ORIGINAL RESEARCH

Status and characteristics of sharks and rays impacted by artisanal fisheries: potential implications for management and conservation

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ABSTRACT. Artisanal fisheries in Kenya face substantial challenges, including inadequate enforcement, absence of tailored regulations for elasmobranch conservation and lack of robust data collection systems, hampering our understanding of fisheries and biological aspects of species. To address these challenges, this study examined the species composition, size, weight and number of shark and ray landings in three sites historically known for large catches of elasmobranchs. This research aimed to characterise Kenyan elasmobranchs fishery and exhibit its overlap with key habitats. Our findings are worrying since 79% of the landed fisheries species are categorised as threatened on the IUCN Red List. This includes the Critically Endangered scalloped hammerhead shark (*Sphyrna lewini*) and white-spotted guitarfish (*Rhynchobatus djiddensis*), both species frequently caught. Further, 97% of sharks and 46% of rays are landed as neonate and immature individuals. Urgent changes are imperative in national fisheries management to prevent the potential local disappearance of several shark and ray species. We recommend specific conservation measures to reduce the capture of threatened species and juveniles, such as banning the landing of threatened species and establishing minimum size limits. Enforcing fisheries regulations, such as mesh size, and prioritizing the protection of key habitats for the most at-risk species are essential proactive steps.

Key words: Artisanal fisheries management, threatened species, juvenile capture, conservation.

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Estado y características de los tiburones y rayas impactados por la pesca artesanal: potenciales implicancias para el manejo y la conservación

RESUMEN. La pesca artesanal en Kenia enfrenta desafíos sustanciales, incluida una aplicación inadecuada, la ausencia de regulaciones adaptadas para la conservación de los elasmobranquios y la falta de sistemas sólidos de recopilación de datos, lo que dificulta la comprensión de las pesquerías y los aspectos biológicos de las especies. Para abordar estos desafíos, nuestro estudio examinó la composición de especies, el tamaño, el peso y el número de desembarques de tiburones y rayas en tres sitios históricamente conocidos por sus altas capturas de elasmobranquios. La investigación tuvo como objetivo caracterizar la pesquería de elasmobranquios de Kenia y exhibir su superposición con los hábitats clave. Los hallazgos son preocupantes, ya que 79% de las especies pesqueras desembarcadas están clasificadas como amenazadas en la Lista Roja de la UICN. Esto incluye al tiburón martillo festoneado (*Sphyrna lewini*) en peligro crítico de extinción, y al pez guitarra de manchas blancas (*Rhynchobatus djiddensis*), ambas especies capturadas con frecuencia. Además, 97% de los tiburones y 46% de las rayas son desembarcados como individuos neonatos e inmaduros. Son imperativos los cambios urgentes en la gestión pesquera nacional para prevenir la posible desaparición local de varias especies de tiburones y rayas. Recomendamos medidas de conservación específicas para reducir la captura de los juveniles de las especies amenazadas, tales como prohibir el desembarco de especies amenazadas y establecer límites de tamaño mínimo. Hacer cumplir las regulaciones pesqueras, como el tamaño de la malla, y priorizar la protección de los hábitats de las especies en mayor riesgo son pasos proactivos esenciales.

Palabras clave: Manejo de pesquerías artesanales, especies amenazadas, captura de juveniles, conservación.

INTRODUCTION

Sharks and rays (Subclass Elasmobranchii which also includes skates and sawfishes) are highly susceptible to overfishing due to their unique biological traits, including slow growth, late maturity and low reproductive rates resulting in slow population recovery (Dulvy et al. 2014). Over one-third of elasmobranch species globally are now threatened with extinction due to overfishing (Dulvy et al. 2021). The loss of elasmobranchs has far-reaching implications for marine ecosystems as these species play a pivotal role in maintaining the delicate balance of marine communities and regulating the biomass of lower trophic taxa (Roff et al. 2016). The viability of fishing elasmobranchs is now a topic of debate necessitating urgent conservation efforts (MacNeil et al. 2020; Simpfendorfer et al. 2023).

Elasmobranchs hold significant global importance providing a vital protein source and income to people (Davidson et al. 2016). Particularly, in Kenya, elasmobranchs have long been valuable resources as food and income for coastal communities, with artisanal fisheries playing a significant role in the local economy (Samoilys and Kanyange 2008; Oddenyo et al. 2019). In Kenya, elasmobranchs are intentionally targeted for their meat and fins and incidentally caught during fishing operations targeting other species (Samoilys et al. 2011; Kiszka 2012). As a consequence of this, the sustainability of elasmobranch fisheries in Kenya faces various threats with awareness of this situation recently addressed in the National Plan of Action (NPOA) on sharks and rays (SDBEF 2023).

Kenyan artisanal fisheries employ various vessels such as dugout and motorised boats, and fishing gears such as gillnets, longlines and handlines, which often result in the unintentional capture of elasmobranchs (Samoilys et al. 2011; Wambiji et al. 2022). Furthermore, small commercial prawn trawl fisheries in the Malindi-Ungwana Bay also contribute to a significant bycatch of elasmobranch species (Munga et al. 2016). Exploitation of threatened shark species, including those classified as Vulnerable Endangered or Critically Endangered by the IUCN Red List of Threatened Species has been reported (Kiilu et al. 2019; Wambiji et al. 2022). Many reef shark populations, particularly in East Africa, are now classified as severely depleted or 'functionally extinct', making them unable to withstand any further fishing pressure (MacNeil et al. 2020).

Additionally, artisanal fisheries in Kenya suffer from inadequate enforcement and lack of regulations for protecting elasmobranch populations. One significant challenge is the frequent under-reporting of elasmobranch catches, which complicates accurate assessments of species stock status and hinders the implementation of effective conservation measures (Bennett et al. 2022). Insufficient fisheries data collection systems further contribute to the lack of information on elasmobranchs as well as limited knowledge of critical biological details such as size and age at maturity, and location of nursery grounds.

To address these issues, we not only conducted a snapshot study on catch landings of shark and ray species in Kenyan artisanal fisheries but also reviewed existing shark and ray information to propose recommendations for the management of fisheries to ensure the long-term survival of these species. The study aimed to characterise Kenyan elasmobranchs fishery and showcase its overlap with key habitats. The study consisted of assessing fisher behaviour, vessels and gears used to target sharks, species composition and catch rates. The research focused on three landing sites, namely Kipini, Ngomeni and Shimoni, which have previously been identified as having high proportions of elasmobranchs based on historical catch data (Oddenyo et al. 2019).

MATERIALS AND METHODS

Study area

Catch landing surveys were carried out at three landing sites, Kipini, Ngomeni and Shimoni (Oddenyo et al. 2019) (Figure 1). Kipini, located at the mouth of Tana River, is a small coastal village

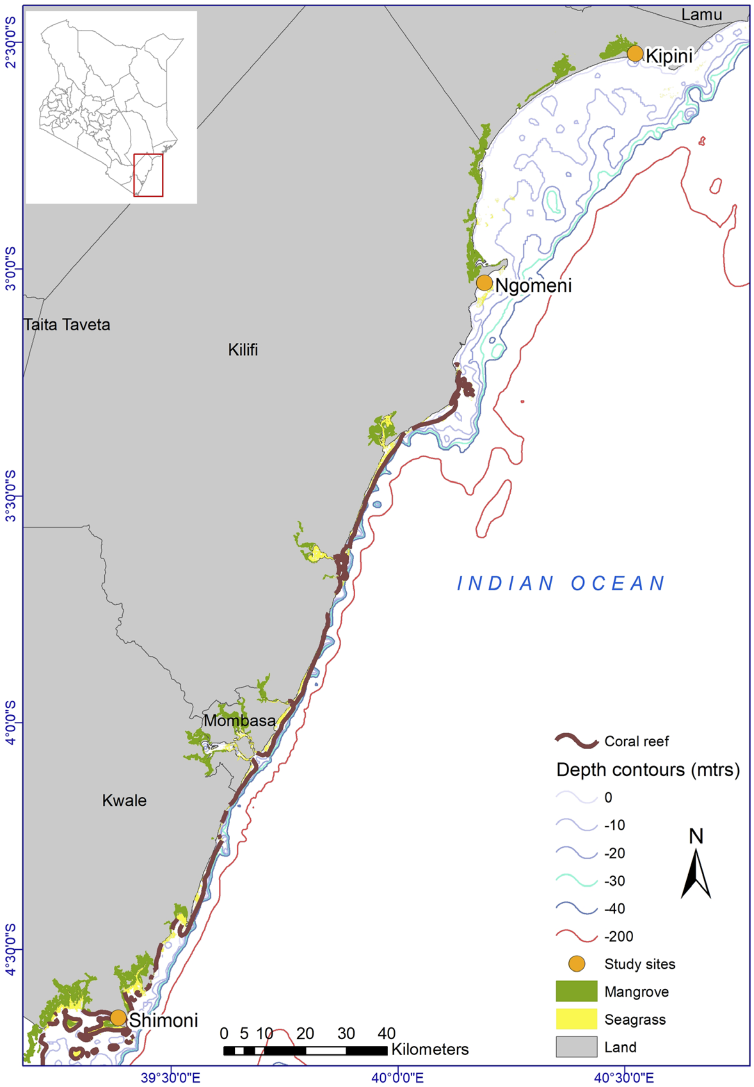

Figure 1. Selected shark and ray (elasmobranchs) landing sites with the adjacent habitats along the Kenyan Coast.

known for its rich mangrove forest. This critical habitat supports diverse marine species. Ngomeni is a traditional fishing village with a long history of artisanal fishing practices situated in the larger Malindi-Ungwana Bay. Shimoni is in the southern coast of Kenya, near the border with Tanzania. It is renowned for its historical and ecological significance, being close to the Wasini Island and Kisite-Mpunguti Marine National Park.

Landing surveys

Data were collected simultaneously in all three landing sites 10 days per month covering neap tides (5 days) and spring tides (5 days) over an 8-month period from May to December 2018. Data collection was conducted monthly because shorter time periods were unlikely to produce reliable estimates (Harley et al. 2001). Data on landed catches were collected in collaboration with three Beach Management Units (BMUs) members from landing sites who had been trained in shark and ray species identification and catch and effort monitoring. Under the Fisheries Regulations 2007, Beach Management Units (BMUs) are defined as community management structures established to manage and govern specific marine and coastal areas in a sustainable and participatory manner. Trained data collectors were provided with pocket shark identification cards to help them in species identification. They were also provided with smartphones to take photos of species requiring further verification; otherwise, species would be identified using field-guides (e.g. Compagno 1984; Anam and Mostarda 2012).

The survey started by asking fishers whether they targeted elasmobranchs during their fishing trip, as well as when they last caught elasmobranchs. Data collectors then noted information on fishing trips including departure and return times, vessel type, propulsion mode, crew size, gear used and fishing location. This was followed by recording weight (W) and total length (TL) of sharks or disc width (DW) of rays with a precision of ± 100 g and ± 0.1 cm, respectively. Total length was measured from the snout to a point on the horizontal axis, in line with a vertical line extending downward from the upper caudal lobe, while DW was measured as the distance across the widest part of the ray disc. Sex of the sampled fish was recorded based on the presence (male) or absence (female) of claspers, and unsexed/unknown when it was not possible to categorize. The landed elasmobranch species were classified based on their IUCN Red List Status (IUCN 2023), and the percentage distribution of threatened species determined. Threatened species included those listed as Critically Endangered (CR), Endangered (EN), or Vulnerable (VU).

Data analysis

Data from the three landing sites were pooled together to evaluate the dynamics of artisanal elasmobranchs fisheries. Percentages were used to present the behaviour of fishers (whether purposively targeting elasmobranchs) and catch frequency (when fisher(s) last caught an elasmobranch) during the fishing trip.

The length at first maturity (L_m) for each species was obtained from FishBase (Froese and Pauly 2023). This information was used to determine the proportion of juvenile captured in artisanal fisheries. Fish with length less than L_m were classified as juveniles, while those with length equal to or greater than L_m were classified as adults.

The relative abundance and biomass of elasmobranch species in landings were examined using data from all fishing gears and landing sites. The SIMPER (Similarity Percentage) analysis was conducted to assess the dissimilarity in shark and ray abundance and biomass across different fishing gears. The analysis provided insights into which shark and ray species contributed the most to the dissimilarity between gear types. Length/disc size analysis was limited to numerically abundant species ($n > 29$ individuals).

The catch per unit effort (CPUE) was calculated for all three sites combined by dividing the total catch for each gear by the number of fishers on the vessel. The Kruskal-Wallis test was performed to assess sex differences and CPUE variations among gears, followed by Mann-Whitney *post-hoc* test for pairwise comparisons. The analyses were performed using the PAST software ver. 4.03 (Hammer and Harper 2001) and R Statistical Software (v4.1.2; R Core Team 2021).

RESULTS

Species composition

Nineteen elasmobranch species were documented in artisanal landings, including eight sharks, nine rays, and two guitarfish (Table 1). One ray species remained unidentified. The species varied in terms of their sex, conservation status and size, with mean lengths for sharks ranging from 55.2 ± 32.4 cm TL in *Carcharhinus melanopterus* to 88.7 ± 8.7 cm TL in *C. sorrah* (Table 1). Mean lengths for rays ranged from 40.2 ± 12.1 cm DW in *Neotrygon caeruleopunctata* to 132.6 ± 99.9 cm DW in *Mobula mobular* (Table 1). Among these, 828 elasmobranch individuals were recorded, with sharks being the dominant group comprising 78% (n = 642) of the total number of landed individuals, while rays and guitarfishes constituted 22% (n = 186).

The composition of elasmobranchs catches was dominated by a few species. Carcharhinidae was the most abundant family, accounting for 46% (n = 384) of the total catch by numbers, while Sphyrnidae and Dasyatidae contributed 31% (n = 258) and 12% (n = 99) of the total catch, respectively. Seven elasmobranch species accounted for over 80% (n = 662) of the landed individuals: sharks *Sphyrna lewini*, *C. falciformis*, *C. amblyrhynchos*, *C. leucas*; rays and guitarfish *Aetobatus ocellatus*, *Rhynchobatus djiddensis* and *Taeniura lymma* (Figure 2).

Relative species abundance varied among elasmobranchs in the artisanal landings. *S. lewini* was the most frequently landed shark species by number, constituting 39% (n = 253) of the total shark catch. In contrast, *Squatina africana* and *Rhincodon typus* were the least abundant shark species in terms of numbers jointly contributing 1% (n = 7) (Figure 2). Among rays, *A. ocellatus* dominated, making up 26% (n = 49) of the total ray landings by number. While *M. mobular* was captured in relatively low numbers (4%, n = 7), other dominant ray species included *T. lymma* (15%, n = 28), *N. caeruleopunctata* (14%, n = 26), and *Himantura uarnak* (11%, n = 20). The guitarfish category was represented solely by *R. dijiddensis* and *Rhina anclystoma*, contributing a combined 21% (n = 39) by number.

Combined artisanal landings amounted to 4,007 kg, with rays and guitarfish contributing 61% (2,430 kg) of the total fish biomass, and sharks accounting for 39% (1,576 kg). *Sphyrna lewini* and *A. ocellatus* remained the dominant species, accounting for 37% (579 kg) and 26% (663 kg) of the total shark and ray landings by weight, respectively. *Mobula mobular* contributed substantially to the landed biomass, representing 20% (498 kg) by weight. *Rhynchobatus dijiddensis* and *R. anclystoma*, together contributed 11% (270 kg) by weight.

The majority (97%, n = 642) of sharks and 46% (n = 186) of rays and guitarfish were juveniles. The four most landed sharks (*S. lewini*, *C. falciformis*, *C. amblyrhynchos*, and *C. leucas*) were almost entirely captured as juveniles (Figure 3 A-D), while one guitar fish *R. dijiddensis* and one ray *A. ocellatus* were all caught as juveniles (Figure 3 F and G).

Sex ratios across all shark and ray species were not significantly different (Mann-Whitney U = 211, p = 0.775). In terms of individual species, female sharks comprised 57% (n = 357) of the shark landings with percentages for specific shark species as: *S. lewini* (58%), *C. amblyrhynchos* (62%), *C. falciformis* (56%), *C. leucas* (54%), and *C. melanopterus* (60%) (Figure 3; supplementary material, Figure S1). Similarly, female rays accounted for 57% (n = 53) of the ray landings, although the sex of most ray individuals remained unknown (Figure 3).

Table 1. Abundance and sex distribution of elasmobranch species by family and IUCN Red-list status. The table displays the number of individuals (n) for each species, followed by the breakdown of individuals by sex (females [F], males [M] and unsexed/unknown [U]) where available. EN: Endangered, VU: Vulnerable, NT: Near Threatened, CR: Critically Endangered. LC: Least Concern, DD: Data Deficient, NT: Near Threatened, EN: Endangered.

Family	Scientific name	Common name	n	Sex	IUCN status	Total length mean ± sd (cm)
Carcharhinidae	*Carcharhinus amblyrhynchos*	Grey reef shark	110	F = 63, M = 39, U = 8	EN	56.3 ± 22.5
	Carcharhinus falciformis	Silky shark	163	F = 91, M = 72	VU	75.8 ± 8.2
	Carcharhinus leucas	Bull shark	77	F = 41, M = 35, U = 1	VU	81.3 ± 19.4
	Carcharhinus melanopterus	Blacktip reef shark	29	F = 11, M = 8	VU	55.2 ± 32.4
	Carcharhinus sorrah	Spot-tail shark	8	F = 3, M = 5	NT	88.7 ± 8.7
Sphyrnidae	*Sphyrna lewini*	Scalloped hammerhead shark	253	F = 143, M = 105, U = 5	CR	58.3 ± 15.8
Rhincodontidae	*Rhincodon typus*	Whale shark	4	F = 1, M = 3	EN	56.8 ± 15.8
Aetobatidae	*Aetobatus ocellatus*	Whitespotted eagle ray	30	F = 16, M = 11, U = 3	VU	68.8 ± 24.0
Dasyatidae	*Himantura uarnak*	Honeycomb stingray	20	F = 11, M = 3, U = 6	EN	65.3 ± 28.3
	Taeniura lymma	Bluespotted ribbontail ray	43	F = 4, M = 2, U = 22	LC	47.3 ± 20.0
	Taeniurops meyeni	Round ribbontail ray	6	F = 1, M = 2, U = 3	VU	107.6 ± 60.7
	Neotrygon caeruleopunctata	Bluespotted stingray	29	F = 3, M = 9, U = 17	DD	40.2 ± 12.1
Myliobatidae	*Mobula mobular*	Giant devil ray	7	F = 3, M = 3, U = 1	EN	132.6 ± 99.9
	Myliobatis aquila	Common eagle ray	5	F = 1, M = 4	CR	49.7 ± 18.3
	Rhinoptera javanica	Flapnose ray	1	U = 1	EN	120
Pristidae	*Pristis* spp.	Sawfish	1	F = 1	CR	110
Rhinidae	*Rhina ancylostoma*	Bowmouth guitarfish	2	M = 2	CR	68.0 ± 8.5
	Rhynchobatus djiddensis	Giant guitarfish	37	F = 9, M = 4, U = 24	CR	70.7 ± 26.6
Squatinidae	*Squatina africana*	African angelshark	3	F = 3, M = 0	NT	69.8 ± 4.9

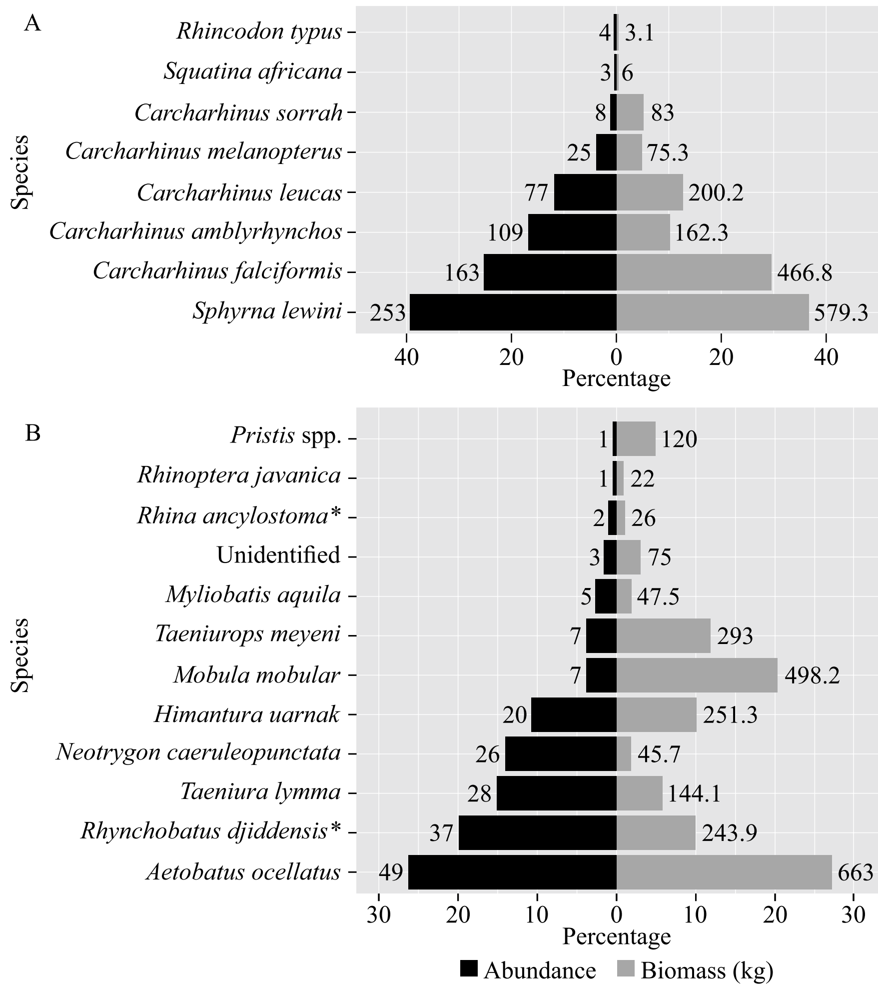

Figure 2. Relative abundance and biomass of sharks (A) and rays and guitarfish (B) captured using six artisanal fishing gear types. Figures display data on counts and weights. Asterisks indicate guitarfish.

The majority (78.9%, n = 15) of the landed species were classified as threatened species based on the IUCN Red List, with five each of Critically Endangered (CR), Endangered (EN), and Vulnerable (VU) species (Figure 4; Table 1).

Characterization of the artisanal elasmobranchs fishery

A total of 226 fishing trips done between May and December 2018 were recorded at the three selected sites (Ngomeni n = 107, Kipini n = 63, Shimoni n = 56). The survey revealed that 19.9% (n = 45) of the fishing trips were purposively targeting elasmobranchs, while 80.1% (n = 181) targeted all fish including elasmobranchs. Among trips purposively targeting elasmobranchs, catch reporting varied from 24.4% for those who caught them a week before to 42.2% for fishers catching elasmobranchs on the same day of the survey (Table 2). A small percentage (4.4%) did not provide a response. Conversely, trips targeting all fish had lower percentages of elasmobranchs caught on the same day (1.7%), compared to those who caught

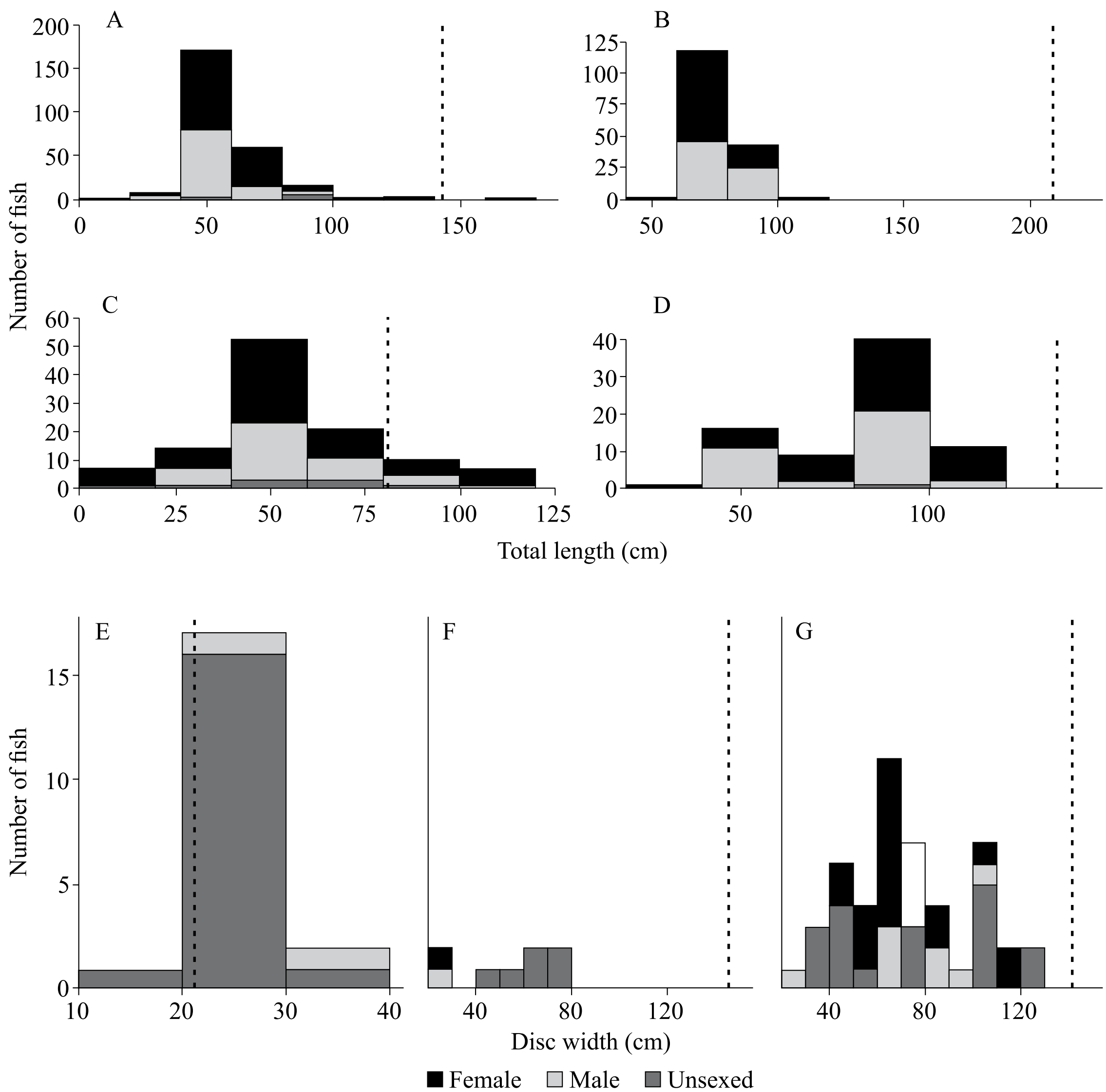

Figure 3. Size distribution of seven most recorded elasmobranch species by sex (female, male, and unsexed). The dashed line indicates the size-at-maturity. Sharks *Sphyrna lewini* (Linf = 307.5 cm) (A), *Carcharhinus falciformis* (Linf = 468.0 cm) (B), *Carcharhinus amblyrhynchos* (Linf = 163.0 cm) (C) and *Carcharhinus leucas* (Linf = 285.0 cm) (D). Rays *Taeniura lymma* (Linf = 36.6 cm) (E), *Rhynchobatus djiddensis* (Linf = 313.1 cm) (F) and *Aetobatus ocellatus* (Linf = 303.2 cm) (G).

them last week (37.0%), with 13.8% not providing an answer. Fishers targeting elasmobranchs reported no catches in the last week, last month, or three months ago time periods. In contrast, trips targeting all fish resulted in catches in those respective time frames (Table 2).

Elasmobranchs were captured using five artisanal fishing gears: gillnets, monofilament gillnets, handlines, longlines, and spearguns (supplementary material, Table S1). Gillnets and monofilaments had mesh sizes ranging from 6.4 to 17.8 cm, while handlines used hooks sized between 4/0 (shank

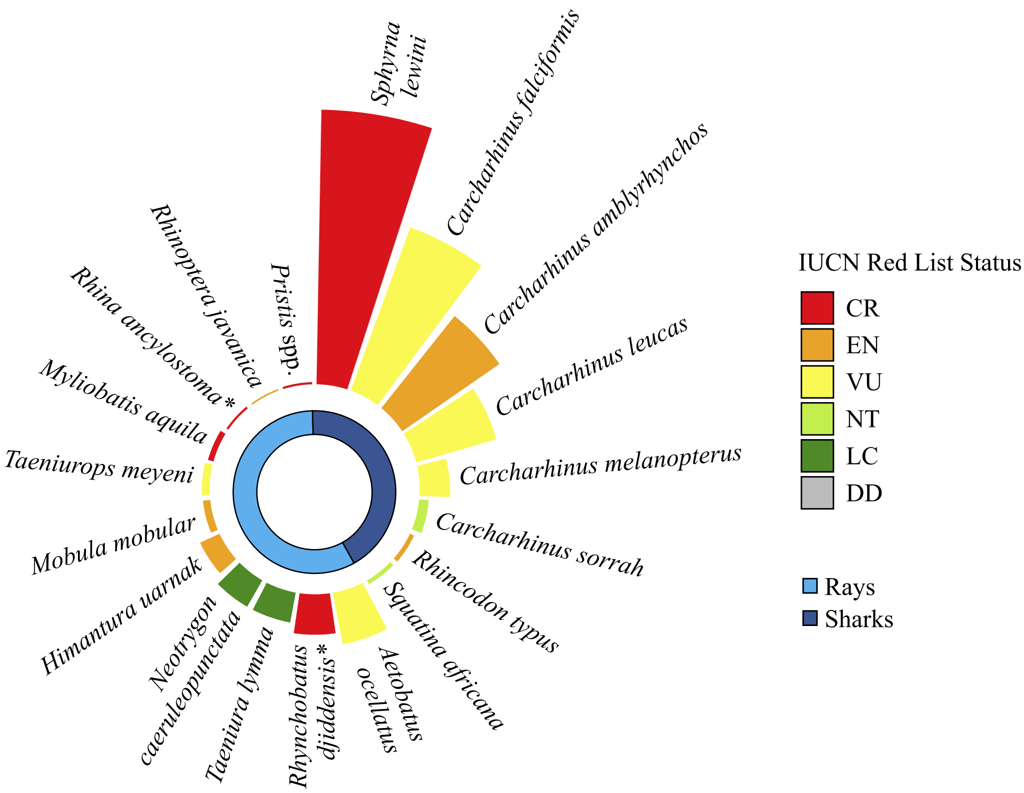

Figure 4. Circular plot showing the abundance (length of bars) and IUCN Red List Status of the 19 elasmobranch species captured in the artisanal fishery. *Rhinidae (guitarfish). CR: Critically Endangered, EN: Endangered, VU: Vulnerable, NT: Near Threatened, LC: Least Concern, DD: Data Deficient.

length 4.7 cm, gape 1.9 cm) to 8/0 (shank length 7.2 cm, gape 2.8 cm) and longlines used hooks sized between 2/0 (shank length 3.9 cm, gape 1.7 cm) to 4/0 (shank length 4.7 cm gape 1.9 cm). Fishers reported they deployed gillnets in depths ranging from 10 to 200 m, monofilament at depths of 15-30 m, handlines at depths ranging from 10 to 150 m and spearguns at depths of 10-20 m. Among vessel types utilised by elasmobranchs fishers, the wooden engine boat locally known as *mashua* emerged as the most frequently used, constituting 76.5% (n = 173) of the total fishing trips. Other vessel types in use included dugout canoes, referred to as *mtumbwi* or *dau* (8.4%, n = 19), fibre boats (5.8%, n = 13), foot fishers (4.9%, n = 11) and larger (> 12 m) wooden boats, also known as *jahazi* (4.4%, n = 10). Most of fishing trips (96.6%, n =

Table 2. Percentage distribution of catch frequency (time since fisher last caught elasmobranch) for fishing trips grouped by fishing behaviour (targeting elasmobranchs [n = 45] and targeting all fish [n = 181]).

	Fisher targeting behaviour	
Catch frequency	Target elasmobranch	Target all fish
Today	42.2	1.7
Yesterday	28.9	2.8
This week	0.0	7.7
Last week	24.4	37.0
Last month	0.0	3.3
Three months ago	0.0	33.7
Not answered	4.4	13.8

196) were propelled by outboard engines ranging from 15 to 45 HP and often supplemented by sails and paddles, while a small number of fishing trips utilised vessels equipped only with paddles (n = 3) or sails (n = 4). The number of fishers per trip ranged from one among speargun fishers to ten fishers among gillnet fishers.

Five artisanal fishing gears were utilised to capture elasmobranchs, including multifilament gillnets (45.9%, n = 95), monofilament nets (18.8%, n = 39), handlines (5.8%, n = 12), longlines (8.2%, n = 17), and spearguns (21.3%, n = 44) (Figure 5 A and B). Among these, net-type gears (multifilament and monofilament gillnets) resulted in the highest number (n = 386, 60.1 %) and weight (880.1 kg, 55.8%) of landed sharks (Figure 5 A). Spearguns and gillnets were responsible for most landed rays and guitarfish together, in terms of both number (n = 117, 62.9%) and weight (1,501.3 kg, 61.8%) (Figure 5 B).

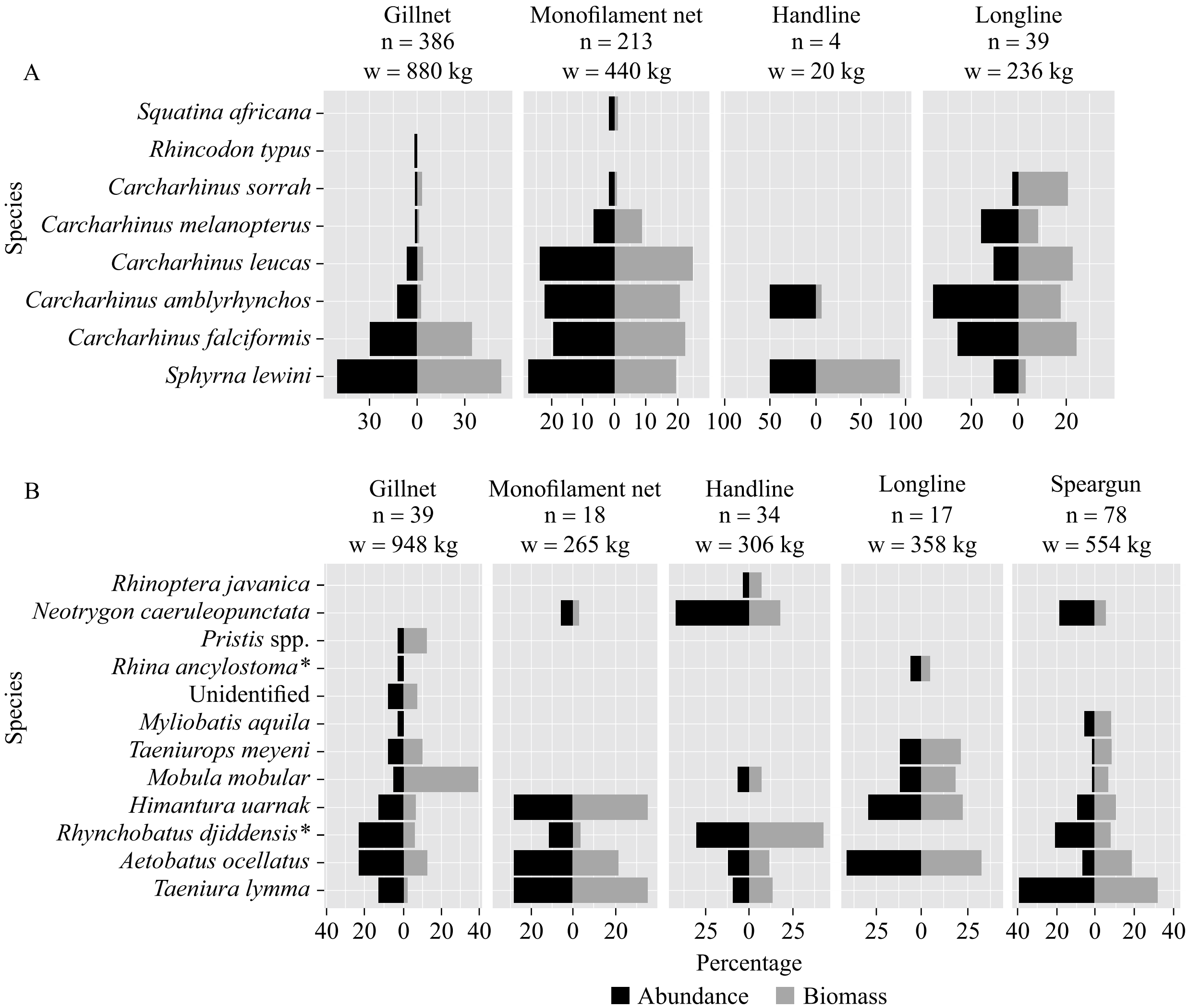

Figure 5. Abundance and biomass catch composition of sharks (A) and rays and guitarfish (B) by artisanal fishing gears across all sites and 226 fishing trips. Asterisks indicate guitarfish.

Sphyrna lewini and *A. ocellatus* were the most caught species using gillnets (multi- and mono-filament). Handline and longline caught mainly *C. amblyrhynchos*, while no sharks were caught by spearguns. Rays were primarily caught using spearguns (44%), followed by handline (20%) and gillnet (18%). *N. caeruleopunctata* and *T. lymma* were the dominant species caught using handline and spearguns, respectively (Figure 5).

The study also revealed a substantial average dissimilarity in species caught by gears targeting sharks with percentages of 78.0% and 81.1% for abundance and biomass, respectively. Key contributors to shark abundance dissimilarity were *S. lewini*, *C. falciformis* and *C. amblyrhynchos*, primarily captured by gillnets, monofilament nets, and longlines (supplementary material, Table S2 A). Gillnets contributed significantly to the catches of *S. lewini* (2.1%) and *C. falciformis* (1.3%). *Carcharhinus amblyrhynchos* was less captured in gillnets (0.5%) but more in longlines (1.4%). *Carcharhinus falciformis* significantly influenced shark biomass dissimilarity predominantly taken by longlines (supplementary material, Table S2 B). *Sphyrna lewini* also made a substantial biomass contribution, with notable catches in handlines (6.2%) and gillnets (5.2%).

There was a significant overall dissimilarity (84.4%) in the abundance of ray species captured across the five fishing gears (supplementary material, Table S3). *Aetobatus ocellatus*, *R. djiddensis*, and *T. lymma* were the primary contributors to these differences recording high mean abundance in longlines (0.8%), handlines (0.7%), and spearguns (0.6%), respectively. The overall average dissimilarity in ray biomass was 89.5%. *Aetobatus ocellatus* contributed 34.4% to this dissimilarity, with higher mean values in gillnets. *Rhynchobatus djiddensis* (12.5%) was the second largest contributor with most biomass occurring in longlines (13.1%) and monofilament nets (6.9%). Interestingly, *T. lymma* (12.2%) exhibited higher mean biomass in handlines (9.3%) compared to other gears.

All gears recorded a median catch rate of around 10 kg fisher^{-1} day^{-1}. There was no significant difference of catch rates between the five fishing gears used to target sharks (KW-test, $p = 0.14$). However, the catch rates of rays and guitarfish showed significant differences (KW-test, $p = 0.01$), with spearguns recording higher catch rates (median 1.4 kg fisher^{-1} day^{-1}) than gillnets (median 0.4 kg fisher^{-1} day^{-1}), monofilament nets (median 0.3 kg fisher^{-1} day^{-1}) and longline (median 0.2 kg fisher^{-1} day^{-1}), (Figure 6). Fishers' income had a similar trend to that of catch rates.

DISCUSSION

Our snapshot study provides evidence on how Kenyan artisanal fisheries threaten shark and ray populations. With almost 80% of landed species listed as threatened on the IUCN Red List and 97% of sharks and 46% of rays landed as immature individuals, national management of these fisheries urgently needs to change.

Threatened species

Fifteen of the 19 species of sharks and rays identified from landings in this study are globally threatened with extinction. The high global demand for shark fins for the Asian fin soup market (Dell'Apa et al. 2014) is considered to have resulted in significant declines of sharks and rays worldwide, making them at risk of population collapse (Dulvy et al. 2021). In Kenya, the use of non-selective fishing gears such as gillnets (Osuka et al. 2021) is considered to have increased the pressure on sharks and rays affecting the size and species being landed (White et al. 2013). The landings observed in this study fell in the lower spectrum of diversity expected for an inshore equatorial region like Kenya. Further, numerous shark species known to inhabit the area (Anam and Mostarda 2012) were absent from the landings. Notably, small coastal species from families such as Carcharhinidae (e.g. *Carchar-*

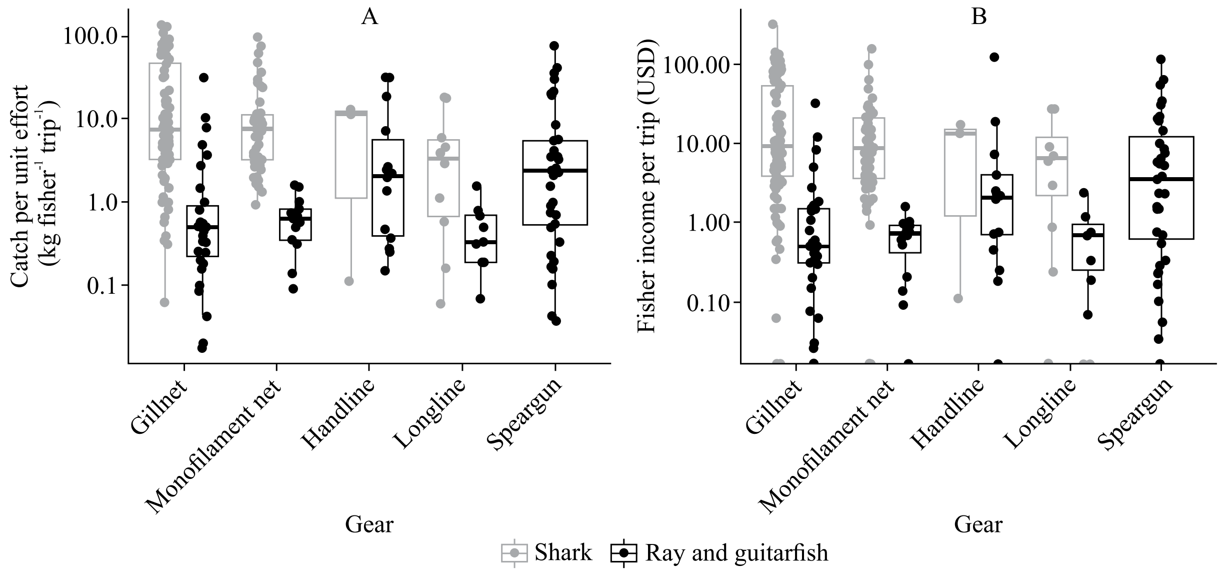

Figure 6. Catch rates (A) of elasmobranchs landed and fisher income (B) by artisanal fishing gears.

hinus plumbeus, *Rhizoprionodon acutus*, *Loxodon macrorhinus*), and Hemigaleidae (e.g. *Hemipristis elongata*) (Anam and Mostarda 2012) were not landed. This absence might indicate overfishing, as these species often diminish following the capture of larger species like bull sharks and scalloped hammerheads (Gallagher et al. 2014). Alternatively, fishers may have been catching these species but not landing them ashore.

All shark species recorded in this study have been recently reported in studies of small-scale fisheries along the Kenyan coast. Two of the three most landed species in this study, *S. lewini* and *C. amblyrhynchos*, are consistent with recent catch landings results from Kiilu et al. (2019) and Wambiji et al. (2022). However, there appear to be changes in the relative frequency of species from earlier surveys. For example, silky shark (*C. falciformis*) was not reported in artisanal fisheries prior to 2013 (Kiilu et al. 2019), but it is one of the four most captured shark species in the current study. Their sudden presence in catch landing reports appears to coincide with the development of fish aggregating devices (FADs) deployment programs in Kenya between 2012 and 2016 (Osuka et al. 2016; Mbaru et al. 2018). Silky sharks, especially juveniles, associate with floating objects and therefore aggregate at FADs, a behaviour that increases their catchability (Filmalter et al. 2015). In contrast, we recorded a total absence of the blacktip shark, *Carcharhinus limbatus* in 2018 landings, which represented the second most caught species in number between June 2012 and May 2013, with nearly 500 individuals landed (Kiilu et al. 2019). The landing sites monitored were the same three sites in both studies and at a similar time of year. All previously reported *C. limbatus* individuals were classified as immature (Kiilu et al. 2019), suggesting that they were likely captured while using small, core areas of their nurseries (Legare et al. 2018). Considering the permanent fishing pressure in the area, our results indicate potential local extirpation of *C. limbatus* within a 5-year period.

Species composition

Juvenile capture

Sharks and rays are highly vulnerable to overexploitation because they have considerably lower reproductive rates and take longer to reach sexual maturity than other fish species (Cortés 2004). The finding that 97% of shark landings were juveniles is therefore of high concern. Several shark species, including *S. lewini*, are known to breed in nearshore, often turbid areas, while adult sharks typically spend more time in pelagic environments (Compagno 1984; Ebert et al. 2021). The size range of *S. lewini* in our catches corresponds to neonates and young-of-the-year (Duncan and Holland 2006; Kiilu et al. 2019), suggesting that they are captured in their nursery grounds (Cuevas-Gómez et al. 2020) and that the artisanal fishers do not venture far enough offshore to capture adult *S. lewini*. In contrast, landings of both immature and mature individuals of *C. amblyrhynchos* reflect more its reef-associated ecology throughout its lifespan (Vianna et al. 2013). Juvenile *C. leucas* are known to spend time in estuarine river systems (McCord and Lamberth 2009), which represent similar habitats found around the Kipini and Ngomeni landing sites on the northern coast of Kenya. This also suggests an overlap between artisanal fishing grounds and key habitats for young stages of *C. leucas*.

Over 45% of rays were caught as juveniles, including all individuals *R. djiddensis* and *A. ocellatus* the most frequently caught guitarfish and ray, respectively. This can be attributed to rays' preference for nearshore habitats, making them vulnerable to the overlap with the artisanal fishing grounds we observed here (Lugendo et al. 2007; Kyne et al. 2020). The coastal proximity makes juvenile rays particularly susceptible to capture due to their small size, inexperience, and frequent use of shallow coastal waters and estuaries as nursery grounds. These areas provide abundant food and protection from predators but are also heavily targeted by fisheries, increasing the risk of capture. Ray species are also often cryptic and dominant in the absence of sharks (Simpfendorfer et al. 2023). This study expands our understanding of the severity of the declines in elasmobranch populations in Kenya and supports findings by Simpfendorfer et al. (2023) on the extensive loss of elasmobranchs on coral reefs. Evidence of recruitment overfishing as described by Froese and Binohlan (2000) is seen here in the high capture of neonates, juveniles and immature individuals including reef-associated *Carcharhinus* species. This situation suggests that historic overfishing has now reduced the reproductive and recovery potential of populations to critical levels (Jennings and Polunin 2001). This is consistent with fishery-independent data citing reef sharks as 'functionally extinct' in Kenyan waters (MacNeil et al. 2020). Further studies to determine nurseries distribution and understand the overlap of key habitats with fishing grounds are urgently needed for the development of effective management measures and conservation strategies for both sharks and rays.

Characterization of Kenyan artisanal fisheries

Fisher behaviour

The behaviour of Kenyan artisanal fishers likely influences the composition of catches since many prefer nearshore shallow and estuarine areas that are more protected from open sea due to boat limitations (Samoilys et al. 2011; Munga et al. 2016). Although most fishing trips used *mashua* vessel with outboard engines, it is probable that the engine size and fuel costs limited the fishers to fish in the shallow water. The wide use of gillnets in artisanal fisheries contributes to the high proportion of immature individuals in catches of reef-associated fish species (Osuka et al. 2021). Rays were caught using a combination of selective and unselective gears, such as spearguns and gillnets, respectively. Kenyan speargun fishers may prefer targeting rays over sharks due to their ease of capture and visibility (Wambiji et al. 2022), while gillnets, especially small mesh monofilaments, capture juvenile rays indiscriminately.

The majority (80%) of fishers in this study did not specifically target sharks and rays, with only a minority (20%) doing so. This suggests that most sharks and rays are caught incidentally by typical artisanal fishers using non-selective gear like gillnets, and many of these fishers operate in proximity to the shore from which they sail or paddle their boats. According to artisanal fishers, shark and ray populations have declined, making it challenging for those intentionally targeting elasmobranchs to recall catches from previous months. However, fishers purposively targeting them appear to catch more frequently, possibly due to their expertise, strategies, or specialised gear.

Fishing gears

The extensive use of unselective gillnets in Kenyan artisanal fisheries (Samoilys et al. 2017) poses a significant threat to elasmobranchs populations. In Kenyan artisanal fisheries, gillnets account for 70% of the total landings, with 37% of these nets being illegal monofilament gillnets (2.5-inch mesh size), making them particularly effective at capturing juveniles (Mangi and Roberts 2007; Osuka et al. 2021). Elasmobranchs are also caught incidentally as bycatch in different fishing operations, such as the small prawn trawl fishery (Fulanda et al. 2011). Surprisingly, no gillnets of large mesh sizes (> 7 inches) were recorded in this study, in contrast to previous findings (Osuka et al. 2021), which could potentially leading to an underestimation of elasmobranch captured here, as gillnets with larger mesh sizes are known to catch vulnerable elasmobranch species. Our results found that speargun had significantly higher rays catch rates than gillnets. This is because fishers using speargun can be highly selective on the species and size of their catch and usually target a smaller range of species (McClanahan and Mangi 2004) including devil rays *M. mobular*, which have high biomass (Froese and Pauly 2023). Spearguns are also popular fishing gear among young fishers because they have low input costs (Government of Kenya 2016; Samoilys et al. 2017). Overall, unselective gillnets, especially illegal monofilament ones, threaten elasmobranchs in Kenyan artisanal fisheries. Spearguns fishers show high catch rates due to their selectivity and focus on high-biomass species.

The analysis of catch rates revealed that all fishing gears recorded similar catch rates, with no significant differences between the five gears used to target sharks. This suggests a uniform efficiency in capturing sharks across these gears (Wambiji et al. 2021). However, significant differences were observed in the catch rates of rays and guitarfish. Spearguns had notably higher catch rates compared to gillnets, monofilament nets, and longlines. This disparity indicates that spearguns may be more effective for targeting rays and guitarfish. Consequently, fishers' income followed a similar trend, reflecting the similarity or variations in catch rates among different fishing gears. This finding highlights the importance of gear selection in influencing both catch rates and economic returns for fishers.

Management implications

It is clear from this study and others that there is an urgent need for conservation efforts to protect coastal sharks and rays in Kenya. Conservation measures designed for threatened species to prevent extinction (Byers et al. 2022) are required urgently within fisheries and other marine legislation in Kenya. Implementing fishing effort controls for sharks and rays is imperative for immediate action. However, to effectively attain the desired conservation outcomes, it is necessary to complement these measures with spatial gear controls. We therefore recommend closed areas such as marine protected areas to safeguard essential nursery grounds such as those in Malindi-Ungwana bay, already identified as an Important Shark and Ray Area (Jabado et al. 2023). Likewise, fishing gear regulations, including the modification and restriction of fishing gears (Tuda et al. 2016), should be established to control landings of small immature individuals. Urgent activation by the Kenya Wildlife Service (KWS) of existing protected species legislation for IUCN Red List species under the Wildlife Conservation and Management Act (Government of Kenya 2013; Sureshchandra 2021) is also needed. This will aid in the prevention of harvesting and trading species such as scalloped hammerhead (*S. lewini*), white-spotted guitarfish (*R. djiddensis*), grey reef shark (*C. amblyrhynchos*), and eagle ray (*A. ocellatus*). Supporting legislation from Kenya Fisheries Service to adhere to this protective legislation for IUCN listed threatened species will also strengthen management. Implementing such management measures would also support the enforcement of the Convention on International Trade in Endangered Species (CITES) in Kenya, specifically for sawfish, wedgefish, hammerhead sharks, and requiem sharks including grey reef shark, silky shark, bull shark, blacktip reef shark and spot-tail sharks. These species are often traded internationally, particularly in the shark fin trade. Consequently, they fall under the purview of CITES regulations, which aim to monitor and control the international trade of endangered species to ensure their conservation and sustainable use.

Our study supports the recommendations from a recent focused study examining the impacts of different gillnet mesh sizes on threatened species that proposed use of medium mesh size gillnets (4.0-6.0 inches) (Osuka et al. 2021). Further we recommend the use of handlines with circle hooks (Oddenyo 2017) so that sharks captured can be returned live to the sea. Species-specific conservation measures are key to manage coral reef elasmobranch populations within sustainable socio-ecological systems. Implementing these regulations may pose challenges for some fishers, so they require active support in finding alternative income sources (Nyawade et al. 2021).

Fisher education and consideration of socio-economic impacts are necessary for sustainable fishing in Kenyan coastal fisheries (Oluoch et al. 2009). Additionally, raising awareness among people that red-listed species are protected under legislation is crucial for ensuring compliance with conservation efforts. Compensation measures should accompany restrictions on legal gear such as gillnets and handlines (Meyers et al. 2020). These measures ought to balance conservation goals with the livelihoods of fishers through offering alternative sources of income, financial compensation, and training programs to help fishers adapt to new fishing techniques (Maina and Samoilys 2011; Booth et al. 2022).

CONCLUSIONS

Our study confirms the global vulnerability of shark populations (MacNeil et al. 2020; Simpfendorfer et al. 2023) and that Kenyan coastal sharks are highly depleted. The depletion of sharks and rays has been shown to have adverse effects on the functioning of the ecosystem as well as the livelihoods of those dependent on these taxa in their artisanal fisheries operations (Heupel et al. 2014; Dulvy et al. 2021). Therefore, it is crucial to implement effective conservation measures and sustainable fishing practices to protect these species and maintain the balance of marine ecosystems and the well-being of local communities. While the data from this study offers a snapshot of the shark and ray species involved in the artisanal fisheries of Kenya, they offer some insights into the status of these species and their conservation measures. Elasmobranchs in Kenya are facing alarming and non-sustainable fishing practices, with high proportions of immature individuals in the catch and the significant capture of species threatened with extinction based on global IUCN Red List assessments. Such practices are likely to drive several shark and ray species populations to local extirpation across Kenyan waters if critical conservation measures are not urgently implemented. In the framework of the precautionary approach to fisheries management, a ban on the landing of IUCN listed threatened species and reducing the capture of juveniles through minimum size limits is recommended. This should be reinforced by fisheries regulations, such as mesh size, and spatial protection of critical habitats such as nursery grounds for species that are most at risk. These proactive measures must be taken to ensure long-term viability of sharks and rays in Kenya as more data becomes available.

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Author contributions

Kennedy E. Osuka: conceptualization; formal analysis; funding acquisition; investigation; methodology; visualisation; writing-original draft. Melita A. Samoilys: conceptualization; funding acquisition; methodology; supervision; writing-review and editing. Peter Musembi investigation; data curation; formal analysis; writing-review and editing. Clare J. Thouless: formal analysis; visualisation, writing-review and editing. Clay Obota: investigation; data curation; writing-review and editing. Joshua Rambahiniarison: methodology; writing-review and editing.

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