Food and Agriculture Organization of the United Nations

Indian Ocean Tuna Commission
Commission des Thons de l'Ocean Indien
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[IOTC-2026-WPEB22-39]

ECOLOGICAL RISK ASSESSMENT OF SHARKS IN INDIA'S ARTISANAL FISHERIES: AN EXPLORATORY STUDY

Muktha M*, Babu C, Gyanranjan Dash, Shoba Joe Kizhakudan, Akhilesh K V, Surya S, Rajesh K M, Swatipriyanka Sen Dash, Anulekshmi C, Najmudeen T M, Shikha Rahangdale, Purushottama G B, Subal Kumar Roul, Remya L, Abdul Azeez, K R Veera Venthan, Livi Wilson, Mahesh V, Sujitha Thomas, Ajay Nakhawa, Eldho Varghese, J Jayasankar, Sijo P Varghese, Sreenath K R, Sanjay Pandey, K Mohammed Koya and Grinson George

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Purpose, expectation and action intended (select one or more and include corresponding text)

Discussions (for information and open discussion):

The paper is to inform meeting members on an exploratory study carried out using Ecological Risk Assessment methods, specifically, Productivity Susceptibility Analysis on three shark species in India's artisanal fisheries. The utility of the Productivity -Susceptibility Analysis (PSA) is given in the Introduction section and the details of how it was used in this study are in the Materials and Methods section. The results indicated low vulnerability for *Alopias pelagicus*, moderate for *Carcharhinus falciformis* and high vulnerability for *Sphyrna lewini*. *A. pelagicus* scored high on productivity, whereas the other two species scored high on susceptibility, indicating that for the former the vulnerability was driven mainly by its inherent life history, whereas for the latter two species the fishery parameters were more critical.

The paper is also to discuss on the possibilities of a Minimum Legal Size for conservation of sharks across IOTC fisheries and Important Shark and Ray Areas (ISRAs) in ABNJ as set out in the Conclusion section.

Feedback (to collect input and suggestions)

[The paper is to request review and comments on…, as set out in Section X]

Conclusion (to record a concluded position or summary)

[The paper is to seek confirmation that…, as set out in Section X]

Recommendation (to ask the meeting to endorse a recommendation)

[The paper is to seek endorsement on…, as set out in Section X]

Decisions (to request formal approval of actions)

[The paper is to seek approval on…, as set out in Section X]

Abstract

Ecological Risk Assessment of sharks in India's artisanal fisheries: An exploratory study

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Shark assessments are often constrained by limited fishery and biological data, especially in the tropical regions and developing countries. The Productivity -Susceptibility Analysis (PSA) is a semi-quantitative tool to assess species vulnerability based on biological productivity and susceptibility to fishing and, in extended frameworks, the effectiveness of existing management measures. This study used an exploratory composite PSA to assess the vulnerability of three shark species -*Alopias pelagicus*, *Carcharhinus falciformis* and *Sphyrna lewini* in Indian artisanal fisheries. The results indicated low vulnerability for *A. pelagicus*, moderate for *C. falciformis* and high vulnerability for *S. lewini*. *Alopias pelagicus* scored high on productivity, whereas the other two species scored high on susceptibility, indicating that for the former the vulnerability was driven mainly by its inherent life history, whereas for the latter two species the fishery parameters were more critical. Additionally, the size composition of these species in Indian landings during 2025 was analysed. Landings of *A. pelagicus* were dominated by adults, while juveniles constituted the majority of landings of *C. falciformis* and *S. lewini*. Landing monitoring survey records were further compared with available fishing-ground information from fishery and exploratory surveys to examine the spatial distribution of these three species in Indian waters. A practical tool to manage and conserve fish stocks in the tropics is partly through the use of Minimum Legal Size (MLS) for retention and trade. and implementation of dynamic area-based management based on life history and abundance in fishing locations. An MLS of 220 cm TL has already been recommended for *S. lewini* for Indian waters. We recommend the urgent estimation and evaluation of species-specific MLS values for *A. pelagicus* and *C. falciformis*, to support the sustainable management of these species in Indian waters

Keywords: elasmobranchs, sustainability, management, Arabian Sea, Bay of Bengal

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Introduction

Elasmobranchs, comprising sharks, rays and skates, represent one of the most threatened and vulnerable faunal groups in the marine ecosystem. The Indian Ocean, falling within the Indo-Pacific region, is one of the most diverse in elasmobranch species. While the region is an elasmobranch fishery hotspot, it is also home to nations with limited stock assessment research, which can provide science-based advisories for stock management. Conducting stock assessment of sharks caught in the IOTC-managed tuna fisheries requires species-specific data, including time series data on catch, effort, and biological parameters (Vase et al., 2025), which are limited from many artisanal fisheries in the Indian Ocean. Often, the data available may be aggregated at the group level rather than at the species-specific level, which significantly limits the applicability and accuracy of conventional stock assessment models (Akhilesh et al., 2023).

An alternative to a detailed stock assessment is the semi-quantitative Productivity Susceptibility Analysis (PSA) (Stobutzki et al., 2002; Murua et al., 2018), a method under Ecological Risk Analysis (ERA). ERA is a data-limited approach for assessing the vulnerability of species to fisheries interactions (Stobutzki et al., 2002; Georgeson et al., 2020). The semi-quantitative PSA evaluates species risk as a function of their biological productivity and their susceptibility to fishing pressure from various gears (Patrick et al., 2010; Hobday et al., 2011; Murua et al., 2018). PSA is considered useful for evaluating the vulnerability of many data-limited species by providing direct results that can be easily interpreted by fisheries managers and policymakers (Griffiths et al., 2017; Williams et al., 2018), enabling its wider applicability in tropical fisheries, many of which are data-limited.

PSA studies on sharks have been carried out in the region, and also under the aegis of the WPEB of the IOTC. Murua et al. (2018) carried out PSA for sharks caught in fisheries managed by the IOTC, analysing 17 shark species caught in longline, purse seine and gillnet fleets. Kiilu et al. (2022) carried out PSA on chondrichthyans from coastal Kenya, examining the impact of artisanal, bottom trawl and longline fisheries on 44 shark species, 38 ray species, 7 guitarfish, 3 sawfish and 1 wedgefish species (Kiilu et al., 2022). PSA has not been done exclusively for elasmobranchs in Indian waters, but recently Hoque et al. (2024) published on the vulnerability of marine species to overfishing from the north-

west coast of India. Vase et al. (2025) published on PSA for marine resources of Gujarat, where they evaluated the vulnerability of 37 species, including 2 elasmobranchs. Given that comprehensive stock status data on WPEB shark species are limited from Indian waters, we conducted a PSA analysis on three selected species: *Carcharhinus falciformis*, *Alopias pelagicus,* and *Sphyrna lewini*. We also highlight the size structure of these three species landed in India, along with their distribution areas within the Indian EEZ. Results of this work will guide improved management measures for these species in Indian waters, including size-based tools like MLS, and area-based spatial tools like Marine Protected Areas (MPAs) and Important Shark and Ray Areas (ISRAs).

Material and Methods

In our study, we used the modified PSA (m-PSA) (Vase et al., 2025) which had 14 attributes for productivity (Table 1) and 12 attributes for susceptibility (Table 2). Values for the productivity attributes for *C. falciformis*, *A. pelagicus,* and *S. lewini* were used either from published literature from India (Varghese et al., 2015, 2017) or from FishBase (Table 3). For susceptibility attributes, scores were based on expert opinion and primary data (Table 4). For both sets of attributes, scores from 1 to 3 were given, 3 indicating highest productivity or highest susceptibility and 1 the least (Tables 5 and 6). Thus, the highest productivity score a species could get was 3, and the score for highest susceptibility was 3. Vulnerability was calculated as the Euclidean distance from the origin as given by Vase et al. (2025): V = $\sqrt{P^2 + S^2}$, where P is the overall Productivity score and S the overall Susceptibility score. The overall P is calculated as $(3 - x)$ where x is the average productivity score (i.e., the total of all productivity scores for a species divided by 13), and overall S is calculated as $(y - 1)$ where y is the average susceptibility score (i.e., the total of all susceptibility scores for a species divided by 12). Hence, V for each species is = $\sqrt{(3 - x)^2 + (y - 1)^2}$ (Table 6). Vulnerability categories from Hoque et al. (2024) were used in the study as follows: low <1.8; moderate between 1.8 and 2; high between 2 and 2.2; very high >2.2. The higher the vulnerability score, the higher the vulnerability of the species to fishing pressure.

Table 1: Productivity attributes used in the study

Attribute	Score 1	Score 2	Score 3
Population growth rate (r)	<0.35	0.35-0.70	>0.70

Maximum age (tmax, years)	>6	3-6	<3
Maximum length (Lmax, cm)	>84.2	42.1-84.2	<42
Age at maturity (tm, years)	>4	2-4	<2
Lm/Linf	>0.75	0.60-0.75	<0.60
Generation time (tg, years)	>4.5	1.5-4.5	<1.5
Asymptotic length (Linf, cm)	>80	40-80	<40
Growth coefficient (K)	<0.50	0.50-1.00	>1.00
Natural mortality (M)	<0.75	0.75-1.50	>1.50
Fecundity	< 5 pups	5-10 pups	>10 pups
Breeding strategy	Low parental investment	Moderate parental investment / semelparous, moderate investment	High parental investment / semelparous, high investment
Recruitment pattern	Short, concentrated annual pulse	Extended seasonal/bimodal peaks	Continuous year-round/bimodal peaks
Mean trophic level (MTL)	>4.0	3-4	<3.0

Table 2: Susceptibility attributes used in the study

Attribute	**Score 1 (lower susceptibility)**	**Score 2 (moderate susceptibility)**	**Score 3 (higher susceptibility)**

Horizontal overlap	<25% overlap	25–50% overlap	>50% overlap
Vertical overlap	<25% overlap	25–50% overlap	>50% overlap
Seasonal migration	Migration decreases capture	Neutral effect	Migration increases capture
Schooling/aggregation/behaviour	Behaviour reduces capture	Neutral effect	Behaviour increases catchability
Morphology affecting capture	Morphology reduces retention	Neutral effect	Morphology increases retention
Commercial value	<₹150/kg	₹150–400/kg	>₹400/kg
Management strategy	Species-specific measures with strong effective, enforced management	Generic measures with moderate effective, enforced management	No effective measure / poor effective, enforced management
Geographic concentration	Stock distributed across >50% of its total regional range	Stock distributed across 25–50% of its total regional range	Stock distributed across <25% of its total regional range
Post-capture survival	Probability of survival >67%	Probability of survival 33–67%	Probability of survival <33%
Fishery impact to habitat	Minimal habitat effect	Temporary/reversible effect	Strong/long-term habitat effect
Breeding-fishing overlap	<25% spawning-month overlap	25–50% overlap	>50% overlap
Lr/Linf	>0.5	0.3–0.5	<0.3

The sizes of the three shark species were measured at various landing centres along the coastline of mainland India namely Veraval in Gujarat, Mumbai in Maharashtra, Karwar and Mangalore in Karnataka, Goa, Calicut, Kochi and Vizhinjam in Kerala, Tuticorin and Chennai in Tamil Nadu, Visakhapatnam in Andhra Pradesh, Puri in Odisha and Digha in West Bengal. The total length (TL) of specimens was measured in cm using a flexible measuring tape, whenever the samples were available

for measurement. A size frequency was estimated with a length bin size of 10 cm and plotted. The size data for 2025 alone was used for this study.

Data from Fishery Survey of India's (FSI) survey trips were also used to map areas of high abundance of these three species in the Indian EEZ. FSI survey data from longline experimental surveys for five years from 2020 onwards were used for this study. FSI survey observations of the selected shark species, including geographic coordinates (latitude and longitude) and catch/abundance (No.), were used for spatial mapping. Records with missing geographic or abundance information were excluded. The spatial analysis was performed in R using the sf, gstat, ggplot2, rnaturalearth, and viridis packages.

The geographic distribution and relative abundance of each species were estimated using Inverse Distance Weighting (IDW) interpolation, with an inverse-distance power of 2 and a maximum of 12 neighbouring observations. A regular prediction grid at 0.1° spatial resolution was generated and spatially restricted to the Indian Exclusive Economic Zone (EEZ) using the mainland and Andaman & Nicobar EEZ polygons. Observations falling outside the Indian EEZ were excluded prior to interpolation. Thus, predicted relative-abundance values were generated only within the Indian EEZ, avoiding extrapolation beyond India's maritime jurisdiction. The interpolated abundance surface was overlaid with the actual FSI observation locations and Indian EEZ boundaries.

Results and Discussion

PSA

The scores of the three species for Productivity, Susceptibility, and Vulnerability are given in Table 5. The Productivity score for all three species was 1.5 due to their similar life histories. The Susceptibility score was highest for *S. lewini* and lowest for *A. pelagicus*, pointing to their differing fishery interactions. The Vulnerability score was highest for *S. lewini*, followed by *C. falciformis* and *A. pelagicus*.

Table 3: Productivity parameters used in the study

Species	Population growth rate- r	Max age - tmax	Max Lt - Lmax	Age at Maturity- tm	Length at Maturity-Lm	Lm/Linf	Generation time- tg	VBG coefficient- Linf	VBG coefficient- K	Natural Mortality-M	Fecundity	Breeding strategy	Recruitment pattern	Mean trophic level-MTL
Alopias pelagicus	0.54	29	428	4.4	157.3	0.460884852	8.7	341.3	0.12	0.18	2	Live bearer	Annual	4.5
Carcharhinus falciformis	0.4	36.4	350	6.6	153.4	0.462048193	13.1	332	0.08	0.13	5	Live bearer	Annual	4.5
Sphyrna lewini	0.44	32.3	430	5.9	143.2	0.465691057	11.5	307.5	0.09	0.14	22	Live bearer	Annual	4.1

Table 4: Susceptibility parameters used in the study

Species	Horizontal area overlap	Vertical area overlap	Seasonal migrations	Schooling/Aggregation and other behavioural responses	Morphology affecting capture	Value of fishery	Management strategy	Geographic concentration	Post-capture survival	Fishery impact to habitat	Overlap between peak breeding and peak fishing months	Lr/Linf
Alopias pelagicus	Low <25%	Medium 25-50%	Seasonal effect limited	Limited	Medium	Medium	Generic	<25%	33-67%	Low	Moderate	0.339
Carcharhinus falciformis	Medium	Medium 25-50%	Neutral	High	Medium	Medium	Generic	Medium	33-67%	Low	Moderate	0.181
Sphyrna lewini	Medium	Medium 25-50%	High	High	High	High	Generic	Medium	<33	Low	High	0.163

Table 5: Productivity scores obtained in the study

Species	Population growth rate- r	Max age - tmax	Max Lt - Lmax	Age at Maturity- tm	Lm/Linf	Generation time- tg	VBG coefficient- Linf	VBG coefficient- K	Natural Mortality-M	Fecundity	Breeding strategy	Recruitment pattern	Mean trophic level- MTL	Productivity
Alopias pelagicus	2	1	1	1	3	1	1	1	1	1	2	3	1	1.46
Carcharhinus falciformis	2	1	1	1	3	1	1	1	1	2	2	3	1	1.54
Sphyrna lewini	2	1	1	1	3	1	1	1	1	3	2	3	1	1.62

Table 6: Susceptibility scores obtained in the study

Species	Horizontal area overlap	Vertical area overlap	Seasonal migrations	Schooling/Aggregation and other behavioural responses	Morphology affecting capture	Value of fishery	Management strategy	Geographic concentration	Post-capture survival	Fishery impact to habitat	Overlap between peak breeding and peak fishing months	Lr/Linf	Score
Alopias pelagicus	1	2	2	1	2	2	2	1	2	1	2	2	1.7
Carcharhinus falciformis	2	2	2	3	2	2	2	2	2	1	2	3	2.1
Sphyrna lewini	2	2	3	3	3	3	2	2	3	1	3	3	2.5

Table 6: Vulnerability scores obtained in the study

Species	Vulnerability score	Vulnerability category
Alopias pelagicus	1.68	Low
Carcharhinus falciformis	1.82	Moderate
Sphyrna lewini	2.04	High

In our study, all 3 species exhibited similar productivity values, with *A. pelagicus* having the lowest at 1.46 and *S. lewini* the highest at 1.62. Given that productivity scores can vary between 1 and 3, values near 1.5 put them in the middle of the productivity spectrum, indicating medium levels of productivity. Murua et al. (2018) reported productivity values of 0.923 for *A. pelagicus*, 1.020 for *C. falciformis,* and 1.040 for *S. lewini*. Their study indicated the pelagic thresher shark as the species with the lowest productivity. These differences could be due to differences in the parameter values used and the methodology used. Hoque et al. (2024) reported a lower productivity score for *S. lewini* of 1.1 from the north-west coast of India. In the Hoque et al. (2024) study, the productivity values for elasmobranchs ranged from 1.1-1.6.

Susceptibility values varied across the 3 species, with *S. lewini* being the most susceptible to fishing pressure. Hoque et al. (2024) reported a susceptibility score of 1.4 for *S. lewini*. In the present study, *S. lewini* had higher scores for productivity as compared to susceptibility. Murua et al. (2018) indicated high susceptibility scores for *C. falciformis* in longline fisheries and for *A. pelagicus* in purse seine and gillnet fisheries.

The highest vulnerability scores were seen for *S. lewini* in our study. Hoque et al. (2024) reported a lower vulnerability category for the species, classifying it as moderately vulnerable to fishing pressure. Murua et al. (2018) indicated that the scalloped hammerhead shark was most vulnerable to gillnet fisheries in the Indian Ocean region. The scalloped hammerhead juveniles and newborns are known to inhabit coastal waters, and given their shoaling nature (Sukumaran et al., 2020), they are very susceptible to coastal artisanal fisheries. Sukumaran et al. (2020), while studying the genetics of the scalloped hammerhead from the Indian coast, found negligible genetic differentiation within the Indian coast samples, pointing towards their movement within the coastal regions of India, making them vulnerable to a number of coastal artisanal fishing gears.

Size structure

The size range of *C. falciformis* was 56-278 cm TL from 2292 sample specimens (Fig. 1). For *C. falciformis*, the highest numbers were seen in the 100-110 cm TL size class, and there was good representation of higher size class individuals. It must be noted that in the present study, fish caught across a variety of fishing gears were pooled for an overall size estimate. The fishing gear included trawls, gillnets and longlines. In an earlier study from the eastern Arabian Sea, Varghese *et al*. (2015) reported a similar size range for *C. falciformis*; however, their highest catches were from the 140-160 cm size class from a total sample size of 473, and was collected from gillnets and longlines alone. Data from the FSI experimental longline survey indicated the size range of 52-226 cm TL for the species, with the dominant size class being 61-80 cm TL (Kar *et al*., 2020).

For *A. pelagicus,* the size range was 116-312 cm TL from 783 specimens (Fig. 2). The most frequently occurring size class was the 190-200 cm TL size class, with very few specimens exceeding the 240 cm TL size class. Kar et al. (2020) reported a size range of 50-165 cm pre-caudal length for *A. pelagicus* in FSI surveys in the Indian EEZ. In their study, the dominant size class was the 121-140 cm PCL.

For *S. lewini*, the size range was 34-292 cm TL from 480 animals (Fig. 3). The highest numbers were seen in the 50-60 cm TL size class, with very few specimens beyond the 170 cm TL size class. The size distribution plots indicated that for *S. lewini* there was a predominance of small-sized animals, which has been indicated in an earlier study by Thomas et al. (2022). *S. lewini* juveniles are coastal in occurrence and are vulnerable to artisanal fisheries operating in nearshore areas. An MLS of 220 cm TL has been proposed by Thomas et al. (2022) to conserve *S. lewini* stocks in the Indian EEZ.

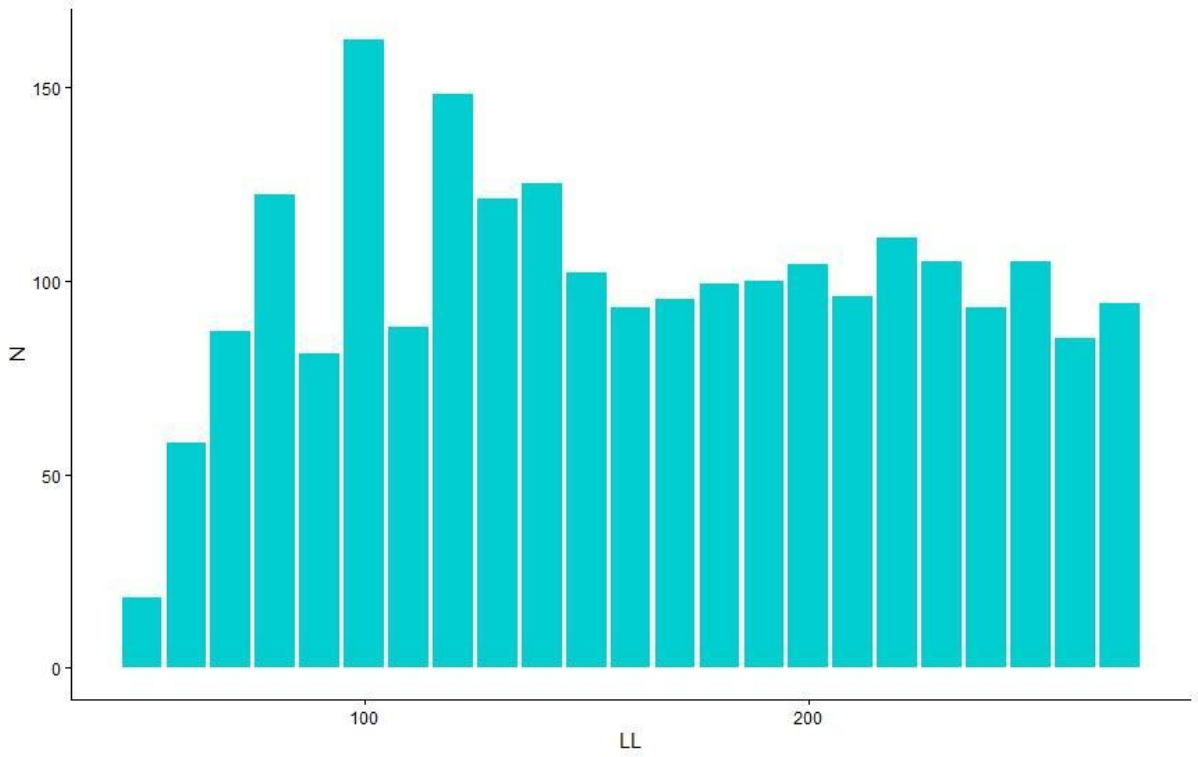

Fig. 1: Size structure (TL) of *C. falciformis* landed along the Indian coast during 2025

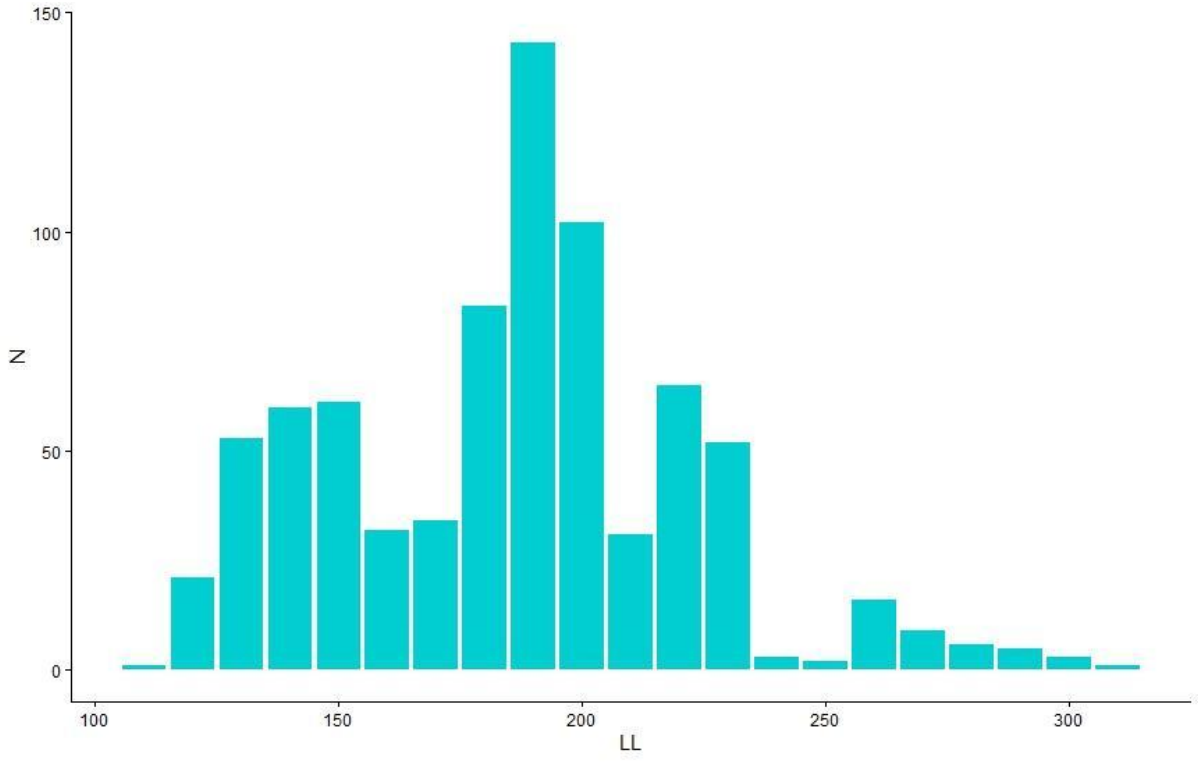

Fig. 2: Size structure of *A. pelagicus* landed along the Indian coast during 2025

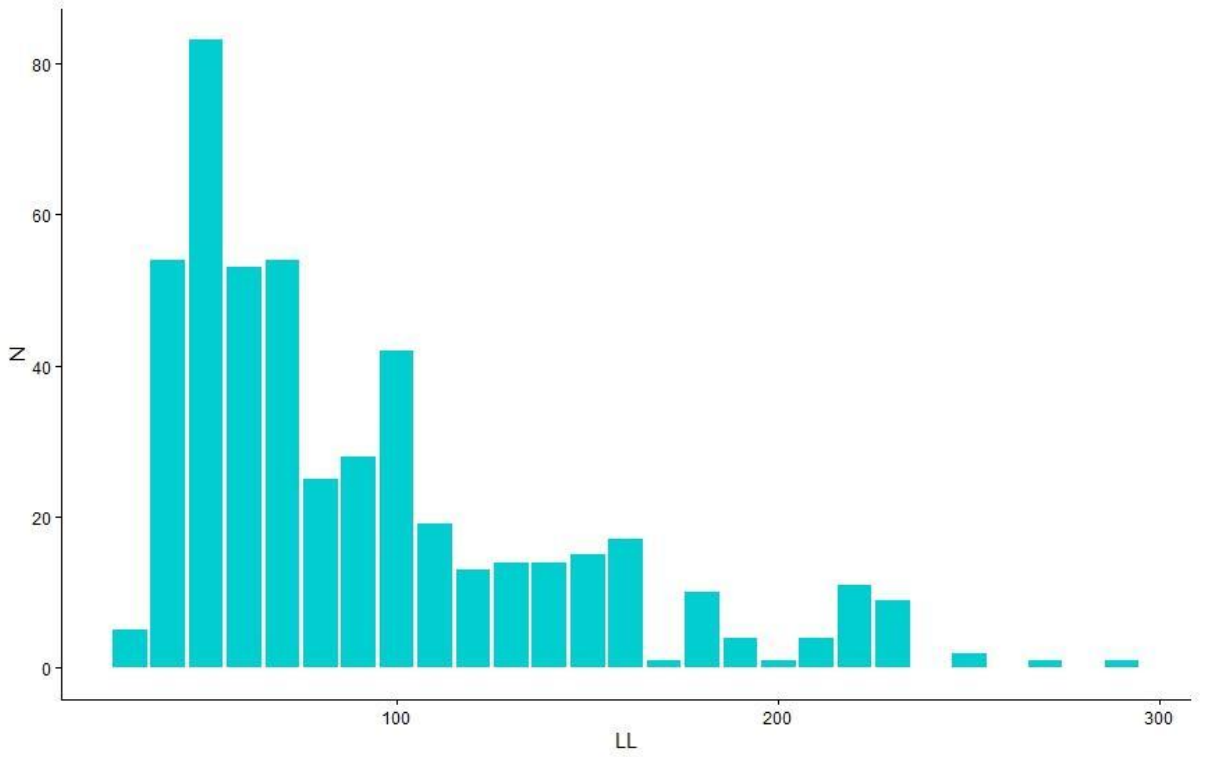

Fig. 3: Size structure of *S. lewini* landed along the Indian coast during 2025

Areas of high abundance

Analysis of the FSI's exploratory survey data indicated distinct areas of distribution for the three species in the Indian EEZ. *C. falciformis* was encountered mainly along the edge of the EEZ off Gujarat in the eastern Arabian Sea (Fig. 4). The relative abundance for silky sharks in FSI surveys was quite low, averaging < 4 animals per 100 hooks. In the case of *A. pelagicus,* the highest occurrence was seen in the Andaman and Nicobar Islands (Fig. 5). The relative abundance was low along mainland India, and even around the Andaman and Nicobar Islands it was quite low (< 3 animals per 100 hooks). *S. lewini* was rarely encountered in the surveys and, from the limited information available, its highest occurrence was seen off Maharashtra, in the eastern Arabian Sea (Fig. 6). Here too, the relative abundance was low, averaging at 2.5 animals per 100 hooks. The high abundance of silky sharks off Gujarat along the edge of the EEZ can be used as input to propose an ISRA in the location, for which further studies would be needed. Similarly, the Andaman and Nicobar Islands could be an ISRA for the pelagic thresher shark.

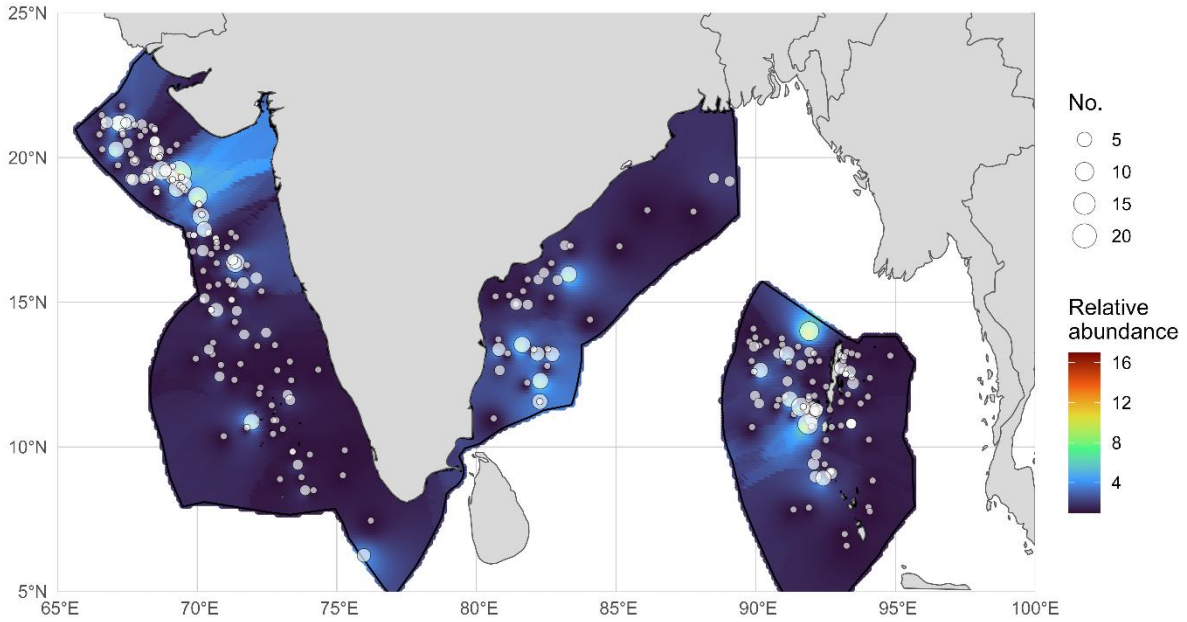

Fig. 4: Areas of *C falciformis* occurrence in FSI surveys

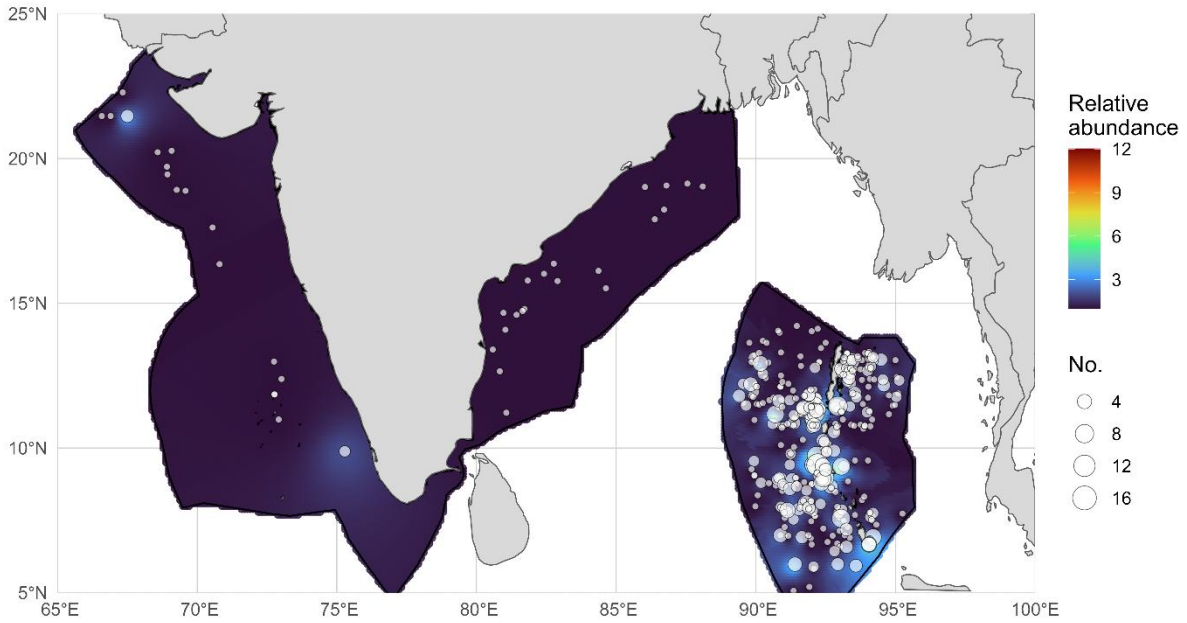

Fig. 5: Areas of *A pelagicus* occurrence in FSI surveys

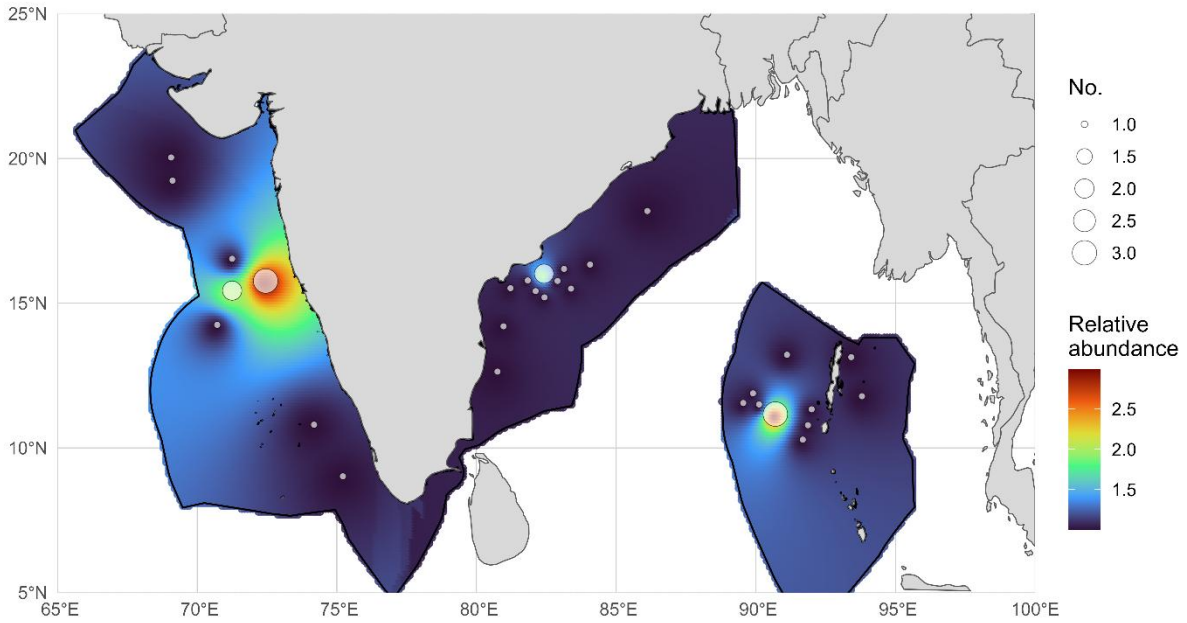

Fig. 6: Areas of *S lewini* occurrence in FSI surveys

Conclusion

Analysis of the PSA results shows that *S. lewini* was the most vulnerable among the 3 species studied, due to its high susceptibility to coastal fisheries. An MLS of 220 cm TL has been recommended for the species; however, prior to its application in Indian waters, wide-scale consultations with stakeholders are needed. Similarly, MLS for *C. falciformis* and *A. pelagicus* needs to be formulated for conservation and sustainable harvest of the stocks of these two species in Indian waters. The distinct geographic areas indicate where potential ISRAs could be recommended for silky and thresher sharks in the Indian EEZ. Given that both silky and threshers are oceanic sharks, the ISRAs proposed for the Indian EEZ would be more effective if modified into ISRAs or even MPAs in the adjacent ABNJ areas, which would require international cooperation for conservation of these species in the region.

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