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Preliminary assessment of the ecological sustainability of a data-limited small-scale shark fishery in India

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Abstract

Small-scale fisheries support millions of people globally, but if poorly monitored and managed, they can negatively impact threatened marine species like sharks. We explore approaches to assess the ecological sustainability of an extremely data-limited, small-scale fishery for blacktip sharks (*Carcharhinus limbatus*) in Goa, India. We use an adapted expert elicitation approach, modified to suit local fishing communities, to collect data on shark catch and develop exploratory population models to understand conditions under which the fishery could be sustainable. An estimated 13,881–15,616 newborn blacktip sharks are targeted and captured annually by gillnets across our study sites. Our adapted expert elicitation protocol can serve as a rapid, cost-effective, and inclusive method to obtain critical data for conservation planning, especially in data-limited, Global South contexts. Our population models reveal that the current levels of shark harvesting are unlikely to be sustainable and can only continue if harvest rates are reduced by at least half and if the current local shark population is relatively high. Our study provides crucial information to inform conservation decision-making, highlighting the need for urgent intervention to regulate Goa's shark fishery. Working with the local community and understanding the socio-economic dimensions of this fishery can help identify appropriate conservation interventions.

KEYWORDS

elasmobranch, expert elicitation, IDEA protocol, interviews, local communities, population model, small-scale fisheries, sustainable management

1 | INTRODUCTION

Globally, small-scale fisheries (SSFs) provide 37 million tonnes of food annually and comprise at least 60 million people (FAO, 2023). Despite accounting for 40% of capture fisheries, SSFs tend to be poorly monitored, with data scarcity on catch, effort, and socio-economics compounding wider issues of management (Exeter et al., 2021; Pita et al., 2019). Poor management of SSFs can be detrimental to marine species and ecosystems, jeopardizing the security of nearly 500 million people who depend, at least

Avanthika Kamath and Harsha Gaonkar are independent researchers for the duration of this study.

partially, on SSFs (Exeter et al., 2021; FAO, 2023). Small-scale vessels can negatively impact vulnerable marine species like cetaceans, turtles, sharks, and rays through intentional or accidental catch (Alfaro-Shigueto et al., 2018; Temple et al., 2024). Data on the catch of these threatened species is essential for developing effective management plans but remains absent from many fisheries, particularly in developing countries, which account for the majority of SSFs (Wade et al., 2021). Collecting reliable SSF data is challenging due to the large proportion of vessels, diversity of gear used, and species caught, and the often remote or inaccessible contexts of many fisheries (Pita et al., 2019). Therefore, there is a pressing need for rapid, reliable, and cost-effective methods to gather sufficient data on SSFs to support decision-making for sustainable management (Hemming et al., 2022; Wade et al., 2021).

Data scarcity on biodiversity and natural resource use is increasingly addressed through interdisciplinary techniques. Structured expert elicitation—a set of techniques to collect quantitative data and aid in decision making—has shown promise in ecological applications, including fisheries management (Burgman, 2016; Martin et al., 2012). Expert elicitation involves asking a diverse group of 'experts' in a particular field to provide quantitative estimates of an unknown variable that are then aggregated to improve accuracy and precision (e.g., starfish density on a reef; Hemming, Burgman, et al., 2018). Expert elicitation has been used to supplement missing data and parametrize population models in fisheries (e.g., Chrysafi et al., 2019), amongst other applications. A more diverse expert group can provide more accurate or useful estimates (Hemming, Burgman, et al., 2018), yet these approaches are rarely employed with non-scientific experts, such as fishing community members with limited or variable formal education. Arlidge et al. (2020) demonstrated the utility of expert elicitation with fishing communities in Peru for rapid, exploratory evaluations of sea turtle captures and bycatch impact. Thus, expert elicitation holds promise as a tool for inclusive data collection in data-limited SSFs.

Sharks and their relatives are amongst the most threatened vertebrate groups, with over one-third of assessed species facing the risk of extinction due to overfishing (Dulvy et al., 2021). Most shark species show conservative life history traits, such as slow growth and low fecundity, which make them highly vulnerable to overexploitation (Bonfil, 1997). Sharks hold financial, food, and sociocultural values for many communities globally, highlighting the need for sustainable shark fishing rather than fishing bans (Booth et al., 2019). With strong science-based management, most shark species have the potential to support sustainable fishing, with some successful examples from around the world (Simpfendorfer & Dulvy, 2017). However, these examples are largely data-rich fisheries from developed countries. A major share of shark landings comes from SSFs in many developing countries, where they remain poorly studied and monitored, with accurate assessments of shark mortality and biological characteristics missing (Humber et al., 2017). This hinders science-based management, threatening the sustainability of these fisheries and the people that rely on them for their livelihoods and food.

India exemplifies many of these challenges. With one of the largest marine fisheries globally and nearly five million fishers in the country, it ranks amongst the world's top shark fishing nations (Akhilesh et al., 2023; Department of Fisheries, 2022). The diversity of fishing gear, vessel types, and landing sites—over 3000 across the coastline—complicates monitoring and management efforts (CMFRI-DoF, 2020a; FAO, 2024). Limited resources and capacity to monitor these fisheries necessitate the development of cost-effective approaches to collect vital information required for management. Simulation models can be useful tools that support better conservation of sharks and management of their fisheries, particularly if they focus on developing management rules that are robust to uncertainty (Milner-Gulland et al., 2001).

The common blacktip shark (*Carcharhinus limbatus*) is a coastal species widely distributed in tropical and subtropical waters. Although considered relatively productive, with females giving birth to up to 11 pups every 2 years, this species has experienced global population reductions of 30%–49% over the past three generations (Rigby et al., 2021). It is currently listed as Vulnerable on The IUCN Red List of Threatened Species due to overexploitation (Rigby et al., 2021). In India, blacktip sharks are commercially important and widely landed, yet face little regulatory oversight beyond a general fins-attached policy (Akhilesh et al., 2023). Local populations of blacktips and other coastal sharks are suspected to be overexploited or even collapsed, especially along the west coast (Kumar et al., 2024; Mohamed & Shettigar, 2016).

Juvenile blacktip sharks (*C. limbatus*) are seasonally targeted across the Canacona region in Goa, on the west coast, in a poorly documented small-scale fishery (Gupta et al., 2025). Our study explored approaches to obtain the required information and assess the ecological sustainability of this shark fishery. We addressed the following questions: (1) How many sharks are captured in small-scale fisheries in Canacona, Goa? (2) How accurate and useful is expert elicitation in providing catch data in a data-limited fishery? (3) Under what conditions can this shark fishery be sustainable?

We used expert elicitation, adapted to suit local fishing communities, to collect data on shark catch. This information helped parameterize an exploratory population model and sensitivity analysis to understand conditions under which the fishery could be sustainable. We combined these various information sources to produce a preliminary assessment of ecological sustainability, where sustainability refers to fishing practices that do not lead to degradation in shark biodiversity or in natural ecosystem processes (Freese, 2012). Our study provides crucial information to inform the conservation and sustainable management of shark fisheries at our study site, as well as demonstrates feasible and cost-effective methods to understand sustainability in extremely data-limited contexts.

2 | METHODS

2.1 | Study site

Previous research (Gupta et al., 2025) found that small-scale fishers in Goa target young blacktip sharks during their pupping season, particularly in the *taluka* (i.e., sub-district) of Canacona in South Goa. Hence, our study focused on this region and species. Canacona has 11 major fishing villages and several smaller centres that undertake primarily gillnet and artisanal fishing with informal beach landings (Figure 1). There are six mechanized, 230 motorized, and 192 non-motorized fishing crafts registered in Canacona. The region supports a fisher population of 3915, with approximately 700 of these being active fishers (CMFRI-DoF, 2020a, 2020b). Data collection was focused on eight fishing villages in Canacona (Figure 1).

2.2 | Expert elicitation interviews

We adapted the IDEA protocol for expert elicitation to obtain accurate estimates of shark catch by gillnets in Canacona. The IDEA protocol (Hanea et al., 2017; Hemming, Walshe, et al., 2018) consists of the following steps: Investigate, Discuss, Estimate, Aggregate. In the first step, experts 'Investigate' the questions and provide their private, individual, best guess for the questions and their associated credible intervals (i.e., an upper and lower bound). This is followed by Round 2, where experts receive feedback on their estimates in relation to other experts, are brought together to 'Discuss' the results, resolve differences, cross-examine evidence, and then

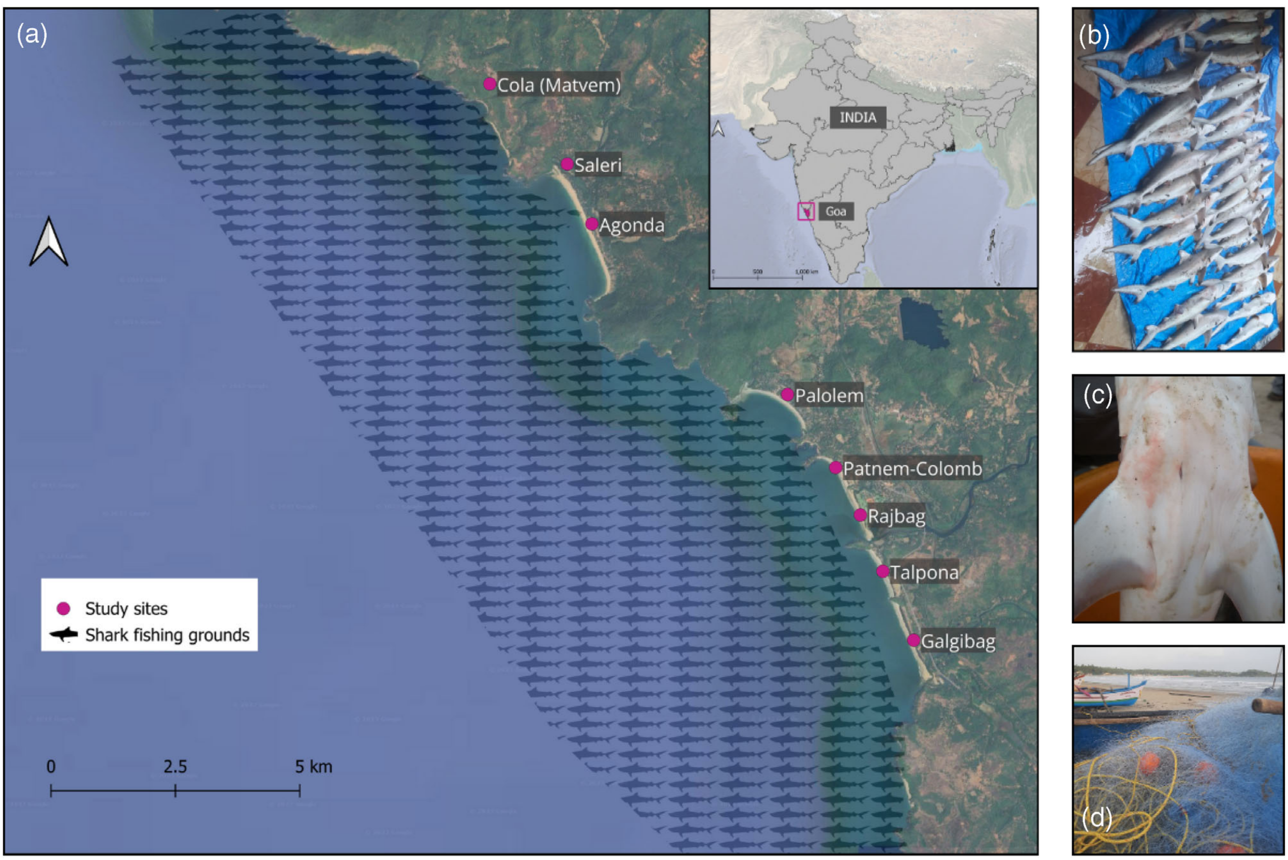

FIGURE 1 (a) Study sites and extent of shark fishing grounds in Canacona, South Goa, on the west coast of India. (b) Blacktip sharks caught by a gillnet. (c) Open umbilical scar between the pectoral fins of a blacktip shark, suggesting a new-born individual (neonate). (d) Gillnet used for shark fishing.

provide a second and final 'Estimate'. Importantly, the aim of the discussion stage in the IDEA protocol is not to achieve consensus but to clarify linguistic ambiguities, encourage critical thinking, and share evidence. These individual estimates are then 'Aggregated' mathematically.

We visited each study village in August 2022 and identified fishers who seasonally catch sharks through informal conversations with local fishers, key informants, and snowball sampling. We focused on interviewing the owner of the shark fishing boat. Many owners went fishing themselves along with their crew, and those who did not actively fish were still responsible for the sale of the sharks. Hence, owners represented the best knowledge of the total shark catch over the entire season.

These boat owners (hereafter, "shark fishers") were approached at the beach, in community areas, or at their homes. We explained the study objectives to each prospective interviewee and provided a brief overview of the interview process. After obtaining informed oral consent, we proceeded with the interview, following procedures approved by the University of Oxford (Ethics Approval Reference: R79807/RE001). In the first round (R1) of elicitation, fishers were asked to provide the upper bound, lower bound, and best estimate (in this order) of their total shark catch over the season for the present year (2022) and previous year (2021). This specific ordering has been shown to elicit the most accurate results (Hemming, Burgman, et al., 2018). Fishers were then asked to provide a 'confidence level' to represent how accurate they thought their estimate might be (Questionnaire in Appendix S1).

Each interviewee was then contacted for the second round of interview (R2) within 12 days of R1. Anonymised estimates of shark catches of all interviewees from R1 were visualized and presented to each interviewee in R2. They were asked to identify their own estimated catch, confirm or modify their estimate, and comment on the catches of other interviewees. R2 also served to facilitate more qualitative and detailed discussions on shark fishing.

The IDEA protocol was adapted in several ways to make it more suitable for the local context and interviewees (Arlidge et al., 2020): (1) Interviewees were asked to estimate their *own* catch, which varies from the catch of others, rather than a single total or average true value, because of the wide variation in catch between fishers and over time in this fishery; (2) We conducted R2 with individual fishers, rather than as a group, due to the potentially sensitive or confidential nature of the catch—fishers would be reluctant to disclose their catches to others; (3) Wording and explanation of the questions were modified to improve understanding by local fishers, after pilot interviews; (4) Several fishers were not available for R2 for different reasons: not reachable or could not be contacted ($n = 8$), busy with fishing activities ($n = 2$), or declined ($n = 1$). Their R1 data were still used in the analysis.

2.3 | Landings surveys

Shark catch was independently surveyed from boats in 2023. Most shark fishing boats landed their catch on the beach at the village of Palolem (Figure 1). Fishing trips started at 5–8 a.m. with boats returning any time between noon and 6 p.m. the same day, depending on the catch and weather conditions. Boats were opportunistically surveyed as they returned. The species and number of sharks caught were recorded, with 1–10 sharks selected at random from each boat and measured for total length (TL), weight, sex, maturity, and presence of open umbilical scars (which signify that they were neonates; Castro, 1993). Fisheries data such as effort, fishing location, depth, and distance from shore were recorded. At the end of the shark fishing season, we interviewed owners of the fishing boats that were surveyed using the adapted IDEA protocol in order to obtain their perceived estimates of shark catch.

Although every effort was made to sample most shark fishing boats and survey all fishing trips by the sampled boats, this was not always possible due to the high variability and unpredictability of shark fishing and inaccessibility of some of the beach landing sites.

2.4 | Data analysis

Our first step in the analysis was to estimate the total shark catches for the Canacona region, for the study years of 2021 and 2022. For this, we first estimated that a total of 40–45 boats engage in shark fishing in Canacona, based on interviews and field observations. We then assessed the sharks caught by the interviewed shark fishers ($n = 31$, approximately 69%–78% of the total shark fishing boats), using the 'best estimate' data provided during the expert elicitation interviews. Missing values of best estimate were imputed based on non-missing data from the relevant round (Appendix S2). The upper and lower bound values were standardized to 80% confidence levels (based on the reported confidence levels from interviewees) for each round to provide credible intervals. Standardized estimates from R2 were used as the final estimate of shark catch for each fisher; for fishers who were not available for R2, standardized R1 data were used. These final estimates were bootstrapped over 10,000 iterations to obtain confidence intervals for shark catch. Finally, these catch estimates for 2021 and 2022, based on our interviewees, were extrapolated and

TABLE 1 Variables and parameters used in the population models.

Parameter	Values used in the present study	Source or reference
Carrying capacity (K)	$K1 = 50{,}000$ $K2 = 200{,}000$	K can be highly variable. For example, K for closely related gray reef sharks (*C. amblyrhynchos*) has been found to be as low as 8000 to as high as 500,000 in different regions (Dunn et al., 2022; Ferretti et al., 2018).
Current (i.e., starting) population size (N_s)	Lowest: 16,701 (for both K values) Highest: 25,000 or 100,000 ($K/2$) Eight other populations equally spaced between this for each K	Manojkumar et al. (2012) for the lowest population size
Stock size threshold (S) A sustainability threshold defined as half the biomass at Maximum Sustainable Yield	$K/4$ (i.e., 12,500 or 50,000)	Cooper (2006)
Annual neonate catch (C)	Five catch scenarios: 2500, 5000, 10,000, 15,000, and 20,000	Based on the expert elicitation results
Fishing mortality rate for neonates (F)	$F = -\log(1 - H)$, where H is the harvest rate of female sharks: $H = C$*sex ratio/total female population size	Haddon (2011)
Bycatch mortality rate ($F_{bycatch}$)	0.01 (added to all age classes except neonates, to represent the low levels of fishing pressure through bycatch)	NA
No. of age classes (a_{max})	20	Smart et al. (2017)
Natural mortality rates (M)	Age-specific mortality rates used, ranging from 0.47 (age 0) to 0.12 (age 19)	Smart et al. (2017)
Age of maturity (a_{mat})	7	Smart et al. (2017)
Fecundity (f)	6.5	Smart et al. (2017)

bootstrapped to get an estimate for the total number of sharks caught in Canacona assuming either 40 or 45 boats were operating.

Next, we assessed the reliability of the expert elicitation method by comparing interview data with empirical data (O'Donnell et al., 2010). Shark catch recorded through landing surveys and estimated through expert elicitation interviews were compared for fishing boats in 2023. As there was a discrepancy between the number of fishing trips for these boats sampled through landing surveys and reported by the owners in interviews, this shark catch was standardized as catch per trip in order to compare the two methods (Appendix S2).

To explore the sustainability of the shark fishery, we used an age-structured Leslie matrix population model adapted from existing models for this species (Smart et al., 2017, 2020). Model parameters such as population size and carrying capacity should ideally be based on local data. However, the data deficiency of our study context meant that we modeled potential scenarios—hence conducting a 'what if' analysis to understand conditions under which this fishery may be sustainable (Milner-Gulland et al., 2001).

1. We set two values for carrying capacity ($K1 = 50{,}000$ and $K2 = 200{,}000$) for blacktip sharks in Goa, since carrying capacity for sharks is globally understudied but thought to be highly variable (Table 1).
2. We set 10 scenarios for current population size (i.e., starting population N_s) for each K value, assuming that the population has been fished for some time and is hence below carrying capacity. The highest population scenario for each K was set as $K/2$, whereas the lowest population scenario was estimated based on a stock assessment for blacktip sharks from the nearby region of Kerala (Manojkumar et al., 2012). Although this assessment may be an underestimate due to the dominance of juvenile sharks in catch and was undertaken over a decade before the present study, we use it to define the lowest N_s for both K values. We generated eight other population sizes in between the lowest and highest N_s for each K.
3. We set five scenarios of annual shark catch (C), bounded by the total shark catch estimates bootstrapped and extrapolated from our expert elicitation interviews. These catch scenarios were converted into instantaneous fishing mortality rates (F), applied only

to the youngest age class (Age 0), to represent the Canacona fishery where only neonates appeared to be caught.

The blacktip shark population was projected for a period of 50 years, modeled for each combination of *K*, N_s and *F* to produce multiple potential scenarios. Model parameters such as fecundity, natural mortality, and age of maturity were adapted from peer-reviewed literature from Australia and Southeast Asia (Smart et al., 2017; Table 1), as reliable local data was not available. We used the stock size threshold (*S*) as a potential measure of sustainability (Cooper, 2006; Table 1). This threshold was calculated for each *K* value used in the model and served as a reference level such that if the shark population falls below this threshold in a particular scenario, the fishing level is likely to be unsustainable. Further details on the steps of the models, scenarios, and parameters used, and the *R* code can be found in Appendix S2.

3 | RESULTS

3.1 | Characteristics of the fishery

We interviewed a total of 31 shark fishers, representing approximately 69%–78% of the total shark fishing boats in Canacona. Of these interviewees, 29 went fishing in 2022 and provided shark catch estimates, whereas 18 went fishing in 2021 and could remember their catch and provided data for this year (Table 2). The most fishers were interviewed from the village of Palolem ($n = 11$), followed by Saleri ($n = 6$). Twelve interviewees (41% for 2022 and 50% for 2021) were interviewed for R2 of the IDEA protocol. In 2023, 42 fishing trips across 11 boats (24%–28% of total shark fishing boats) were surveyed for catch. The owners (i.e., shark fishers) of five of these boats (three of whom were also interviewees in 2022) were also interviewed to obtain shark catch estimates.

Landings surveys confirmed that juvenile blacktip sharks (*C. limbatus*) formed the bulk of the shark catch, with other shark species such as juvenile scalloped hammerheads (*Sphyrna lewini*, mean TL: 53.5 cm) and adult spadenose sharks (*Scoliodon laticaudus*) captured in low numbers (Table 2). Most measured blacktip sharks (92%) had open or healing umbilical scars, suggesting that they were neonates, born within the last 4–6 weeks (Castro, 1993). This finding is further supported by the sizes of landed sharks (mean TL: 72.5 cm), which are within the size at birth recorded for this species (Rigby et al., 2021).

TABLE 2 Overview of demographics of interviewed shark fishers (2021–2023), characteristics of the shark fishery and gear, and biological characteristics of sharks in landing surveys in 2023.

Fisher demographics (2021–23)	
Mean fisher age	43.2 (between 25 and 63)
Years of fishing experience	22.4 (between 5 and 45)
Main livelihood	Fisheries: 44% of fishers ($n = 14$) Tourism: 37.5% of fishers ($n = 12$)
Fishery and gear characteristics (landings surveys in 2023)	
Fishing vessel size	30–38 ft in length with an outboard motor
Gear used	Shark-specific gillnet (locally called *Mori maag*)
Mesh size	4–6 inches
Net width	400–2000 m
Fishing effort	Multiple hauls per trip, each haul having a soak time of up to 90 min
Shark biological characteristics (landings surveys in 2023)	
Species	Blacktip (*Carcharhinus limbatus*), >90%, Scalloped hammerhead (*Sphyrna lewini*), Spadenose (*Scoliodon laticaudus*)
Total number of blacktip shark captures recorded in 2023	945
Number of sharks measured	63
Sex ratio	29F, 34M
Maturity	All immature individuals Open or healing umbilical scars: 92% Closed scars: 8%
Average size	72.5 ± 0.5 cm TL 2289 ± 57.6 g weight

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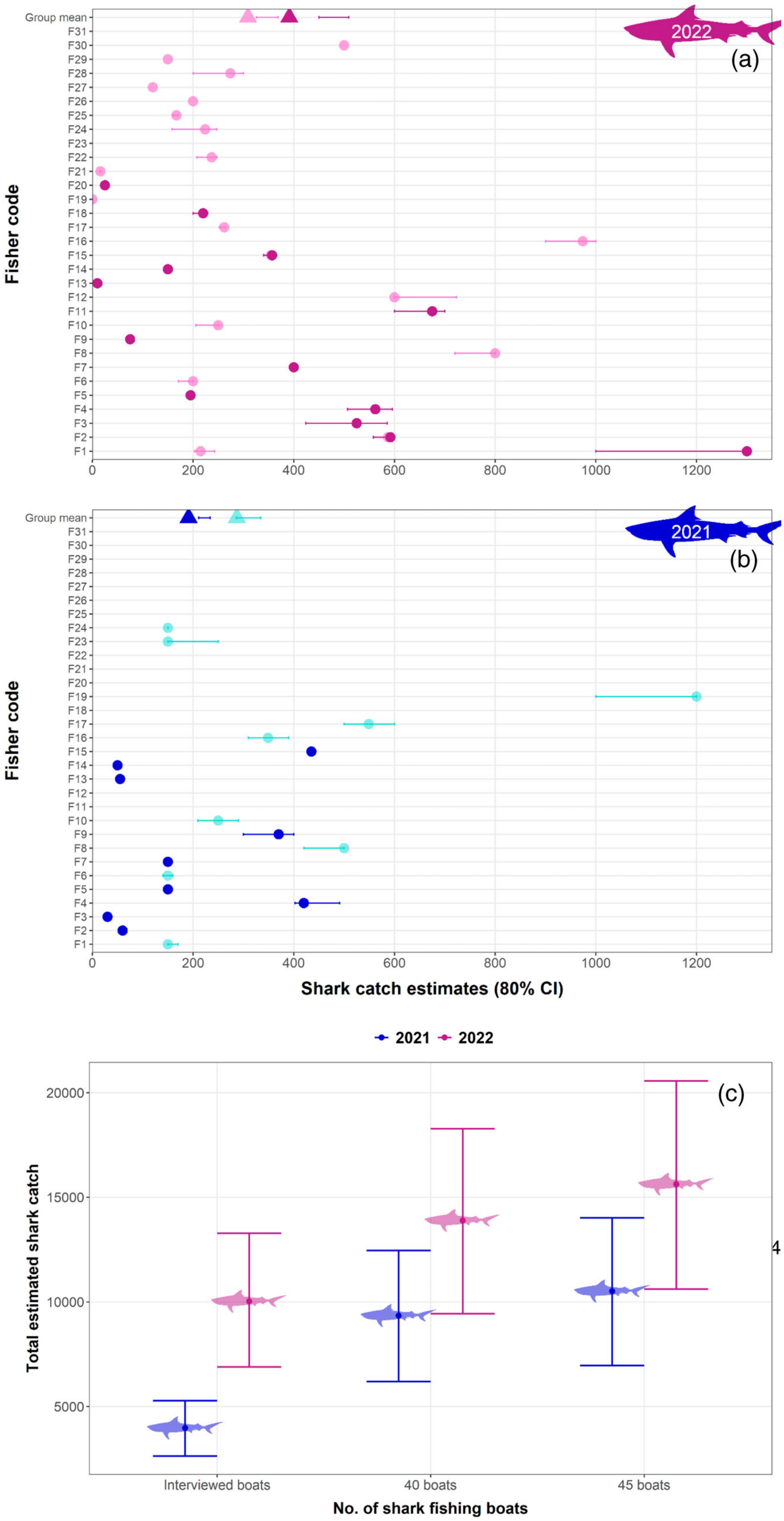

FIGURE 2 Legend on next page.

3.2 | How many sharks are captured in small-scale fisheries in Canacona, South Goa?

Interviewed fishers were estimated to have caught a total of 10,060 blacktip sharks in 2022 ($n = 29$ fishers) and 5168 sharks in 2021 ($n = 18$ fishers). Shark catch was highly variable, ranging from 10 to 1300 sharks caught per fisher over the entire season. Fishers who were interviewed in R2 ($n = 12$) were all able to identify their catch estimates in the anonymised R1 catch data that was presented to them (Appendix S4). These interviewees had little to no change in their responses for estimated catch, with one exception (Figure 2a,b). Fisher ID F1 changed his catch estimate drastically, from 215 sharks caught over the season in 2022 (R1) to 1300 sharks (R2). The fisher stated a lack of trust in the research team during R1, leading him to understate his catch. Better trust and understanding were developed during R2, where the fisher stated he felt comfortable to provide accurate catch data, and showed the research team video evidence of his catch. The re-estimated catch of Fisher F1 in R2 was supported by two other fishers in their R2 interviews.

These catch estimates were bootstrapped and extrapolated over 40 and 45 fishing boats. According to this analysis, we estimated a total of 13,881 sharks caught (95% CI: 9469–18,272) if 40 boats were operating in 2022, or 15,616 sharks caught (95% CI: 10,653–20,556) if 45 boats were operating. In 2021, 9351 sharks (95% CI: 6216–12,427) for 40 boats, or 10,520 sharks (95% CI: 6993–13,980) for 45 boats may have been caught (Figure 2c). Lower catch in 2021 as compared to 2022 was due to poor weather conditions that year, according to interviewees.

3.3 | How accurate is an adapted expert elicitation approach at estimating catch?

We compared shark catches (standardized per fishing trip) between landing surveys and interviews for the 5 boats in 2023 that had the most complete data. Catch per fishing trip was found to be similar across the two methods for most boats, except for Boat 1 where there was a difference of 34 sharks caught per trip between landing survey and interview estimates (Figure 3). For Boat 3, a large number of sharks ($n = 95$) was caught in a single trip, and this number was consistent across landings data and interview estimates (where the fisher specifically mentioned this fishing trip and the high number of sharks caught).

3.4 | Under what conditions can this fishery be sustainable?

The blacktip shark population was projected for 50 years under different conditions: two carrying capacities (K), with 10 starting populations (N_s) each, and facing five levels of fishing mortality (F). Fishing mortality was calculated from annual shark catch for Canacona (Table 1), which ranged from a minimum of 2500 neonates (the lowest possible total catch for the fishery as a whole, estimated from 2021, Figure 2c) to a maximum of 20,000 neonates (the highest possible total catch for the fishery as a whole, estimated from 2022, Figure 2c).

If carrying capacity of blacktip sharks is low ($K1 = 50{,}000$), our models find that the local shark population will reach extinction within 20 years of fishing at a harvest rate of at least 15,000 neonates per year, irrespective of N_s. At harvest rates of 5000–10,000 neonates/year, all populations fall below the sustainability threshold by 20 years of fishing (with most reaching extinction when catch is 10,000). If N_s is high (over 20,000 sharks) and harvest is 2500 neonates per year, the populations decline but take 30 years to fall below the sustainability threshold (Figure 4).

If carrying capacity is high ($K2 = 200{,}000$), only low N_s populations reach extinction within 20 years of fishing at 10,000 neonates per year or higher. However, all populations fall below the sustainability threshold at these levels of harvest by 35 years. With shark harvests of 2500–5000/year, high N_s populations can sustain these

FIGURE 2 Estimates of sharks caught by interviewed fishers in 2022 (a) and 2021 (b), from R1 (light pink/light blue) and R2 (dark pink/dark blue), showing the upper bound, lower bound and best guess. Upper and lower bounds have been standardized to 80% confidence intervals. Triangles represent the aggregate values over all interviewees for each round. One fisher (ID F19) provided a very high estimate of his shark catch in 2021, which was not supported by other interviewees. Fisher F19 was not available for R2; hence due to limited confidence in his catch estimates, this datapoint was removed from further analysis. (c) Estimates of total shark catch in Canacona based on total potential number of shark fishing boats operating in this area (40–45 boats), extrapolated from the current dataset (29 boats in 2022, pink; 18 boats in 2021, blue). The estimates have been bootstrapped to obtain the confidence intervals of total shark catch.

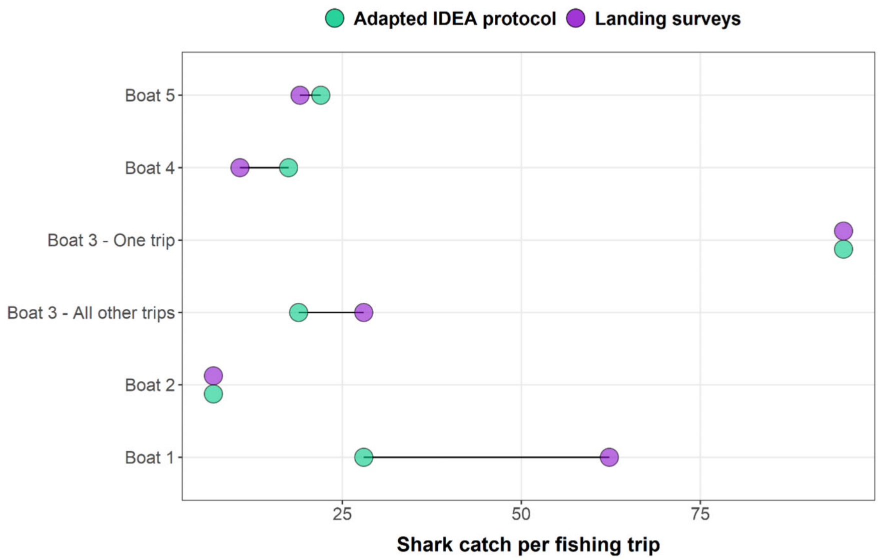

FIGURE 3 Comparison of catch data from interviews using the adapted IDEA protocol (green) and from landings surveys (purple) conducted for 5 fishing boats in 2023. Shark catch is standardized as catch per fishing trip (CPUE) across both methods.

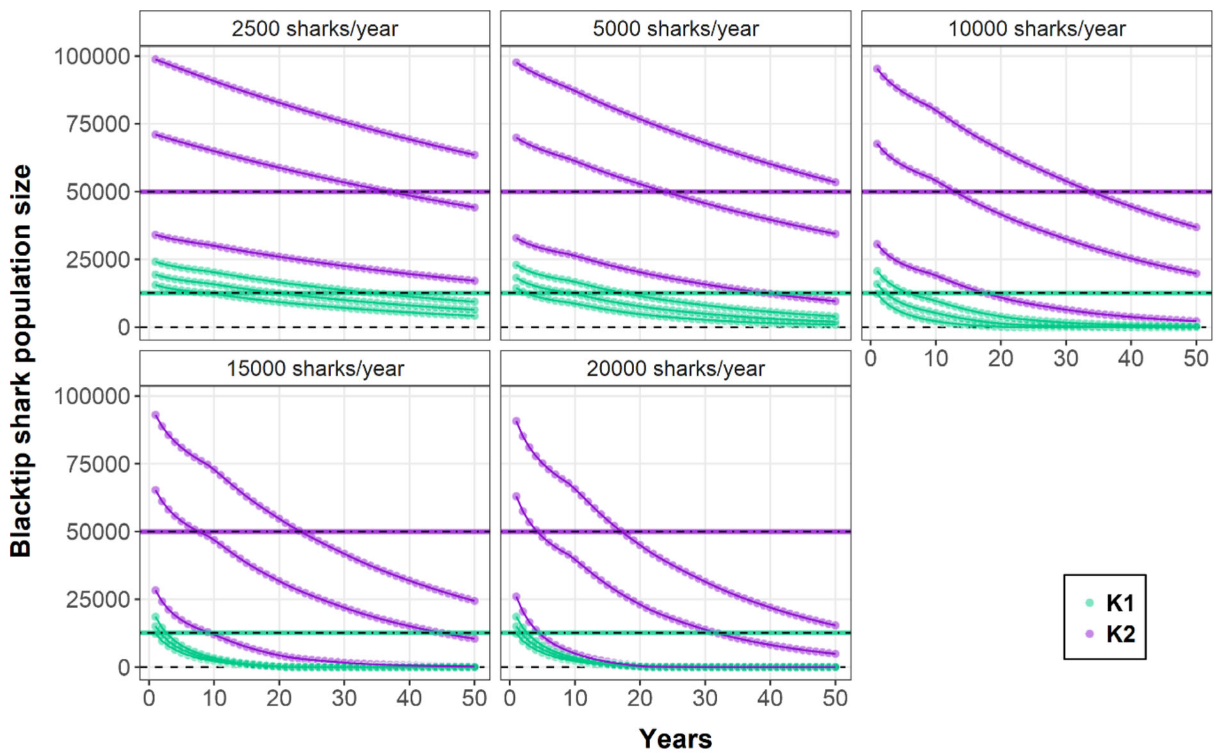

FIGURE 4 Trajectories of shark populations, for a few selected starting population sizes (N_s) and carrying capacity scenarios ($K1$ = green, $K2$ = purple), projected over 50 years under five different levels of fishing pressure (catches of 2500, 5000, 10,000, 15,000 and 20,000). Sustainability thresholds (K/4) are represented as horizontal lines for each carrying capacity ($K1$ = 12,500, green; $K2$ = 50,000, purple).

levels of fishing for at least 50 years without falling below the threshold (Figure 4).

Based on these results, it is unlikely that the current harvest of 10,060 neonates per year is sustainable, unless the carrying capacity is very high (over 200,000) and current population sizes are very high. However, if catch were restricted to 5000 neonates annually, and if both carrying capacity and current population are relatively high, this fishery may be sustainable (Figure 5).

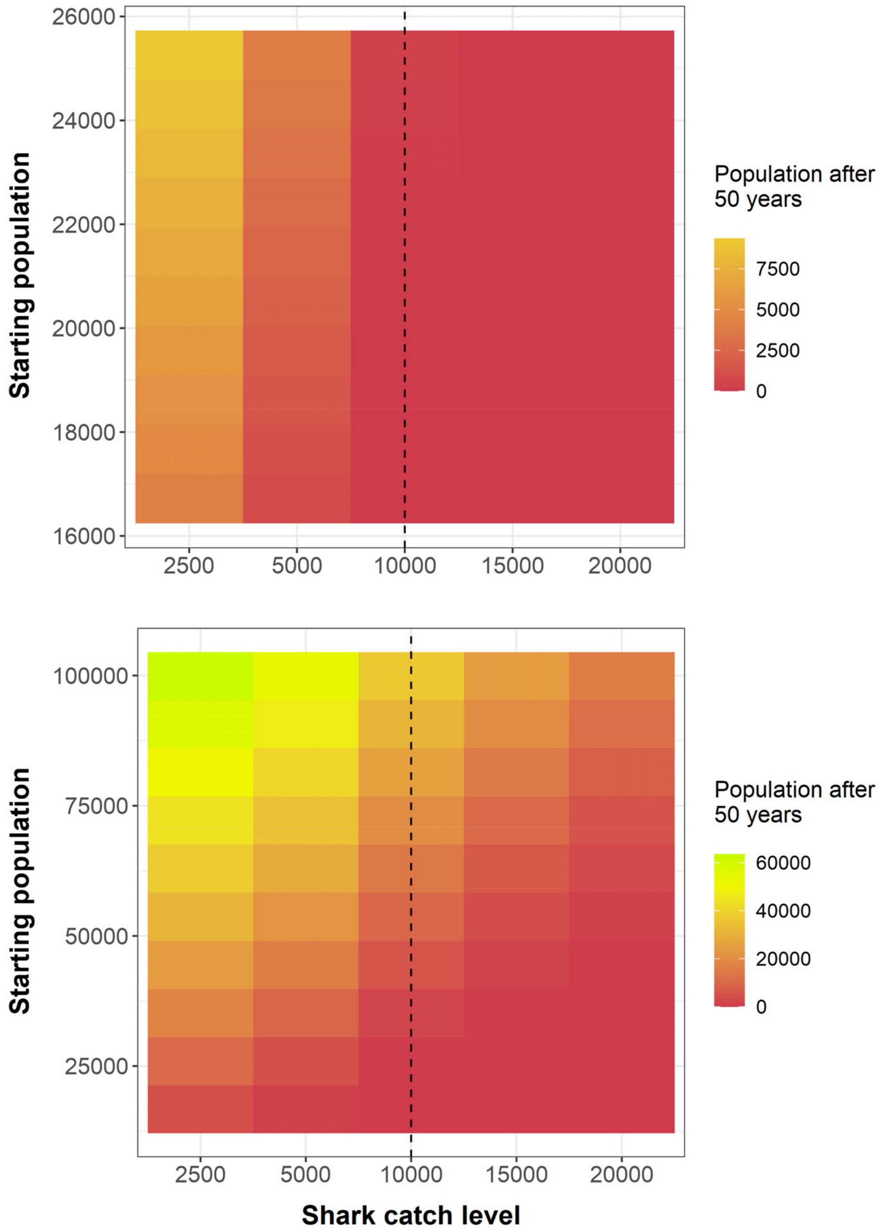

FIGURE 5 Shark populations projected for 50 years of fishing, under different conditions of carrying capacity ($K1$ = top graph, $K2$ = bottom graph), starting population sizes (N_s, y-axis) and shark catch levels (x-axis). The colors represent the final population after 50 years for each combination of conditions, where yellow represents the stock size threshold ($K/4$) for each K value. Red tiles are populations that fall below this threshold, whereas green tiles are population that remain above the threshold after 50 years of fishing. The vertical black line gives the current catch level in Goa based on the expert elicitation data (10,060 sharks).

4 | DISCUSSION

We used an adapted IDEA protocol for expert elicitation to assess catch of sharks in an undocumented small-scale fishery in India. Our analysis finds that between 13,881and 15,616 neonate and juvenile blacktip sharks are potentially being captured by gillnets in a seasonal, targeted fishery. An exploratory population model revealed that this level of harvesting is unlikely to be sustainable, and can only continue if harvest rates are reduced by at least half and if the current population of blacktip sharks is relatively high. Our adapted expert elicitation protocol performed fairly well in obtaining estimates of shark catch, showing potential as a rapid and cost-effective method to obtain crucial data for decision making. We provide data and insights on the catch and sustainability of shark fisheries in Goa for the first time, and highlight the need for urgent management intervention to regulate this fishery.

4.1 | A cost-effective and inclusive approach for data-limited fisheries

Our results show that expert elicitation protocols, if suitably adapted, could serve as useful, cost-effective and feasible methods of monitoring SSFs, which will especially prove helpful in the >3000 marine fishing villages across India's coastline that are poorly monitored at present (CMFRI-DoF, 2020a; FAO, 2024). The approach does come with some challenges and limitations. For instance, people may inflate their reported catches to gain recognition, or under-report to conceal illegal activities (Jones et al., 2008). Overestimation has particularly been noted when collecting data from small-scale fishers (Arlidge et al., 2020; O'Donnell et al., 2010). While these biases may exist in our data, we found that the two rounds of interviews through the protocol helped build trust with community members, leading to more honest and accurate estimates. Conducting the second round of interviews individually, rather than a group, also allowed fishers to triangulate or comment on other interviewees' estimates without social pressures such as groupthink (Mukherjee et al., 2015). The variable and stochastic nature of fisheries catches introduce additional challenges, making methods like this more susceptible to bias. Although we did record some discrepancy between catches estimated through expert elicitation and through landing surveys, the protocol proved sufficiently robust to provide the first catch estimates for an undocumented fishery, and inform exploratory models to explore ecological sustainability.

Aside from the quantitative assessments, interview-based methods such as this are valuable as they can incorporate the knowledge and understanding of local people (Jones et al., 2008). As the movement to include local communities in conservation efforts grows, it is essential to expand our definition of 'expert' beyond scientists and academics (Scheba & Mustalahti, 2015; Zayonc & Coomes, 2022). Although the IDEA protocol is not inherently participatory, it can be adapted to include local resource users in monitoring, decision-making, and management through participatory processes. It can facilitate management that is more inclusive of local communities' insights and knowledge. Expert elicitation can support broader initiatives aimed at creating incentives, resources, and capacity for local stakeholders to engage in research and monitoring (Wade et al., 2021). For instance, in our study, approaching fishers with their own data appeared to be useful in building their interest in monitoring their own catch and potentially participating in future research and conservation action. This engagement is crucial for fostering community involvement and ownership of conservation initiatives, which are key to the long-term sustainability of SSFs.

4.2 | Ecological sustainability

Our analysis suggests that, at the present catch rate in Goa, fishing of blacktip neonates is likely unsustainable. Some studies have found that harvest of neonates or juveniles is not as detrimental to certain shark populations as harvest of breeding adults (Kinney & Simpfendorfer, 2009; Prince, 2002). In fact, neonate (age 0–1) survival may have relatively little influence on the overall population growth rate for blacktip sharks, and exclusive harvest of this age class may be sustainable (Smart et al., 2017). Consequently, our results imply that neonate fishing in Goa is occurring at such a high rate that it crosses the threshold for sustainability. Furthermore, our interviews indicate that this shark fishery is becoming increasingly popular in Goa, with more fishers entering the fishery annually, possibly driven by growing demand for shark meat amongst locals and tourists (Gupta et al., 2025; Karnad et al., 2024). The high value and potentially growing rarity of sharks may incentivize further fishing (Temple et al., 2024). As a result, shark harvest may rise in the coming years, exacerbating the threat to this population.

Blacktip sharks have the potential to support a sustainable fishery. For example, stringent management measures were implemented for the Atlantic blacktip shark population in response to overfishing in the 1990s. These included reduced commercial quotas, recreational size and bag limits, and allowed shark populations to successfully recover (SEDAR, 2020). While these measures have facilitated the sustainable harvest of blacktip sharks over the past few decades by American fishing fleets, the socio-economic and political context in our study site is significantly different. Our models suggest that shark fishing in Goa may be sustained if catch is restricted to 5000 neonates per year, assuming both a high carrying capacity and current population. However, such catch limits will be challenging to implement in practice. Conventional, top-down management through stock assessments and quotas is not always effective or ethical in small-scale fisheries (Berkes, 2003). Nevertheless, recognizing that blacktip sharks can, theoretically, be sustainably fished is crucial for guiding management approaches.

Limited understanding of the sustainability of a fishery can lead to poor decision making and management outcomes, such as banket bans (e.g. Castellanos-Galindo et al., 2021) or open-access, unregulated fisheries (Thiao et al., 2012). In data-limited contexts where there is parameter uncertainty, a "what if" modeling approach that explores scenarios is more feasible and informative for understanding the potential for sustainability under different conditions than attempting to directly model sustainability (Milner-Gulland et al., 2001). Some assumptions do exist with our models, which should be considered. While we attempted to model different scenarios of carrying capacity and shark populations to account for data gaps, it is possible that our models do not accurately represent the true shark population in this region. Model parameters were adapted from research in Australia and Southeast Asia (Smart et al., 2017) and not from local shark populations. Despite these caveats, such models are useful in the contexts of uncertainty and data scarcity to support preliminary decision making. They also highlight crucial data gaps that should be prioritized for future research, like population estimates of blacktip sharks. Such approaches could be used in combination with adaptive management—research efforts could address the critical data gaps over time to improve estimates and models, and then devise better management strategies (Johnson, 2011).

In the context of sustainable management, it is essential to consider the existing local management regimes, informal rules, or regulations within a small-scale fishery. In data-limited SSFs, the absence of documentation and management from external scientific or management authorities does not imply that the fishery is unmonitored or unregulated by the community or local institutions (Gutiérrez et al., 2011; Jentoft, 2004). Approaches used in the present study, such as expert elicitation and population models, should complement existing community-based monitoring and management measures rather than work against them. Integrating these tools with traditional practices can enhance the effectiveness of conservation efforts and foster collaboration between scientists and local communities (Berkes, 2003; Cinner & Aswani, 2007). For instance, methods like expert elicitation can set the stage for participation of local fishers in research (Arlidge et al., 2020; Brittain, 2019), which could be used to initiate a community-based monitoring programme for the shark fishery. This could serve to collect vital data to inform adaptive management, while building engagement and trust with local communities for further action.

Our study provided important insights on the ecological sustainability of the shark fishery in South Goa; however, the socio-economic sustainability and underlying drivers remain poorly understood. While explicit community-based regulations for this fishery were not evident, further study is needed to understand the role of local institutions. The next steps for this fishery should focus on understanding the socio-economic dimensions, such as characteristics and motivations of shark fishers, their economic dependence on sharks, and perceptions of management and conservation.

5 | CONCLUSION

In data- and resource-limited contexts, it is vital that research efforts produce information that can contribute meaningfully to decision making for conservation, management, and policy. Our study illuminates an undocumented shark fishery in India, assessing its status and sustainability to determine whether, and to what extent, it needs to be regulated. We utilized simple, cost-effective, mixed methods that show promise for further development as tools for monitoring data-limited fisheries, particularly SSFs in the Global South. Given that the shark fishery in Goa is likely operating at unsustainable rates, we underscore the urgent need to understand the socio-economic dimensions of this fishery and identify management interventions that are both feasible and appropriate within the local context.

AUTHOR CONTRIBUTIONS

T. G., W. N. S. A., D. K., and E. J. M. G. conceived the ideas and designed the methodology. T. G., A. K., and H. G. collected the data. T. G. analyzed the data with assistance from WNSA and EJMG. T. G. led the writing of the manuscript. All authors contributed critically to the drafts and gave final approval for publication.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

All data used in this manuscript are either presented in the main text, in the supplementary, or will be available on the data dryad repository (archival is in process). Data collection followed procedures approved by the University of Oxford (Ethics Approval Reference: R79807/RE001).

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SUPPORTING INFORMATION

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