nearshore areas have been profoundly impacted by destructive fishing practices, and hence gear-based management and the establishment of MPAs have been implemented to mitigate these effects (McClanahan and Mangi 2004; Mangi and Roberts 2006). Overpopulation, unemployment and poverty among coastal communities drive noncompliance and the use of illegal and highly efficient fishing gears (Ochiewo 2004; Mangi et al. 2007). To enhance sustainable management of marine fisheries, a balance has to be achieved between the protection of environmental values and fulfilling the socioeconomic needs of the fisher communities.

The State Department for Fisheries, Aquaculture and the Blue Economy (SDFA-BE) in Kenya is working towards developing fishery-specific management plans, especially for contentious fishing gears, such as ringnets. Ringnets were recently introduced to Kenya by migrant fishers from Tanzania. The contribution of ringnets to Kenyan fisheries has been remarkable in recent times, with catches at fish landing sites like Gazi and Vanga being dominated by this fishing gear during the northeast monsoon period (Maina and Osuka 2014; Okemwa et al. 2017). In 2016, about 861 fishers participated in ringnet fishing on the Kenyan south coast, operating approximately 40 fishing nets (Okemwa et al. 2017).

Ringnets are similar to purse-seine nets. A cork line (float rope) strung with cork floats keeps the ringnet afloat, and a weighted lead rope with purse rings at the lower edge of the net ensures that the net hangs vertically in the water column (Samoilys et al. 2011) (Figure 1). Some fishers and fish dealers (some of whom own ringnet fishing gear

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and employ fishers) perceive ringnets to be the most suitable gear for targeting surface-dwelling and migratory pelagic fish species of high commercial value. Proponents of the gear cite a reduction of pressure on the artisanal-dominated reef fisheries and enhanced economic benefits to fishers as some of the benefits of the gear (Okemwa et al. 2017). However, recent studies indicate that ringnet fishing might be occurring in shallow reef areas, and this might be damaging to coral reef and seagrass ecosystems (Okemwa et al. 2017).

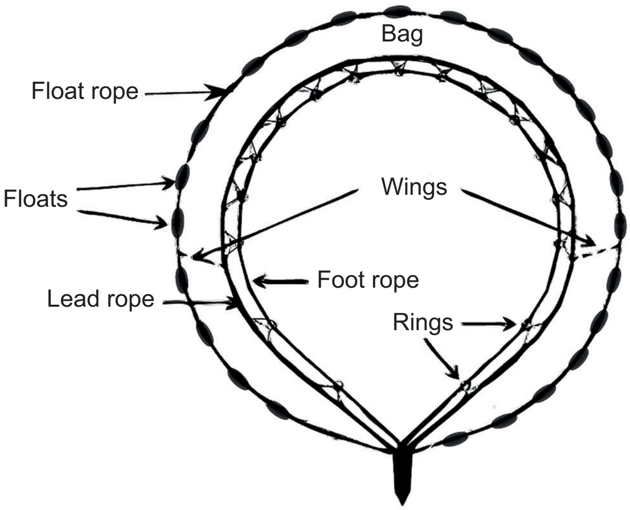

Figure 1: Illustration of a ringnet (adapted from Okemwa et al. [2017])

SDFA-BE is at an advanced stage of developing a management plan for the gear (Okemwa et al. 2017). The management plan intends to mitigate the environmental impacts of ringnets by limiting catches, fishing effort and fishing areas. A precautionary approach was used to develop the proposed measures to regulate ringnet fishing activities, given the absence of detailed studies of the spatial dynamics of the fishery and/or the potential impacts of the gear on the environment. Our study implements an area-based risk assessment to (i) describe spatial patterns of fishing effort and catch distribution, and (ii) determine the likely environmental risks associated with ringnets in areas where ringnet fishing occurs.

Several methods have been proposed to assess the environmental risks of fishing. For example, Pitcher and Preikshot (2001) used a multidimensional assessment to assess the sustainability of fisheries, and Zhou

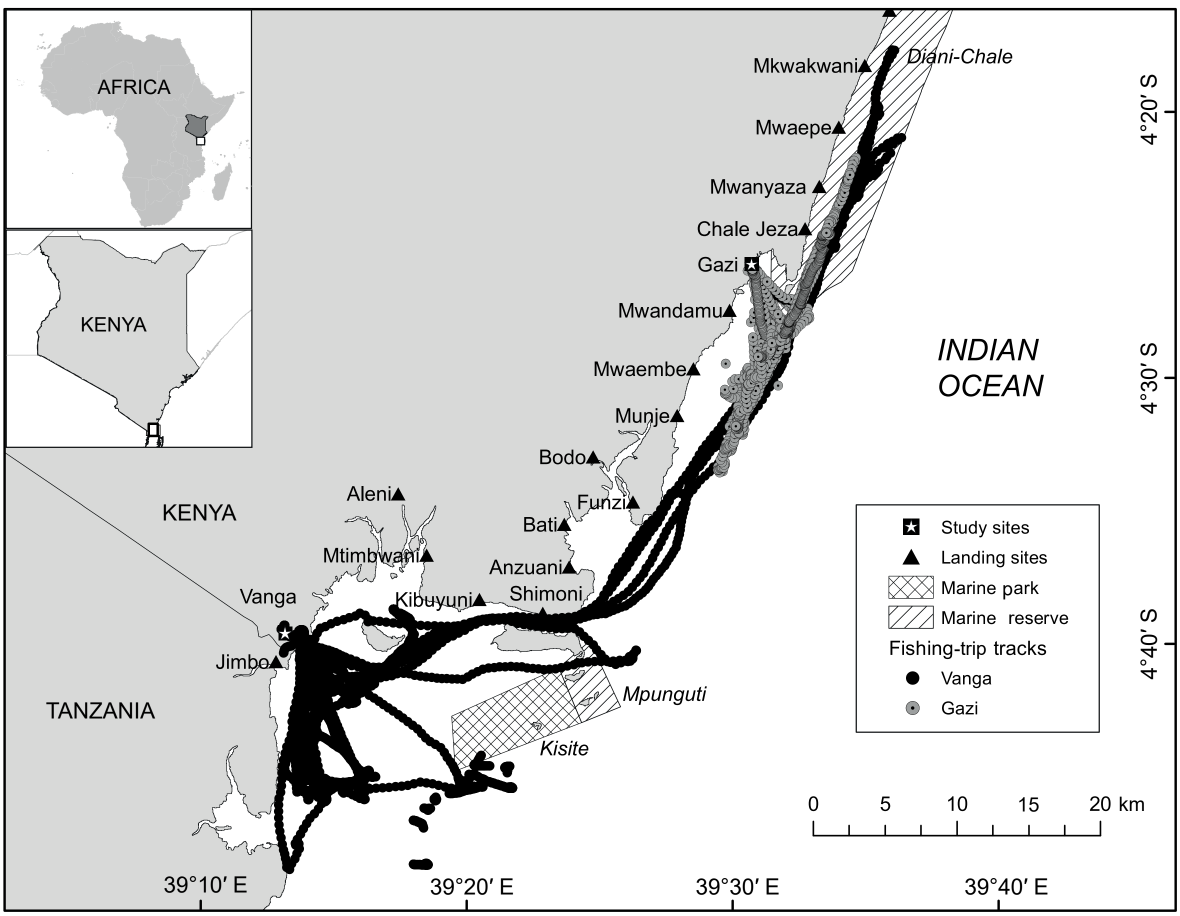

Figure 2: Map of the study area on the south coast of Kenya, showing the study sites, marine protected areas, main fish landing sites, and fishing-trip tracks where spatial data were collected

et al. (2016) used both qualitative and quantitative data to conduct a species-specific risk assessment. A key challenge identified in both of these methods is the incorporation of a spatial dimension, which is essential for integrating fisheries into marine spatial planning (MSP) (Janßen et al. 2018). Incorporating the use of geographic information systems (GIS) into this study enabled us to combine datasets on nearshore marine habitats, fisheries, MPAs and the distribution of sea turtles to conduct an environmental risk assessment of ringnet fishing along the Kenyan coast.

Methods

Study area

This study focused on the south coast area, from Gazi, near the southern border of the Diani-Chale Marine National Reserve, to Vanga, on the Kenya–Tanzania border (Figure 2). Fishing-trip tracks were conducted from both locations (i.e. Gaza and Vanga), which are of ecological and socio-economic significance owing to their proximity to critical habitats for marine megafauna such as sea turtles (Pérez-Jorge et al. 2017; Temple et al. 2018). Three MPAs in close proximity are located in the study area, making this coastal stretch important both for artisanal fishers, who benefit from spillover of resources from protected areas (McClanahan and Mangi 2000), and for tourism (Pérez-Jorge et al. 2017). Monsoon winds influence sea conditions seasonally in the area (McClanahan 1988). During the southeast monsoon (April–September), rough seas limit fishing activities and movement offshore, whereas the northeast monsoon (October–March) is characterised by conditions that allow fishers to navigate further offshore (Tuda et al. 2008). The study area has the highest concentration of ringnet fishers in Kenya (Government of Kenya 2012), most of whom originate from Tanzania (Fulanda et al. 2009; Wanyonyi et al. 2016).

Collection of catch and effort data

Studies on spatial allocation of fishing effort continue to be a challenge in developing countries which are dominated by artisanal fishers. Most fishing vessels do not have real-time

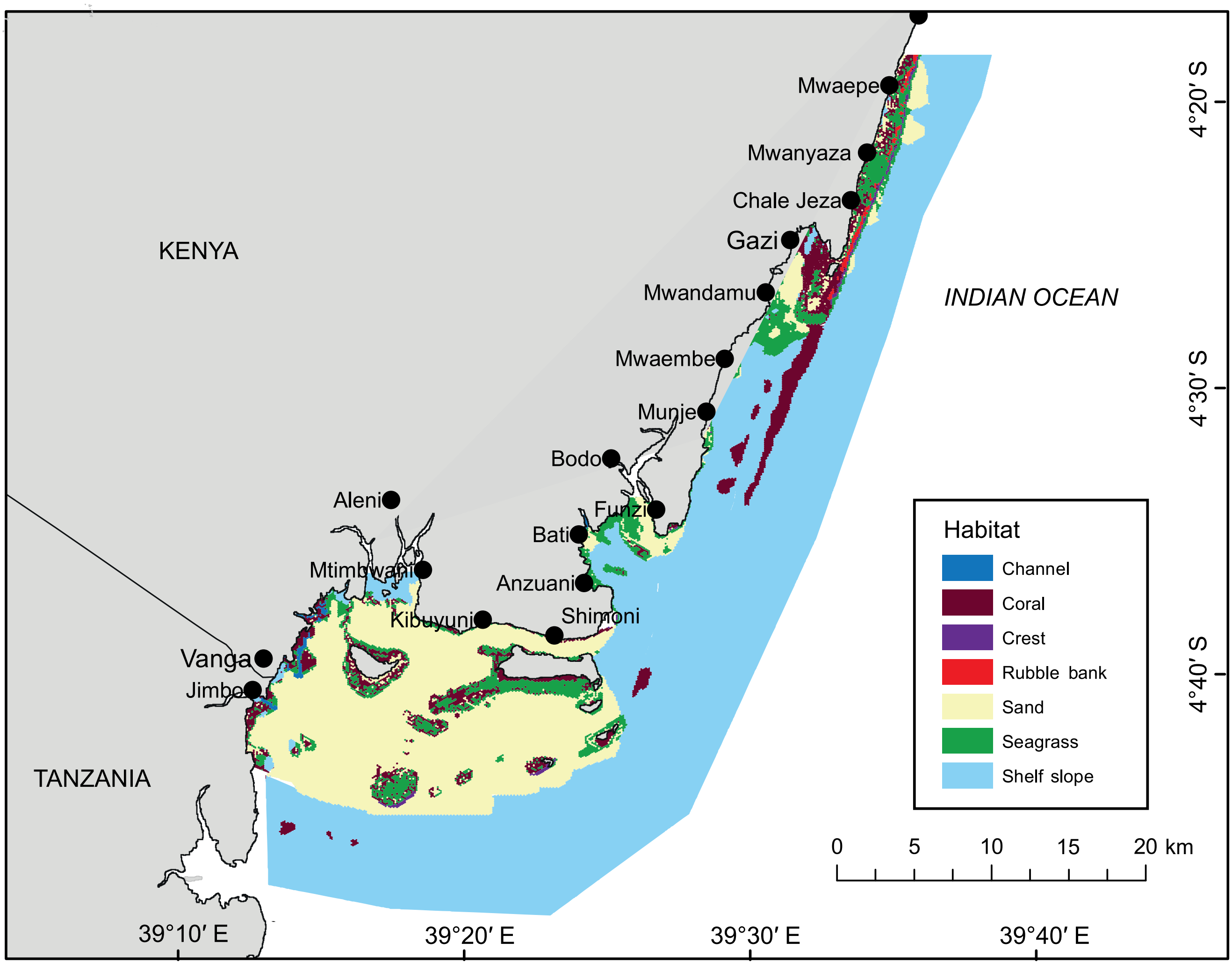

Figure 3: Habitat distribution in the study area on the south coast of Kenya, based on Maina et al. (2015) and UNEP-WCMC, WorldFish Centre, WRI, TNC (2010)

tracking devices, such as vessel monitoring systems (VMS) and transponders; hence, it is difficult to determine the spatial delineation of catch and effort, which is critical information needed for MSP and fisheries management. Several attempts have been made to map small-scale fishing effort along the Kenyan coast (e.g. Daw et al. 2011; Thoya and Daw 2019), using portable GPS devices supplied to artisanal fishers for use during fishing trips and complemented by logbooks used to record catches and trip details (Daw et al. 2011). For this study, observers from beach management units (BMUs) were recruited to collect data during fishing trips. BMUs are organisations comprising stakeholders who traditionally depend on fisheries activities for their livelihoods (e.g. fishers, fish traders, boat owners and fish processors) and are jointly responsible, with government, for the management of these activities under the co-management system of ocean governance (Oluoch and Obura 2008). We collected data from 89 fishing trips conducted from December 2015 to January 2016. Two observers boarded ringnet vessels during fishing trips from Gazi and Vanga. The observers were trained to use a GPS device and to record trip information in a logbook. Aboard the vessels, the observers set up the GPS devices to record the position every two minutes. The observers also recorded fishing data, such as catch quantity and species. Catch per unit effort per haul (CPUE, kg h^{-1}) was calculated by dividing the total catch by the number of hours fished.

To map fishing effort, a line was drawn between the start and end position of each haul. The lines were then overlaid on a grid of hexagonal cells with a minimum width of 500 m, and the cells crossed by each line were determined in ArcMap 10.5. With the assumption of constant speed during fishing activity, the fishing effort and catch for each grid cell were obtained by dividing the hours spent during each haul, and the amount of catch for each haul, by the number of grid cells fished during the haul, as suggested by Piet et al. (2007), Bastardie et al. (2010) and Hintzen et al. (2012).

Environmental risk assessment of ringnet fishing activities

The criteria for selecting risks associated with ringnet fishing were based on issues raised by stakeholders during meetings

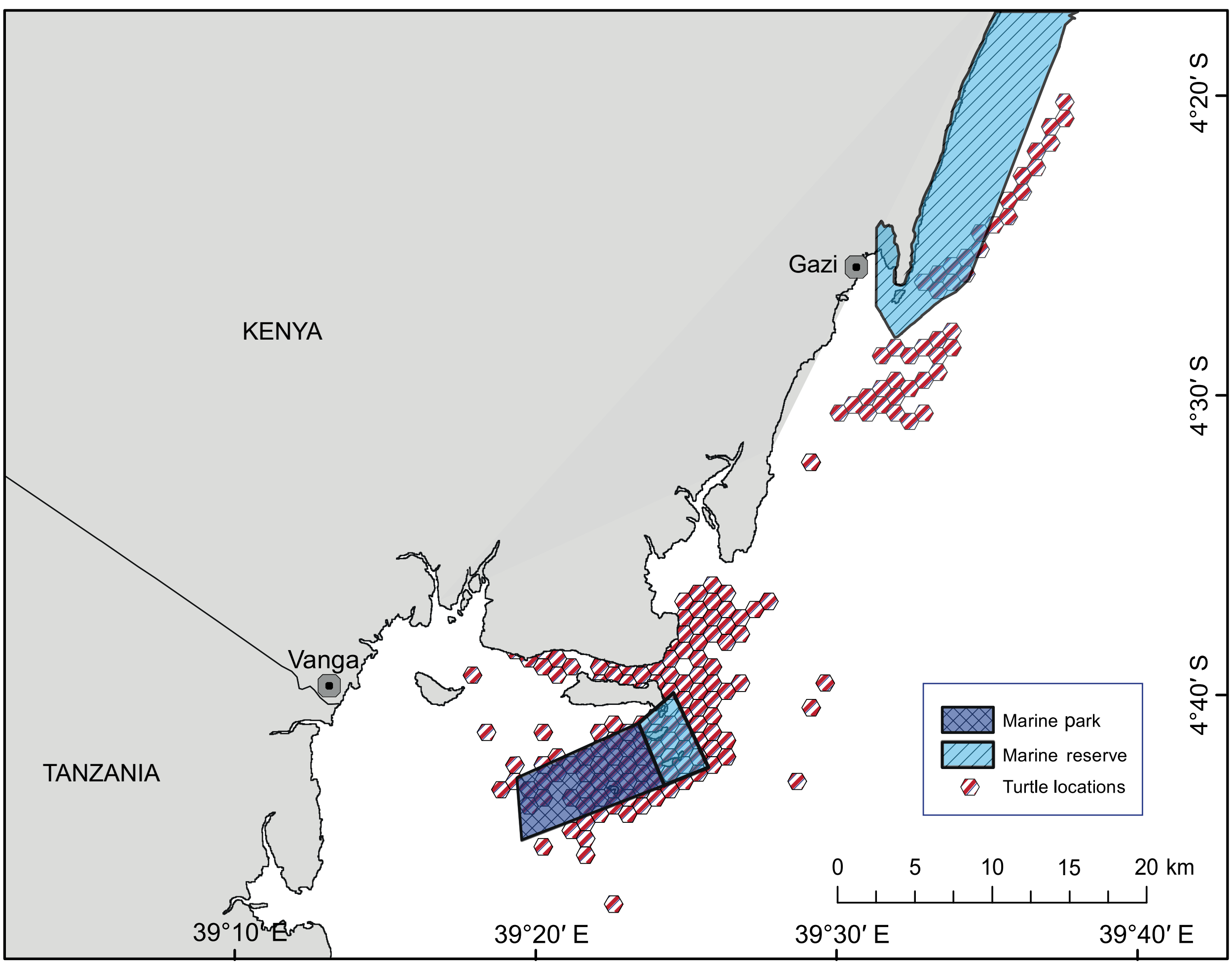

Figure 4: Gridded distribution maps of sea turtles off the south coast of Kenya, obtained from a combination of telemetry and sighting data, showing likely areas of interaction between sea turtles and the ringnet fishery (Source: KMFRI and GVI)

of the ringnet management plan development forum (for more information see Okemwa et al. [2017]). These risks included: (i) destruction of sensitive fish habitats; (ii) encroachment into marine reserves; (iii) capture of coral-reef fish; and (iv) capture of sea turtles. Our analysis focused on the interaction of ringnet fishing effort with sensitive habitats (coral), MPAs and endangered species (sea turtles).

We combined habitat maps developed by Maina et al. (2015) with maps of the global distribution of warm-water coral reefs (UNEP-WCMC, WorldFish Centre, WRI, TNC 2010) to characterise the habitat types within the fishing areas (Figure 3).

To address stakeholder concerns about the use of ringnets near MPAs, we analysed ringnet fishing effort in the proximity of MPAs. We calculated the distance from the centroid of each fishing-effort grid cell to each MPA. We also calculated the cumulative sum of fishing effort per grid cell at different distance intervals from the MPAs to obtain the spatial distribution of effort near MPAs.

We defined turtle hotspots within the study area as being areas where encounters with foraging or migrating sea turtles would be likely. Vessel-based surveys, carried out from January 2006 to December 2014, around the Kisite-Mpunguti MPA were used to identify turtle hotspots. A team of four observers conducted the surveys, which involved scanning the water surface within a 180° field of view during conditions of Beaufort sea state ≤3 and good visibility. Once sea turtles were sighted, the research vessel approached them to collect species-specific information (Pérez-Jorge et al. 2015, 2017). In addition, we obtained sea-turtle tagging data from the Southwest Indian Ocean Fisheries Project (Machaku et al. 2014). The tagging data consisted of spatial positions of two turtles tagged to monitor their foraging ground in the area (Machaku et al. 2014). We combined the survey and tagging data into grid cells of 500-m width to represent sea-turtle hotspots in the study area, as shown in Figure 4.

We used spatial multicriteria analysis (SMCA) to quantify the environmental risks associated with ringnet fishing. SMCA enables the combination of several spatial data layers to measure the attainment of conflicting goals or objectives (Malczewski 1999). The use of SMCA in fisheries management enables the combination of quantitative and qualitative information, and the weighing of criteria and indicators, while taking into account possible constraints (Andalecio 2010). Figure 5 shows a summary of the SMCA approach used.

Both qualitative and quantitative datasets were assigned values of either 0 or 1, where '0' denotes the absence of a feature and '1' its presence, to enable direct comparison of the attributes (Geneletti 2002; Andalecio 2010) (Table 1). Gridded ringnet fishing effort (h) was standardised to values of 0 to 1, with '1' being the highest effort and '0' being no effort, and with intermediate values for intermediate levels of effort. For threatened species, '0' and '1' represented the absence or presence of the species, respectively, whereas for critical habitats '0' and '1' represented the absence or presence of the habitat. For MPAs, '1' represented areas within a 1-km radius of the MPA, whereas '0' represented areas beyond the 1-km radius.

Weighting is a critical part of the SMCA process. In this study, we applied equal weights to all the criteria as they were considered of equal importance by stakeholders (Okemwa et al. 2017). Several methods are used in the aggregation of several indicators, such as the analytic

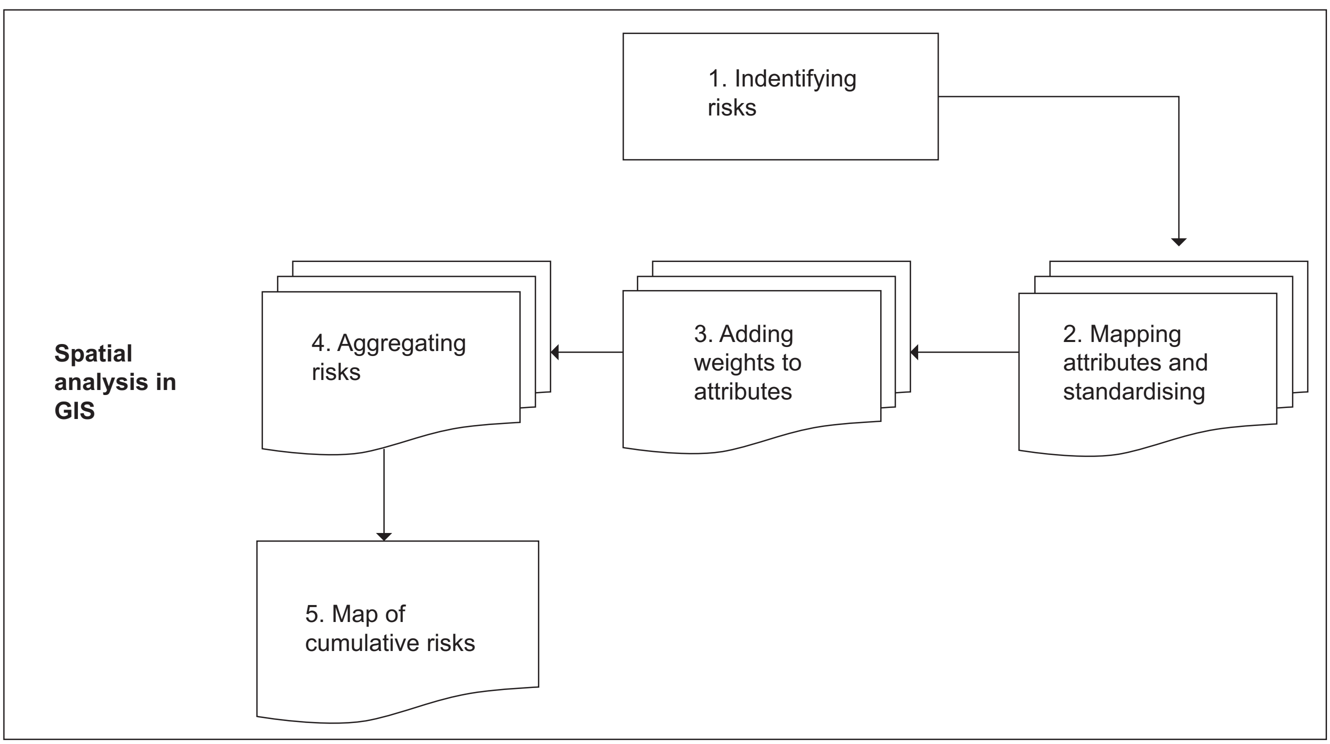

Figure 5: Model of the spatial multicriteria analysis approach to assess environmental risks associated with the ringnet fishery in Kenya

hierarchy process (AHP) and the weighted-sum model (also known as simple additive weightings), which we used. This method involves converting the criteria to the ordinal scale, adding weight to each criterion and summing the resulting scores to a total weighted score (Andalecio 2010; Hwang and Yoon 2012; Nijkamp et al. 2013). For the final risk map, we categorised the aggregated weighted sums into three categories of risk area: low (0–0.33), medium (0.34–0.66) and high (0.67–1).

Results

Ringnet fishing effort and catch distribution

Fishing effort was concentrated primarily within the 0–30 m depth range (Figure 6a). The CPUE increased gradually from shallow areas to the 21–30 m depth zone, and decreased beyond that (Figure 6b). The hotspot for CPUE was in the north of the study area, between Mwaepe and Gazi, which corresponded to an area with lower fishing effort (Figure 7a, b).

Potential environmental risks of ringnet fishing effort

Ringnet fishing effort varied among the different habitats, with most of the effort concentrated in the coral reef and seagrass habitat (56%) and sand habitat (36%) (Figure 6c). Highest catch rates were achieved in sand habitats, and the lowest in the rubble bank and crest habitats (Figure 6d).

The distribution of ringnet fishing effort suggested low effort near the boundaries of Kisite Marine Park (Figure 7a). Less than 5% of effort occurred between 0 and 1 km, 11% within 5 km, and 38% within 10 km of the park (Figure 8a). Seventeen percent of effort was concentrated inside marine reserves, 37% within 5 km, and 52% within 10 km (Figure 8b). The fishing effort near Kisite Marine Park was applied mainly by fishers from Vanga (Figure 2), whereas effort inside Diani-Chale Marine National Reserve was applied by fishers from both Vanga and Gazi. Unlike the Diani-Chale Marine National Reserve, where almost 17% of total fishing effort was

Table 1: Summary table of attributes and evaluation criteria used in a spatial multicriteria analysis of the environmental risks associated with the ringnet fishery on the south coast of Kenya

Attribute	Layer	Criteria for low risk	Criteria for high risk
Ringnet fishing effort	Gridded ringnet fishing effort	Low fishing effort	High fishing effort
Critical habitat	Gridded habitat type	Overlap with low fishing effort	Overlap with high fishing effort
Threatened, endangered and protected species (TEP species)	TEP species distribution map	Overlap with low fishing effort	Overlap with high fishing effort
Marine protected areas	Proximity to marine protected areas	Overlap with low fishing effort	Overlap with high fishing effort

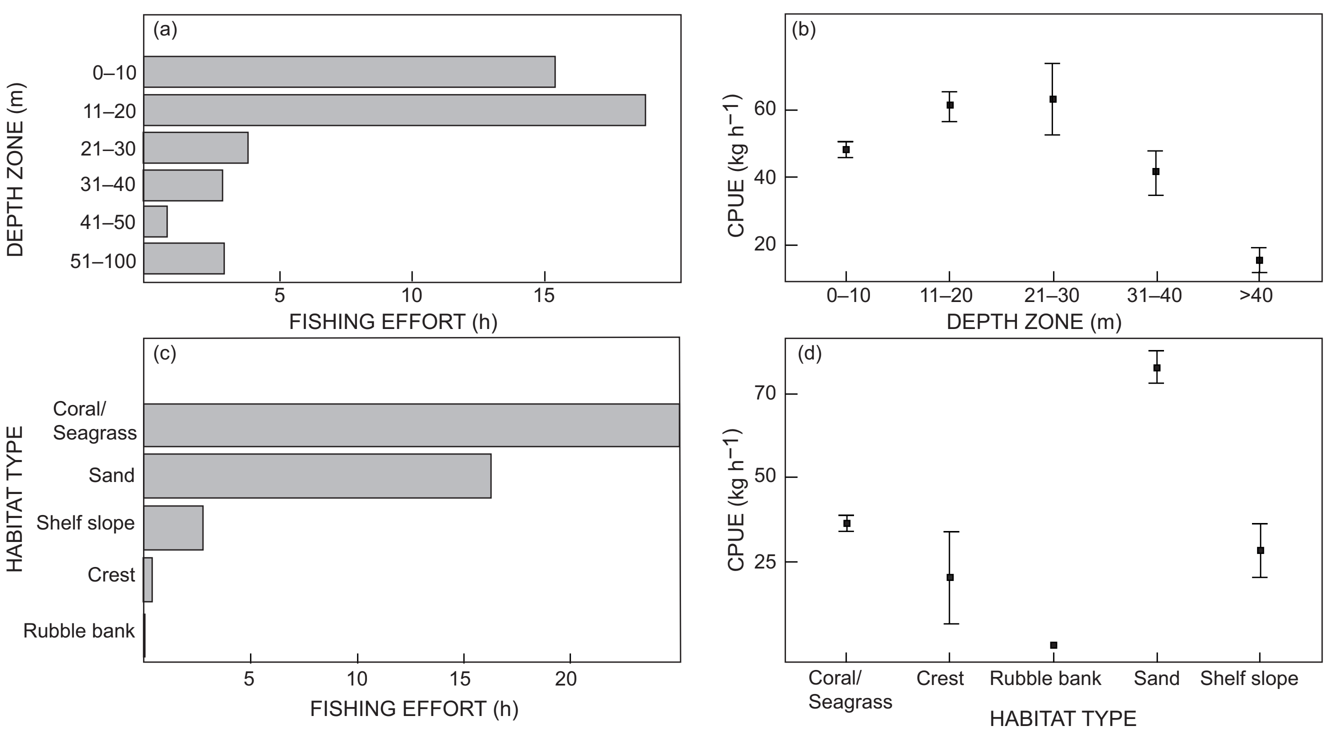

Figure 6: Distribution of (a, c) fishing effort by depth zone and habitat type, and (b, d) catch per unit effort (CPUE) by depth and habitat type, in the ringnet fishery on the south coast of Kenya

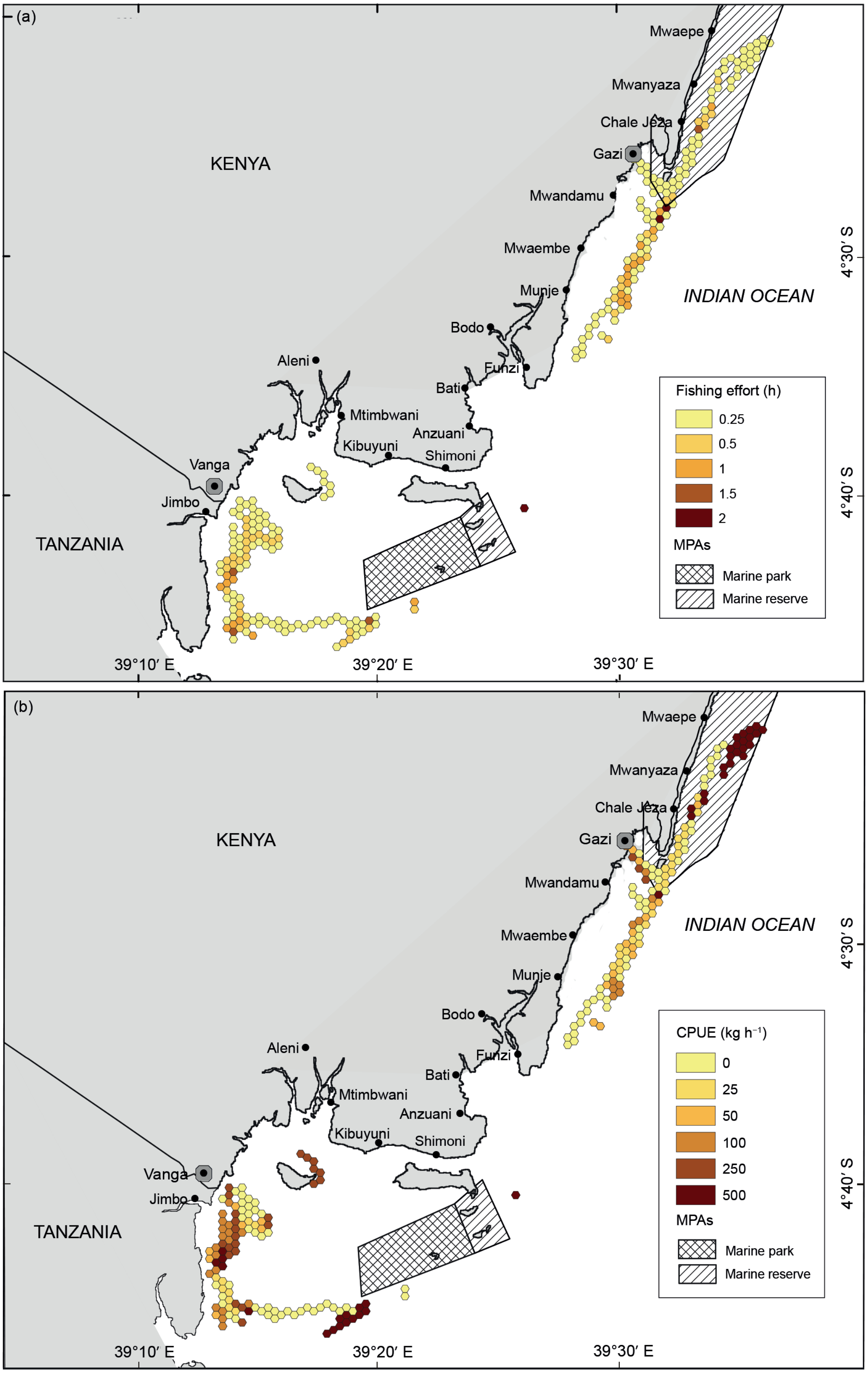

Figure 7: Grid-based maps (500-m-minimum-width hexagons) showing the distribution of (a) fishing effort, and (b) catch per unit effort (CPUE), in the ringnet fishery on the south coast of Kenya

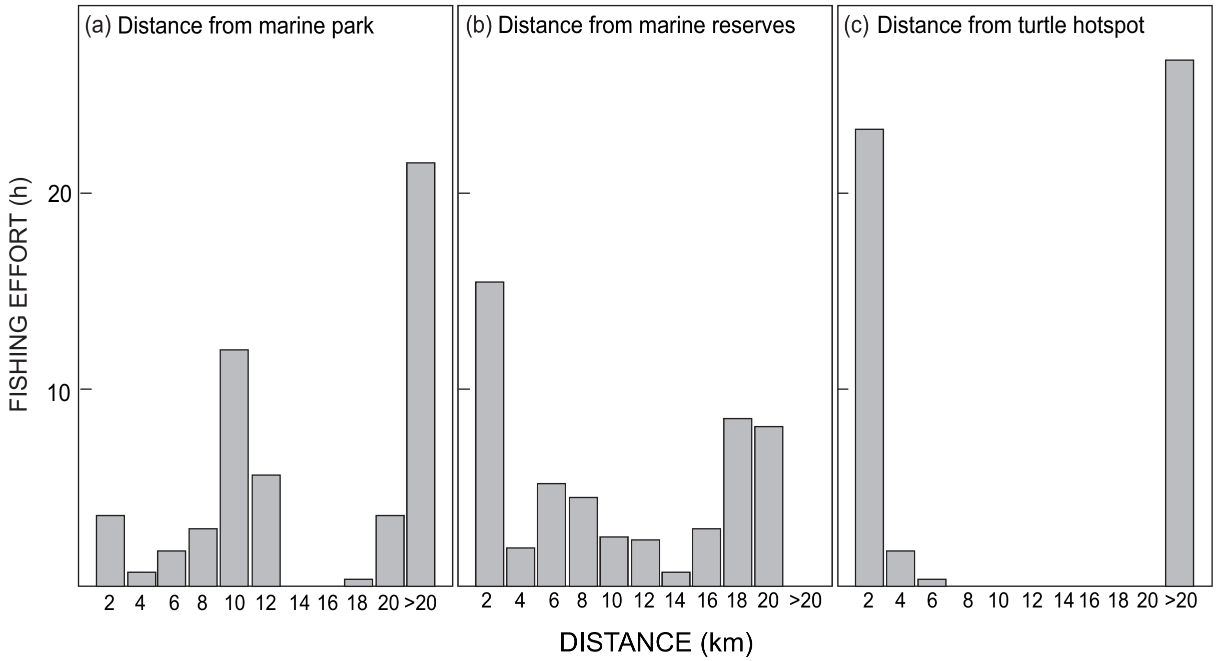

Figure 8: Distribution of fishing effort by ringnet fishers around (a) Kisite Marine Park, (b) marine reserves, and (c) sea turtle hotspots on the south coast of Kenya

observed, there were no fishing activities in the Mpunguti Marine Reserve (Figures 2, 7a). Twenty-one percent of fishing effort occurred in the area with a high probability of encountering sea turtles. Fifty-seven percent of the ringnet fishing effort was concentrated in an area within a 2-km radius of sea-turtle hotspots (Figure 8c).

The study area was categorised as a primarily medium-risk area in terms of cumulative potential impacts of ringnet fishing, other than in the vicinity of Gazi, where high-risk areas were identified (Figure 9). Most of the MPAs also fell within the medium-risk category, although a small area of the Diani-Chale Marine Reserve was categorised as a high-risk area. Areas farther offshore were mostly categorised as low-risk.

Discussion

This study utilised a participatory approach to map fishing effort and combined it with environmental datasets to determine the potential impacts of ringnet-fishing on nearshore marine ecosystems along the Kenyan south coast. The ability to combine spatial data on fishing effort, habitats and endangered species using the SMCA method provided an opportunity to categorise the area according to the level of current threats. This approach can help guide management efforts by identifying one or more key locations where management action can be concentrated.

Ringnet fishing forms a large component of local fisheries, and management of the gear is needed. Some parts of the study area were categorised as high-risk, indicating that the gear might have some negative ecological impact in those parts and that management intervention might be required.

The results indicate a strong influence of habitat type and bathymetric profile on the distribution of ringnet fishing effort, with distribution restricted to a narrow area suitable for fishing. The high concentration of effort in nearshore coral-reef and seagrass areas can be interpreted similarly to the findings of other studies where fishing effort is dependent on factors that help to maximise profits, such as fuel costs (Cabrera and Defeo 2001; Bastardie et al. 2013), as well as safety. However, the observed uneven distribution of fishing effort and catches reflects the patchiness of suitable fishing grounds in the study area. Locations with higher catches corresponded to low fishing effort. This differed from similar studies elsewhere, such as those of MacArthur and Pianka (1966) and Stephens and Krebs (1986), where effort was focused in locations with the highest expected harvest. Hence, our study suggests that high catch might not be the only factor influencing the choice of fishing ground by ringnet fishers. The fishing operation includes the use of SCUBA divers to locate schooling fish and guide them towards the net (Okemwa et al. 2017). This process is complicated and dangerous; thus, fishers might prioritise their safety over fishing in deeper, more productive areas, especially when sea conditions are not suitable for the divers (Abernethy et al. 2007).

The low fishing effort in the vicinity of Kisite Marine Park might be influenced by the high surveillance effort of the Kenya Wildlife Services (KWS), resulting in high compliance (Maina et al. 2015). However, the high ringnet fishing effort within the Diani-Chale Marine National Reserve is a concern. According to the Wildlife Conservation and Management Act (2013) (http://kenyalaw.org), only subsistence fishing is permitted in a marine reserve.

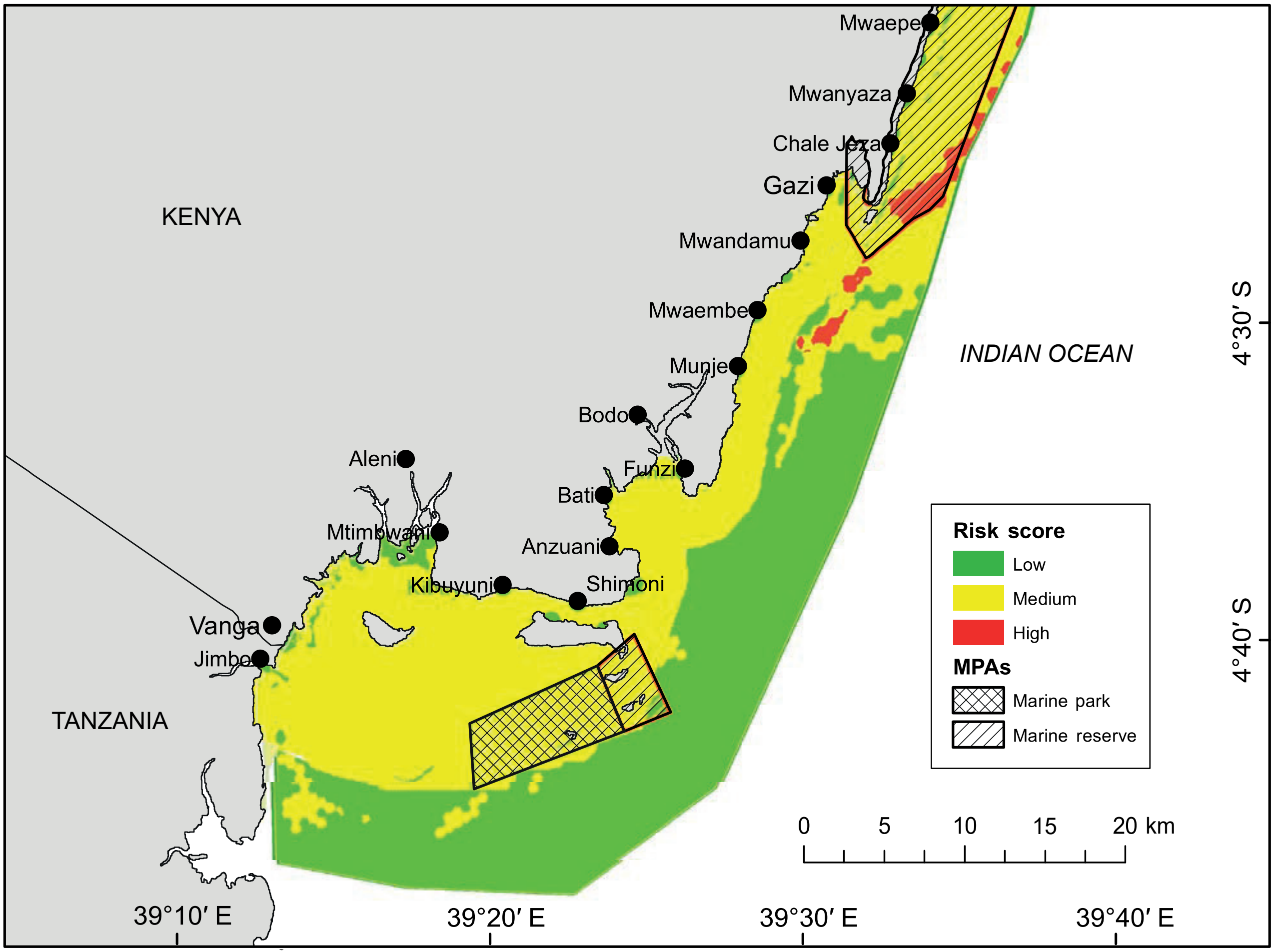

Figure 9: Map depicting results of the analysis of cumulative environmental risks associated with ringnet fishing activities on the south coast of Kenya

This study has demonstrated the use of integrated spatial datasets on sea-turtle distribution to determine possible areas of interactions with ringnet fishing operations, and has identified high-risk areas where management interventions are needed to reduce interactions.

Bycatch of long-lived marine megafauna such as sea turtles poses a major ecosystem challenge worldwide (Lewison et al. 2004). Spatial data pertaining to marine megafauna help to determine possible areas of interactions between ringnet fishing operations and protected species, and to identify locations where management interventions are needed to reduce bycatch. Most of the locations where there was a possibility of interaction between sea turtles and ringnet fishing were ranked as high-risk areas. It should be noted that our model gave a cumulative scenario of total fishing effort and occurrence of sea turtles, whereas both ringnet fishing effort and the occurrence of sea turtles are seasonal, and a dynamic management framework in both space and time should be implemented, which was beyond the scope of our study.

Conclusions

This study provides information that can inform some aspects of the management plan that is under consideration for the ringnet fishery, such as zonation of the fishing area. The study combined gridded fishing-effort data with satellite-derived data pertaining to habitat type, the location of MPAs and spatial data on threatened species, using an SMCA approach to assess environmental risks. New insights are provided into factors that influence the distribution of ringnet fishing effort in the study area, mostly being habitat type and depth. We recommend that further studies be undertaken into the direct impacts of ringnet fishing and the socio-economic drivers of the fishery. We also recommend that management measures be developed that take into account the spatial dynamics of fishing effort, which will enhance the conservation of sensitive habitats and endangered marine megafauna.

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