Threatened Shark Species in the Fisheries off Porbandar, India

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Abstract

Sharks, as apex predators, hold significant ecological importance and are subjects of considerable conservation concern worldwide. India, a prominent shark-catching nation, grapples with the challenge of conserving vulnerable shark species while sustaining fisheries. Understanding the influence of seasons on shark life history and shark landings in different fisheries is an important aspect of crafting effective conservation and management strategies. This paper contributes to this understanding by investigating the seasonal dynamics in the landings of Threatened species of sharks in Porbandar, India, in 2014-2015. Fish landing data collected from December 2014 to October 2015 was explored and analyzed for elasmobranchs. Among the 36 species observed in the landings, 11 were ray species, and 25 were shark species. Of the 25 shark species, 16 were Threatened species: four Critically Endangered species of the bowmouth guitarfish, giant guitarfish, halavi guitarfish, and the scalloped hammerhead shark; two Endangered species of sandbar shark and pelagic thresher shark and eight Vulnerable species including spinner shark, bull shark, pig eye shark, blacktip shark, graceful shark, silky shark, milk shark and grey bamboo shark. Of these, the seasonality, size classes, and sex of the blacktip, milk shark, and scalloped hammerhead sharks (with sample size greater than 90) were further investigated through trend and chi-squared analysis. The scalloped hammerhead shark had significantly higher catches during the monsoon season, with more females and significantly larger individuals compared to other seasons, though all were immature. They seem to use the study area mainly as a nursery ground and for early growth. Significantly more blacktip sharks were caught, with a higher number of females and immature males, during the monsoon season when the near-shore gill net fishery is active. The study area was probably used only as a nursery ground, given the absence of adult males. Milk sharks of all size classes were caught all through the year, which matches their non-migratory nature. They exhibited significantly higher catches during the post-monsoon season ,with more females and larger sized individuals compared to other seasons. Given this knowledge, future studies need to include spatio-temporal mapping of nursery habitats and breeding grounds. This can build a foundation for place-based fishing strategies that reduce the capture of these Threatened species.

Keywords: Shark life history, fisheries management, marine conservation, fisheries compliance

1. Introduction

Sharks are specialized predators capable of occupying diverse aquatic habitats, ranging from coral reefs and mangroves to deep oceanic waters (Heithaus et al., 2022). As apex predators, sharks play a pivotal role in maintaining the delicate balance of marine ecosystems (Heupel et al., 2014). Their presence at the top of the food chain regulates the populations of their prey, preventing overgrazing and ensuring the survival of a wide array of marine species and ecologies. Moreover, sharks exert influence on the distribution and behavior of lower trophic levels, thereby promoting ecological stability and contributing to the overall health and resilience of this unique marine environment (Ferretti et al., 2010). Yet, one-third (37.5%) of all known species of sharks have been listed as Threatened by the IUCN Red List of Threatened Species (Dulvy et al., 2021). Jabado et al., 2018 have shown in fact, that the Arabian Sea harbours 15% of all described chondrichthyan species, of which 78 species were assessed as Threatened (Critically Endangered, Endangered, or Vulnerable), and 27 species as Near Threatened, while twenty-nine species were Data Deficient. Due to sharks' slow growth, large size, low reproductive rates, and late maturity, they are profoundly susceptible to overexploitation (Sherman et al., 2023). The scarcity or patchy distribution of biological productivity, compounded by climate change, further increases their vulnerability to fishing pressure, leaving them with limited chances for recovery (Field et al., 2009; Queiroz et al., 2019).

India, renowned for its rich marine biodiversity, hosts several orders of sharks, including cow sharks, bramble sharks, dogfish sharks, sawsharks, bullhead sharks, mackerel sharks, carpet sharks, and ground sharks (Akhilesh et al., 2014; Venkataraman & Raghunathan, 2015). Worldwide, 296 of 582 species of coastal sharks are listed as Threatened (Pacoureau et al., 2023), most of which are requiem sharks that also form a major proportion of fish landings in the tropics. Of the 56 species of requiem sharks (family Carcharhinidae) described, 26 have been confirmed in Indian waters (Ebert et al., 2013; Akhilesh et al., 2014). India's significance as a major shark fishing nation ranks second only to Indonesia (Zacharia & Vivekanandan, 2013). Such fishing has decimated local shark populations (Karnad et al., 2020).

In recognition of the alarming decline in shark populations, the Indian Government initiated a series of conservation measures. Initially, a complete ban on shark capture was enforced in 2001 under the Wildlife (Protection) Act of 1972. However, due to concerns from fishing communities, the ban was narrowed down to nine out of the ninety-nine shark species within Indian territorial waters. In pursuit of sustainable shark fisheries, the 'fins naturally attached' policy was introduced in 2013, requiring sharks to be landed with their fins intact. Furthermore, the export and import of shark fins were prohibited in 2015 under the Foreign Trade (Development and Regulation) Act of 1992. Despite some regulations in place, most elasmobranchs other than whale sharks are still being overexploited given the inability of technological innovations to be able to discern between them and other similar-sized fish and also the inability of policy to discern between extractable resources versus conservation needs in marine ecosystems.

Particularly, some of the most intense fishing occurs on the west coast of India on the Gujarat coast. Its inshore waters are believed to be some of the most overfished in the country (CMFRI, 2010b). From a countrywide perspective, the largest fleet of trawlers (32.9%) and the second highest number of gill-net vessels (20.4%) operate within these waters (CMFRI, 2010b). Lying between 21°38'19.64"N and 69°35'33.02"E, Porbandar is one of the 121 fish landing centers in the state, accounting for 9% of the total fishing population (approximately 218000 active fishers) of Gujarat (CMFRI, 2010a: Shrivastava & Akolkat, 2015). The fishery craft and gear in Porbandar include trawlers (very few of which have long lines), gill nets, and dol nets (a fixed-bag net that catches fish along moving tides in estuaries; these were not sampled in this study). Each type of vessel has a designated landing site, with landings either transported directly to sorting units or sold at the auction market (Barnes et al., 2018).

Other publications from the same SOSF grant have shown that local consumption is the main driver of shark catch in this area (Barnes et al., 2018; Karnad et al., 2020). Barnes et al. (2018) also presented the seasonality of catch for commercially important shark species in Porbandar. In this paper, we focus exclusively on Threatened species caught in the fisheries off Porbandar and discuss the seasonal variations in their catch numbers and their life history stage. Understanding the influence of seasons on shark catch can provide valuable insights for species-specific place-based conservation and fishing strategies.

2. Methods

2.1 Data Collection

The data utilized in this study was collected by Sutaria et al. (SOSF Grant 282, 2014-2016) under the Save Our Seas Foundation project. Data was collected at two fish landing sites in Porbandar from December 2014 to October 2015, landed at trawl and gill-net landing sites, as well as those that passed through the auction market. The sampling process was executed during the time window of 06:30 to 15:00 hours. To ensure data integrity and avoid duplications, distinct sampling days were allocated for the landing sites and the auction market. The sampling period was segmented into three seasons: pre-monsoon (January to May), monsoon (June to September), and post-monsoon (October to December). The rationale for this division was to explore potential variations in landings across different seasons. Notably, monsoon samples primarily comprised landings from gill-net operations. It is noteworthy that, even though trawl operations were prohibited between May 15th and August 15th, a subset of samples was still sourced from 13 trawl vessels that continued to operate. The comprehensive sampling effort spanned 147 days, encompassing 77 pre-monsoon days, 35 monsoon days, and 35 post-monsoon days.

During each sampling session, a random pile of sharks was selected from a landing, from which a minimum of 15 individual sharks were sampled for analysis. Shark specimens were identified using established morphological characteristics as described by Ebert, Fowler, and Compagno (2013). All sampled individuals underwent measurement, sex determination, and stage of development; pregnancy was noted if visible. The total length (LT) of each shark was measured

with precision to the nearest centimeter by aligning the body along a straight axis, ensuring that the snout and upper caudal fin were approximately in alignment. To identify the sex of an individual, the presence or absence of claspers was noted. In males, the maturity was recorded by examining the extent of the calcification of the claspers. They were categorized as immature (claspers not calcified), maturing (claspers partially calcified), or mature (claspers fully calcified).

2.3 Data Analysis

The data analysis process commenced by initially evaluating the caught shark species to obtain a comprehensive overview of the species composition. Subsequently, each individual species was cross-referenced with the IUCN Red List (2023) to ascertain its present conservation status, shedding light on the extent of Threat within the captured species.

Of the 16 Threatened species identified, specific focus was directed towards species with substantial sample size (n=90 or more) in the data set for an assessment of a) patterns in catch across the three seasons, and b) sex ratios, size class, and life stage. This subset included the blacktip shark, milk shark, and scalloped hammerhead shark. The catch data for these identified species was aggregated across the distinct seasons of pre-monsoon (January to May), monsoon (June to September), and post-monsoon (October to December) periods by sex and size. Following this aggregation, a statistical analysis was conducted using the chi-squared test to determine whether significant differences existed in catch numbers across these different seasons.

Lastly, the results are discussed to explore potential associations with the species' known lifecycle information. The observed catch data for different seasons are discussed with the available information on mating, reproductive activity, migration, nursery habitat selection, birthing, maternal behavior, feeding, and vulnerability to elucidate how the behavior of the species might influence its catch patterns across seasons.

The rays were identified but not sampled as described above. The guitarfish were often found in the marketplace or trader warehouses, where perfect measurements and species identification were not always possible and hence 16 individuals were not identified.

3. Results & Discussion

3.1 Summary of sharks and rays observed, highlighting Threatened species

Among the 36 species of elasmobranchs observed, 11 were ray species, and 25 were shark species (Table 1). Of the 3501 elasmobranchs observed during the study period, the bulk of the observations comprised spade nose sharks (*Scoliodon laticaudus),* grey sharp nose sharks (*Rhizoprionodon oligolinx),* bigeye hound sharks *(Iago omanensis)* and milk sharks (*Rhizoprionodon acutus),* that Barnes 2018 explored for their demographics and length-weight relationships, given their importance for local consumption and livelihood.

Of the 25 different shark species, 6 are classified as Critically Endangered, 2 are classified as Endangered, and 8 are classified as Vulnerable (Table 2) totalling 472 individuals. Of these, one Critically Endangered and two Vulnerable species are explored further for seasonal differences.

Table 1. Summary of sharks and rays landed in Porbandar in 2014-2015

#	**Scientific name**	**Common name**
1	*Carcharinus altimus*	Bignose shark
2	*Carcharinus brevipinna*	Spinner shark
3	*Carcharinus leucas*	Bull shark
4	*Carcharinus amboinensis*	Pigeye shark
5	*Carcharinus limbatus*	Blacktip shark
6	*Carcharinus macloti*	Hardnose shark
7	*Carcharinus plumbeus*	Sandbar shark
8	*Carcharinus sorrah*	Spottail shark
9	*Carcharinus amblyrhynchoides*	Graceful shark
10	*Carcharinus falciformis*	Silky shark
11	*Chiloscyllium arabicum*	Arabian Bamboo shark
12	*Chiloscyllium griseum*	Grey Bamboo shark
13	*Alopias pelagicus*	Pelagic Thresher shark
14	*Rhizoprionodon acutus*	Milk shark
15	*Rhina anclystoma*	Bowmouth guitarfish
16	*Rhynchobatus djiddensis*	Giant guitarfish
17	*Rhinobatos halavi*	Halavi guitarfish
18	*Rhinobatos punctifer*	Arabian guitar fish
19	*Rhinobatos granulatus*	Sharpnose guitarfish
20	*Rhincodon typus*	Whale shark
21	*Rhizoprionodon oligolinx*	Grey sharpnose shark
22	*Scoliodon laticaudus*	Spadenose shark
23	*Sphyrna lewini*	Scalloped Hammerhead shark
24	*Galeocerdo cuvier*	Tiger shark
25	*Iago omanensis*	Bigeye houndshark
26	*Himantura leoparda*	Leopard whipray
27	*Aetobatus cf ocellatus*	Spotted Eagle ray
28	*Gymnura poeccilura*	Variegated Butterfly ray
29	*Himantura imbricata*	Scaletail whipray
30	*Aetobatus flagellum*	Longhnosed eagle ray
31	*Manta alfredi*	Reef Manta ray
32	*Mobula japanica*	Spine tail devil ray

33	*Rhinopetra javanica*	Cownose ray
34	*Pastinachus sephen*	Fantail whipray
35	*Torpedo sinuspersici*	Marbled torpedo ray
36	*Urogymnus asperrimus*	Porcupine ray

Table 2. Summary of sharks sampled and their corresponding conservation status listed as Threatened by the IUCN Red List. *Whale shark was observed as a dead stranding event and was not part of fish landing or market surveys.

IUCN Conservation Status	Scientific Name	Common Name	Number Of Individuals
Critically Endangered	*Rhina anclystoma*	Bowmouth guitarfish	5
	Rhynchobatus djiddensis	Giant guitarfish	1
	Rhinobatos halavi	Halavi guitarfish	4
	Glaucostegus granulatus	Sharpnose guitarfish	1
	Sphyrna lewini	Scalloped Hammerhead shark	116
	*Rhincodon typus**	Whale shark	1
Endangered	*Carcharinus plumbeus*	Sandbar shark	3
	Alopias pelagicus	Pelagic Thresher shark	4
Vulnerable	*Carcharinus brevipinna*	Spinner shark	1
	Carcharinus leucas	Bull shark	33
	Carcharhinus amboinensis	Pigeye shark	1
	Carcharinus limbatus	Blacktip shark	92
	Carcharinus amblyrhynchoides	Graceful shark	11
	Carcharinus falciformis	Silky shark	6
	Chiloscyllium griseum	Grey Bamboo shark	6
	Rhizoprionodon acutus	Milk shark	187

3.2 Size, Sex and Seasonality of Three Threatened Species

Of the 16 threatened shark species observed, blacktip sharks, milk sharks, and scalloped hammerhead sharks had enough samples for further exploration at 92, 189, and 116 individuals, respectively. The data for these species were used to explore seasonality, sex, life history stage, and size range.

A chi-square test of independence was conducted to examine the relationship between the catch of the three shark species: blacktip shark, scalloped hammerhead shark, and milk shark, and seasonality. The analysis showed a significant association between each species' catch and seasons, with $X^2(2, N = 397) = 91.97$ and $p < .00001$ for all three species (Table 3).

Specifically, blacktip sharks were significantly more frequently caught during the monsoon season compared to the pre-monsoon and post-monsoon seasons. Scalloped hammerhead sharks also had significantly more catches during the monsoon season than in other seasons. Milk sharks had significantly more catches during the post-monsoon season compared to the pre-monsoon and post-monsoon seasons. In conclusion, all three shark species exhibited a significant seasonality pattern in their catches, with distinct preferences for certain seasons.

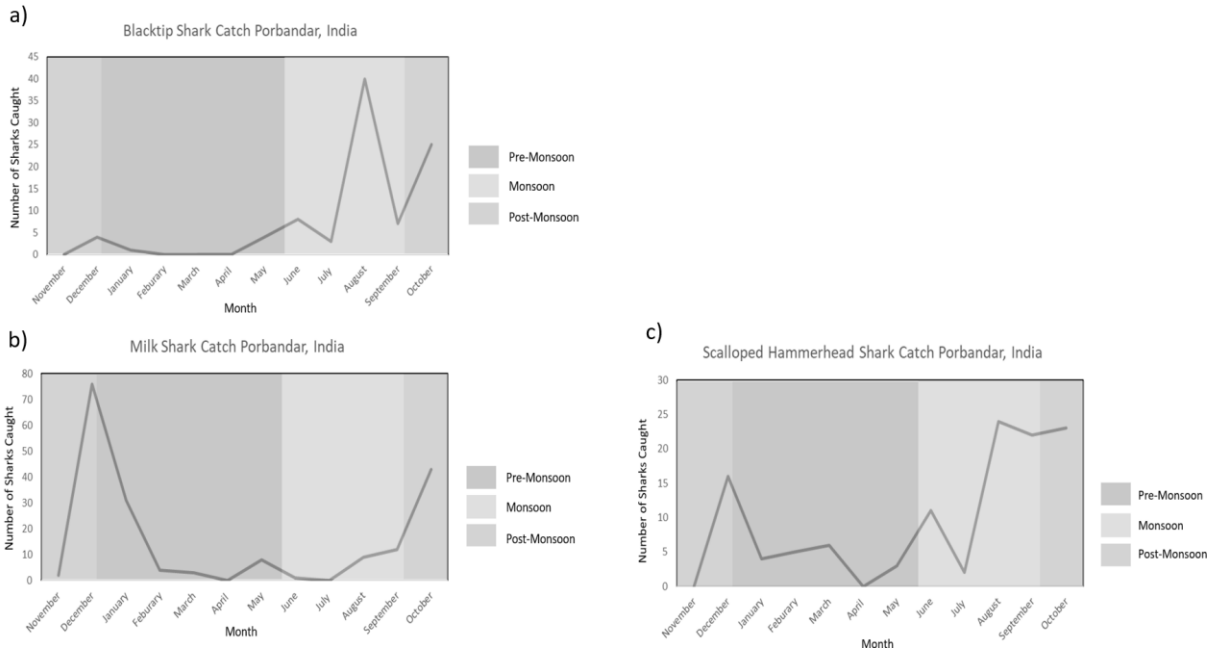

Figure 2. Shark catch across seasons, based on port sampling data collected in Porbandar December 2014 to October 2015. a)Blacktip sharks b) Milk sharks c) Scalloped hammerhead sharks

Table 3. Chi-squared Analysis of Shark Catch and Seasonality. The numbers in each cell represent the observed cell totals. The numbers in parentheses represent the expected cell totals. The numbers in square brackets represent the chi-square statistic for each cell.

	Pre-Monsoon	Monsoon	Post-Monsoon	Row Totals
Blacktip Shark	5 (15.99) \[7.55]	58 (32.21) [20.65]	29 (43.80) [5.00]	92
Scalloped Hammerhead	18 (20.16) [0.23]	59 (40.61) [8.32]	39 (55.22) [4.77]	116
Milk Shark	46 (32.85) [5.27]	22 (66.17) [29.49]	119 (89.98) [10.70]	187
Column Totals	69	139	187	395 (Grand Total)

The Scalloped Hammerhead Shark (*Sphyrna lewini*) holds a conservation status of Critically Endangered. At birth, they are 42 to 55 cm in length, with males maturing at 140 to 165 cm and females maturing at approximately 212 cm. They can grow as large as 3.7 to 4.2 m. Our results show that 116 scalloped hammerhead sharks were caught during the study period. They landed throughout the year, but all males and females were immature, with the largest male observed at 106cm and the largest female observed at 113.2cm. Their numbers were higher in the monsoon and post-monsoon periods (Figure 1, Table 3). Overall, the number of females was higher than males, and the size of females was also higher than males. The chi-squared analysis only for females resulted in X^2 (4, 210) = 45.370, with a p-value of 0.001, indicating a significant difference in catches between seasons, with the highest number of females in the monsoon. Additionally, during the monsoon season, the catch had proportionately larger female scalloped hammerhead sharks (112cm to 49.4cm) (X^2 (4, 115) = 22.464, P-value < 0.001) than in other seasons.

Table 4. The distribution in the catch of Scalloped hammerhead shark across seasons, Porbandar 2014-15.

	Season	Total	Size range (Tl in cm)	Average Total length in cm (SD)
Females	Pre	11	51.5-111	81.9 (SD 24.99)
	Mon	38	49.4-112	61.71 (SD 11.93)
	Post	22	68-113.2	85.45 (SD 13.73)
Males, M1	Pre	7	49.7-74.5	60.35 (SD 8.61)
	Mon	21	47.5-88.5	59.69 (SD 9.02)
	Post	17	48-106	77.88 (SD 16.09)

The Blacktip Shark (*Carcharhinus limbatus*), a medium-sized requiem shark species, is listed as Vulnerable by the IUCN. At birth, they are 53-65 cm in length, with males and females maturing at 150-170cm. They can grow as large as 2.55-2.8m. Our results show that the 92 individuals were caught during the study period. They landed throughout the year, but the numbers were lowest in the pre-monsoon months, and highest during the monsoon (Table 4.). Mature females were found only in the pre-monsoon. All the other times, the sharks were

immature. The overall sex ratio was equal. In terms of size, the Chi-squared analysis did not find a significant difference in the size of blacktip sharks caught across seasons.

Table 5. The distribution in the catch of Blacktip shark across seasons, Porbandar 2014-15.

	Season	Total	Size range (Tl in cm)	Average Total length in cm (SD)
Females	Pre	3	80.7-159.4	106.93 (SD 45.43)
	Mon	27	59-87.5	72.71 (SD 5.96)
	Post	15	70-104	79.38 (SD 8.78)
Males, M1	Pre	2	67.2	67.2
	Mon	31	61-88.5	73.71 (SD 7.43)
	Post	14	72-81	76.72 (SD 3.6)

The Milk Shark (*Rhizoprionodon acutus*) has been listed as Vulnerable by the IUCN. At birth, they can be 27-30 cm in length, with males maturing at 63-71cm and females maturing at approximately 62-74 cm (in some areas, males and females can mature as late as 90cm). They can grow as large as 1.75 m. The highest landing of Milk sharks was recorded post-monsoon. While there are moderate catches in pre-monsoon. Notably, this species appears to be rare in the monsoon months of June and July, during which time the fishery is limited to near shore gill nets and hooks & lines. The results also show that mature and immature individuals were present all year around, with more females than males. Additionally, in the post-monsoon, a chi-squared test revealed a significant sex-based difference in catches. Significantly more females of the milk shark species were caught compared to males during the post-monsoon time (X^2 (4, 210) = 45.370, P-value < 0.001). When considering size, the data suggested a potential size-dependent seasonality for milk sharks. Smaller immature milk sharks (27 to 55 cm) were more commonly caught during the monsoon season, while larger and mature milk sharks (55 to 88 cm) were predominantly caught in the post-monsoon season.

Table 6. The distribution in the catch of Milk sharks across seasons, Porbandar 2014-15.

	Season	Total	Size range (Tl in cm)	Average Total length in cm (SD)
Females	Pre	20	28-71	55.69 (SD 12.83)
	Mon	14	32.68.5	50.5 (SD 15.80)
	Post	63	28-88	60 (SD 12.86)
Males, M1	Pre	19	35-64	53.16 (SD 9.6)
	Mon	4	27-53.5	41.77 (SD 10.96)
	Post	30	32-66	56.3 (SD 9.1)
Males, M2	Pre	4	54.5-64	57.5 (SD 4.4)
	Mon	1	52	52
	Post	4	62-69	66.12 (SD3.11)
Males, M3	Pre	3	85-88	86.5
	Mon	3	81-84	82.5
	Post	22	61-88	77.9 (SD 5.57)

3.3 Lifecycle and Conservation Concern

3.3.1 Scalloped Hammerhead Shark

The scalloped hammerhead shark is characterized by its unique hammer-shaped head with scalloped edges. Thriving in warm oceanic and coastal waters, it tends to form schools. The Critically Endangered classification underscores the pressing threats to its existence, primarily driven by overfishing. The demand for its fins, meat, and other body parts in commercial markets has led to severe population declines. Given its complex social behaviours and distinctive head morphology, the scalloped hammerhead shark is of paramount concern in conservation efforts aimed at ensuring its survival.

The increased catches during both the monsoon and post-monsoon seasons could be influenced by environmental factors or prey availability that attract these sharks to specific areas during these times, potentially making them more vulnerable to fishing activities. Conversely, the monsoon season, characterized by changing water conditions and potential disruptions, may lead pregnant female scalloped hammerhead sharks to seek sheltered areas for giving birth. This migration toward and residence in birthing areas can expose these sharks to elevated fishing activities.

The species exhibits only one distinct lifecycle stage in the waters off Porbandar, with all immature males and females in the landing all through the year, but with a minor spurt in growth during the post-monsoon. This suggests that scalloped hammerhead sharks inhabit areas around Porbandar as nursery grounds and years of early growth. They are potentially vulnerable depending on the location of their breeding areas and nursery grounds. Additionally, there is potential vulnerability as they migrate closer to the shore during the monsoon period, and their vulnerability becomes moderate as they move from nursery areas to the open ocean.

Literature on adult sharks states that during the pre-monsoon period (January to May) (Simeon et al., 2021), pregnant females may carry developing embryos and migrate towards breeding areas and nursery grounds (Gallagher et al., 2018). As the monsoon (June to September) arrives, mating activity likely diminishes, adult males stay offshore while pregnant females are in the gestational phase in nursery grounds. Notably, there are no adult males or females in the catch. After giving birth, adult females move from nursery areas toward the open ocean (FishBase, n.d.-c), which is probably the reason why no mature females were observed in our study, or adult females and males, if caught, were processed on the fishing vessel and thus could not be sampled on land.

3.3.2 Blacktip Shark

The blacktip shark is found in tropical and subtropical waters worldwide and is commonly encountered in coastal shallows. The population of blacktip sharks is on the decline due to threats like overfishing and habitat degradation.

Our analysis showed a significant increase in blacktip shark catches during the monsoon season. This finding aligns with the unique lifecycle and behaviour of blacktip sharks, which tend to mate in the months leading up to the monsoon season. Additionally, the monsoon season may impact their selection of nursery habitats, influenced by changing water conditions and potential disruptions from heavy rains and turbidity.

During the pre-monsoon period (January to May), mating activity may commence, with potential mating as early as January. Pregnant females may carry developing embryos during this phase and display migratory patterns toward breeding/nursery areas while scouting for suitable habitats. As the monsoon period (June to September) arrives, mating activity likely diminishes, and pregnant females are in the gestational phase. Migration continues towards breeding/nursery areas, potentially influenced by weather patterns (FishBase, n.d.-a). Some females might give birth during this period, with births primarily occurring during the monsoon. Mothers may hover around pups post-birth, showing maternal care. In the post-monsoon period (October to December), mating activity may commence again, and pregnant females continue their gestation. Migration behaviour includes moving towards breeding/nursery areas, and sharks settle in preferred nursery habitats, picking sheltered areas for pup safety (FishBase, n.d.-a).

It is potentially vulnerable to fishing activity during the pre-monsoon and monsoon periods due to its altered migration patterns, while its vulnerability becomes moderate during migration in the post-monsoon period. (Table 6).

3.3.3 Milk Shark

The milk shark is recognised by its sharp snout and pale coloration. It inhabits warm coastal waters. Unfortunately, its Vulnerable status signifies the challenges it faces, primarily from fishing activities and the degradation of its habitat. Often incidentally caught in various fisheries due to its small size, the milk shark is undergoing population decline but is an important source of sustenance and economy locally.

Mating for the milk shark does not exhibit clear seasonality but occurs throughout the year. Pregnancy in this species is viviparous, with a remarkable one-year-long gestation period, and a female gives birth to 1-8 pups once a year. Migration behavior is not well-known, as populations tend to remain local without extensive migratory patterns. When it comes to nursery habitat choice, milk sharks inhabit shallow, local estuaries and mangrove forests throughout the year. Birthing occurs throughout the year, but just once a year per individual. Maternal behavior includes females actively seeking out local nursery areas when it is time to give birth, but no parental care is provided to the pups after birth (FishBase, n.d.-b). They are also not known for extensive migrations, and their populations tend to remain local, implying that their movement patterns remain relatively consistent throughout the year.

Due to its local and shallow coastal habitat preference, the species is vulnerable to fishing throughout the year, unlike migratory species that are susceptible only at certain times of the year. Given the milk sharks' rather plastic and generalist reproductive strategy, and that adults and immature individuals use the same area, it is not surprising that they are present year around and in all life stage groups in our results.

Table 7. Sex of sampled sharks by season

Sex	Species	Pre-Monsoon	Monsoon	Post-Monsoon	Total
Female	**Milk Shark**	20	14	63	97
	Blacktip Shark	3	27	11	41
	Scalloped Hammerhead	11	38	22	71
	Total	34	79	97	210
Immature Male	**Milk Shark**	19	4	30	53
	Blacktip Shark	2	31	14	47
	Scalloped Hammerhead	7	21	16	44
	Total	29	56	61	146
Maturing Male	**Milk Shark**	4	1	4	9
	Blacktip Shark	0	0	0	0
	Scalloped Hammerhead	0	0	0	0
	Total	4	1	4	9
Mature Male	**Milk Shark**	3	3	21	27
	Blacktip Shark	0	0	0	0

Scalloped Hammerhead	0	0	0	0
Total	**2**	**3**	**21**	**26**

4. Conclusion

Our investigation reveals a concerning trend of IUCN-listed shark species being captured in Porbandar, India, despite the implementation of various regulatory measures aimed at their conservation. Sharks classified as Vulnerable, Endangered, and Critically Endangered by the International Union for Conservation of Nature (IUCN) continue to be caught in Indian waters. This raises concerns regarding the effectiveness of existing regulations, the pressing need for enhanced enforcement and monitoring, and the far-reaching conservation implications of this ongoing issue.

The presence of IUCN-listed sharks in the catch is not merely indicative of regulatory non-compliance; it has profound conservation implications. These species face varying degrees of risk of extinction, and their continued capture threatens their very survival. Among the captured species are the spinner shark, bull shark, blacktip shark, graceful shark, silky shark, and milk shark, each of which plays a unique and crucial role in marine ecosystems. The loss of these species could set off a chain reaction of ecological consequences, disrupting the delicate balance of oceanic food chains and potentially leading to unforeseen and adverse impacts on marine biodiversity.

It is crucial to acknowledge that our insights into shark catch and seasonality are contingent upon certain assumptions, primarily that fishing activities were consistent and that sampling was conducted consistently, randomly, and representative of a larger population.

Our research underscores the pressing need for conservation strategies specifically tailored to address the intricate dynamics between shark populations and fisheries. To effectively safeguard these vital marine species, further research and policy development should delve into the spatial and temporal aspects of fishing efforts and shark catches. This exploration can pave the way for considerations such as the establishment of protected areas or seasonal closures, aligning with the reproductive and birthing cycles of different shark species.

Additionally, it is known that fishing activity persists during periods of supposed seasonal closures (Barnes et al., 2018). Therefore, heightened enforcement measures are imperative to ensure the efficacy of existing regulations. The commitment to protecting vulnerable shark populations demands resolute action, including the enforcement of closed seasons, in order to preserve these species for future generations.

A cornerstone of successful conservation efforts lies in effective collaboration with fishing communities. Engaging with fishermen to gain insights into their perspectives and concerns is indispensable for crafting regulations that are not only ecologically sustainable but also socially acceptable. To foster cooperation and alleviate the economic pressures associated with catching threatened shark species, incentive-based approaches, such as offering alternative livelihoods or financial incentives for sustainable fishing practices, warrant serious consideration.

In conclusion, the development and implementation of these tailored conservation strategies represent our commitment to not only arresting the further decline of shark populations but also contributing to the overall health and resilience of marine ecosystems. By addressing the complexities revealed in our study, we can forge a path toward a more sustainable future, one where sharks continue to play their crucial role in maintaining the balance and diversity of our oceans.

Table 6. Blacktip shark life history in relation to seasonality in India

Lifecycle Stage	Pre-Monsoon Period (Jan-May)	Monsoon Period (Jun-Sep)	Post-Monsoon Period (Oct-Dec)
Mating	Mating activity may occur as early as January.	Mating activity likely diminishes.	Mating activity may commence.
Pregnancy	Pregnant females may carry developing embryos.	Pregnant females are in gestational phase.	Pregnant females continue gestation.
Migration Behavior	Migratory patterns towards breeding/nursery areas.	Potential changes in migration due to weather.	Migration towards breeding/nursery areas.
Nursery Habitat Choice	Scouting for suitable nursery habitats.	Picking sheltered habitats for pup safety.	Settling in preferred nursery habitats.
Birthing	Some females might give birth during this period.	Births likely occur during the monsoon.	Continued birthing; pups are born.

Maternal Behavior	Mothers leave for nursery habitats before giving birth.	May hover around pups post-birth.	No maternal care; pups independent.
Feeding Behavior	Opportunistic foraging		
Fishing Vulnerability	Potentially vulnerable due to altered behavior.	Potential vulnerability due to altered migration.	Moderate vulnerability due to migration.

Table 7. Milk shark life history in relation to seasonality in India

Lifecycle Stage	Pre-Monsoon Period (Jan-May)	Monsoon Period (Jun-Sep)	Post-Monsoon Period (Oct-Dec)
Mating	No clear seasonality in reproductive cycle		
Pregnancy	Viviparous with one year long gestation period.		
Migration Behavior	Not known for extensive migration. Populations remain local.		
Nursery Habitat Choice	Shallow, local estuaries and mangrove forests.		
Birthing	Females give birth to one to eight young throughout the year		

Maternal Behavior	Females will look for local nursery areas when it is time to birth pups. No parental care given after birth.
Feeding Behavior	Opportunistic foraging
Fishing Vulnerability	Vulnerable throughout the year given the species is local and in shallow coastal waters.

Table 8. Scalloped hammerhead shark life history in relation to seasonality in India

Lifecycle Stage	Pre-Monsoon Period (Jan-May)	Monsoon Period (Jun-Sep)	Post-Monsoon Period (Oct-Dec)
Mating	Mating activity may commence	Mating activity likely diminishes	Mating activity may commence
Pregnancy	Pregnant females may carry developing embryos	Pregnant females are in gestational phase	Pregnant females continue gestation

Migration Behavior	Migratory patterns towards breeding areas	Migration to nursery areas for pregnant females	After giving birth, females move from nursery areas toward open ocean
Nursery Habitat Choice	Scouting for suitable nursery habitats	Picking sheltered habitats for pup safety	Settling in preferred nursery habitats
Birthing	Some females might give birth during this period	Births likely occur during the monsoon	Continued birthing; pups are born
Maternal Behavior	Mothers leave for nursery habitats before giving birth	May hover around pups post-birth	No maternal care; pups independent
Feeding Behavior	Foraging activity influenced by prey availability	Potential changes in prey distribution	Feeding behavior may continue as usual

Fishing Vulnerability	Potentially vulnerable depending on location of breeding area	Potential vulnerability due to migration close to shore	Moderate vulnerability due as sharks move from nursery areas to open ocean

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