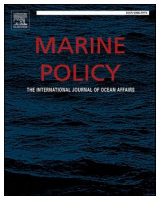
Marine Policy 173 (2025) 106580

Contents lists available at ScienceDirect

Marine Policy

journal homepage: www.elsevier.com/locate/marpol



Identifying leverage points for sustainability in India's shark supply chains

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ARTICLE INFO

Keywords:
Conservation
Elasmobranch
Fisheries
Market dynamics
Uncertainty
Wildlife trade

ABSTRACT

Sharks are highly threatened by overfishing, but hold important subsistence, economic and cultural values for many communities globally, highlighting the need for sustainable and equitable fisheries management. A robust understanding of market structure and dynamics of shark trade, and how they may be driving their fishing and consumption, is needed to develop effective policies for sustainability. Our study described the actor types, supply chain and market dynamics of shark fishing in two sites (Goa and Kakinada) in India to identify leverage points for interventions. Shark meat, rather than fins, was found to be the main traded product at both sites. Shark harvest appeared to be driven predominantly by supply-side factors, although we also identified the importance of demand-side factors (like rising consumption) in influencing shark trade. In Goa, small-scale fishers emerged as the supply chain actors with whom interventions might have most leverage, as they seasonally targeted juvenile sharks, and were found to have relatively high access and negotiation power in the market. In Kakinada, wholesalers appeared to monopolise trade in shark products, particularly fins, and may be a pivotal leverage group. We describe the main uncertainties in our evidence, such as consumption patterns and motivations related to different shark products, to be addressed by future research. We outline a set of potential interventions and policies, from enhancing fisher access to increasing supply chain traceability, to improve the sustainability and socio-economic outcomes of shark trade.

1. Introduction

Wildlife trade is a major driver of biodiversity loss globally, contributing to extinction risk in over 14,000 species [11,45], yet millions of people depend on this for their livelihood and sustenance [19]. Endangered species like sharks are part of this trade, with 36 % of sharks and rays threatened with extinction due to overexploitation [25]. Sharks hold important subsistence, economic and cultural values for many communities globally, highlighting the need for sustainable and equitable fisheries management [33,72,75]. Conservation efforts for sharks include supply-side interventions such as domestic fishing regulations and habitat protection [71]; interventions on transport and sale, like the listing of over 60 species on Appendix II of the Convention on International Trade of Endangered Species of Wild Fauna and Flora [14]; and demand-side interventions, such as demand reduction campaigns (e.g. for shark fins, [83]). However, many of these policies have been developed with limited knowledge of the supply chain and market dynamics within which they are implemented, which can lead to interventions that are ineffective or have unintended consequences due to market distortions. For example, trade bans that restrict supply without reduction in demand can drive up prices and create strong incentives for black markets [12,30,9].

Markets can be described as the combination of institutions, processes, infrastructure and social relations where parties engage in

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https://doi.org/10.1016/j.marpol.2024.106580
Received 19 March 2024; Received in revised form 8 November 2024; Accepted 23 December 2024
Available online 30 December 2024

exchange [21,55]. Understanding the structure of markets, which refers to the configuration of actors and their interactions, can help identify specific points in supply chains that might be causing or maintaining unsustainable practices [58,84]. For example, analysis of the structure of live reptile markets in Indonesia identified a small number of 'gatekeepers' who controlled the market [58]. Strategic enforcement action targeted at these gatekeepers can be more efficient than intervening with the larger number of harvesters. Market dynamics, which refers to whether the market is dominated by supply- or demand-driven processes, can guide where interventions for sustainability should be targeted. For instance, McNamara et al. [46] found that urban bushmeat trade in Kumasi, Ghana, was dominated by supply-side processes, indicating that efforts should focus on harvesters, whereas Smith et al. [73] found demand-driven trade of fish maw in Bangladesh, suggesting interventions with consumers would be more effective. Hence, assessing the structure and dynamics of shark markets can help design effective interventions that address the drivers of unsustainable trade, and identify the leverage points where the interventions need to be implemented [46,55].

India is amongst the top three shark and ray harvesting nations globally; shark fishing in the country is largely unmanaged [36]. Targeted shark fishing was prevalent in the 1980s and 1990s, driven largely by the international demand for fins [40]. Landings have declined since then despite increasing fishing effort, suggesting that shark populations are overexploited [1]. Twenty-six shark and ray species are currently protected under India's Wildlife Protection Act, and shark finning and fin exports are prohibited [1,85]. Effectiveness of these policies is uncertain, however, as illegal fin exports persist, alongside the (often incidental) harvest of protected shark species, and shark populations continue to decline [39]. Additionally, there are currently no regulations for the harvest and trade of non-protected species and non-fin products [1]. Shark fishing continues to be driven by increasing demand for various shark products and poorly controlled trade, and conservation and management efforts have not been able to keep pace with these drivers [39]. A better understanding of domestic shark market and its role in driving unsustainable fishing in India is needed to support better management across the supply chain and improve sustainability of the system, to the benefit of all.

This study described the supply chain and market dynamics of shark fishing in two locations in India (Goa, on the west coast, and Kakinada, on the east coast) to identify leverage points for interventions to improve sustainability (Fig. 1). We focus on the harvesters (i.e. fishers) and traders (e.g., wholesalers, middlemen, vendors) of shark products. We adapted methods and frameworks by McNamara et al., [46], Oyanedel et al., [55] and Milner-Gulland & Shea [48] to investigate shark trade across three analytical levels (actor, inter-actor and market), assessing the different actor types, flow of shark products, their price determinants and supply-demand dynamics (Table 1). We used this evidence, gathered from mixed methods and across multiple analytical levels, to explore interventions which could address different leverage points across the system, and mapped key uncertainties. Each component of the study, from the frameworks used to the proposed interventions, is described as separate sections ahead.

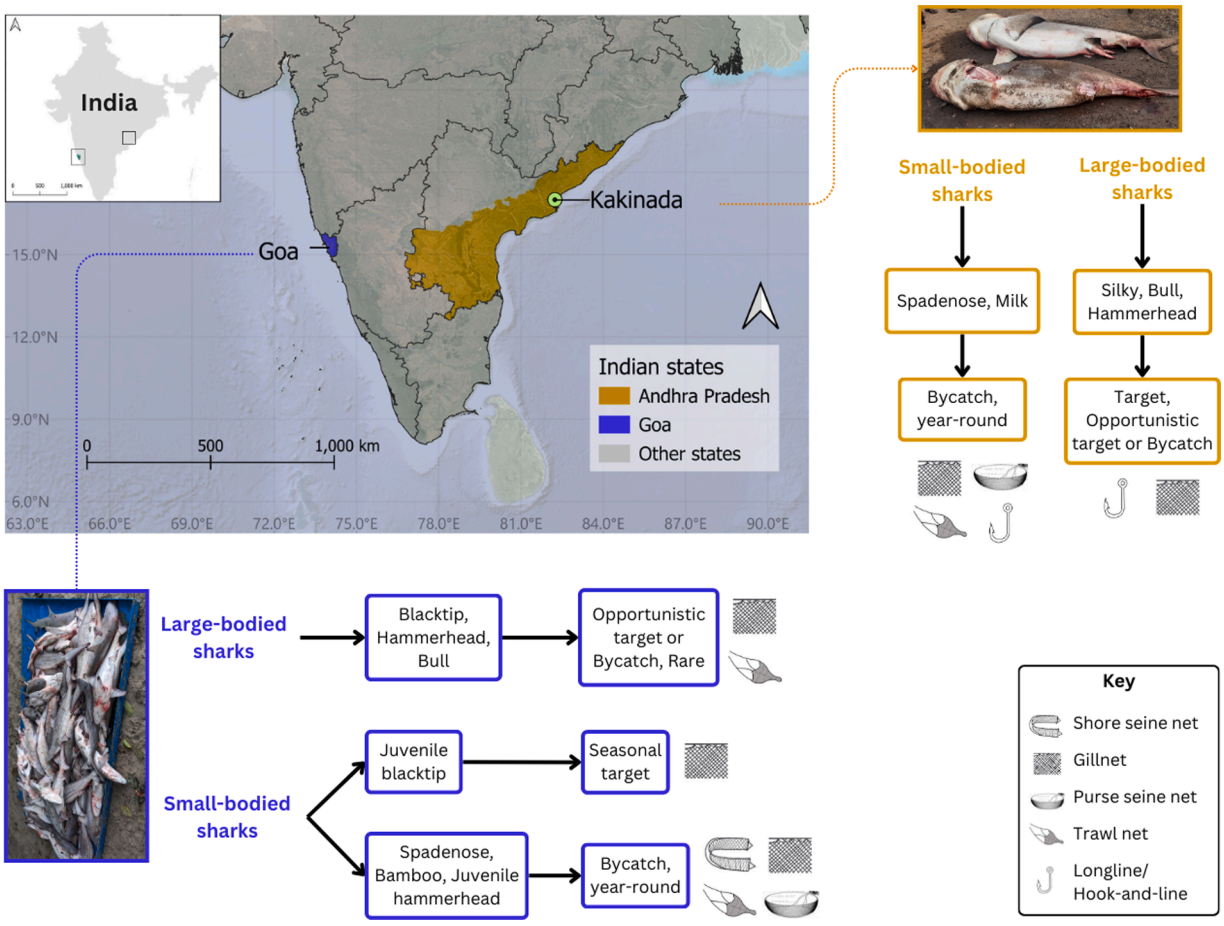

Fig. 1. The study sites of Goa and Kakinada (in the state of Andhra Pradesh) in India (top left). The main groups and species of sharks caught, mode and gear of capture in each site are also shown. The shark species in the figure refer to: Spadenose: *Scoliodon laticaudus*, Bamboo: *Chiloscyllium spp.*, Hammerhead: *Sphyrna lewini,* Blacktip: *Carcharhinus limbatus,* Bull: *Carcharhinus leucas,* Silky: *Carcharhinus falciformis,* Milk: *Rhizoprionodon acutus.*

Table 1
The different components of the present study, adapted from frameworks developed by [46,55] and [48].

Component of the study	Dimension	Description
Analytical levels		
Actor analysis	Motivations	Reasons for an actor's behaviour or particular forms of engagement in a market. Categorised as: **Instrumental**: Driven by economic benefits **Non-instrumental**: Driven by non-economic reasons such as social norms **Mixed**: Exhibiting both instrumental and non-instrumental motivations
	Access	Ability of actors to operate in, and collect benefits from, a market, via formal or informal mechanisms. Categorised as **High**, **Medium** and **Low.** **High** access was categorised when actors showed several diverse and key access mechanisms such as having decision-making or negotiation power, control of prices and market dynamics, knowledge of the supply chain, monopolies and high entry barriers. **Medium** access was categorised when actors exhibited some access mechanisms and had power over some elements of the supply chain, but limited access to other elements and processes. **Low** access included actors receiving low proportion of economic benefits, limited knowledge of the supply chain, low control and decision-making power, indebted to other actors.
Inter-actor analysis	Supply chain structure and flow of products	The structure of the supply chain for sharks at each study site, interaction between actors and the flow of products (meat, fins, others), capital and information through the supply chain.
Market analysis	Prices of shark products	The prices of different shark products at each site, and each point of the supply chain, price determinants (i.e. factors that influence the product prices and quantities) and the own-price elasticities of shark supply.
	Market dynamics	If a market is controlled by a supply- or demand-driven process, determined through set of characteristics such as response of harvesters to price signals, resource condition and consumer choice.
Interventions and uncertainties		
Interventions for sustainability	-	Interventions were categorised as those targeted at particular points in the supply chain (e.g. fishers, traders or consumers), and those applied over the entire supply chain. Interventions were developed based on evidence from this study, with the help of published literature.
Uncertainty	Degree of uncertainty	The degree of uncertainty in the results was assessed qualitatively based on the availability of primary data and the accuracy of information gathered through observations and interviews [30]. Categorised as **High**, **Medium** and **Low.** **High** degree of uncertainty refers to results where a particular dimension remains poorly understood or quantified, or where evidence from this study is not very reliable. **Medium** degree of uncertainty are dimensions that the study results describe to some extent, but gaps in understanding remain that require further assessment. **Low** degree of uncertainty are dimensions that are well understood or described through the results of this study.
	Prioritisation of uncertainty	Prioritising which of the identified uncertainties need to be addressed based on how important and controllable they are. Categorised as **High**, **Medium** and **Low.** **High** uncertainty has a significant and important impact on management outcomes, and can be controlled or mitigated. E.g., compliance of fishers with regulations. **Medium** uncertainty has some impact on management outcomes, and can be controlled or mitigated to a limited extent. **Low** uncertainty has a low impact on management outcomes, and cannot be controlled. E.g., taxonomic uncertainty.

2. Analytical frameworks

Following Oyanedel et al. [55], our study considers 3 levels of analysis: (1) Actor, (2) Inter-actor, and (3) Market. Actor analysis describes the key actors participating the shark supply chain, their roles, motivations for participation and market access. Motivations describe the reasons for an actor's behaviour or particular forms of engagement in a market, and can be instrumental or non-instrumental (Table 1; [2,61]). Access refers to the ability of actors to operate in, and collect benefits from, a market, via formal or informal mechanisms [65].

Inter-actor analysis describes the structure of the supply chain, interaction between actors and the flow of products, capital and information through the supply chain [30,55]. The market analysis describes the factors that determine quantities being traded and their prices, the supply-demand dynamics of the products and whether trade is supply- or demand-driven. McNamara et al. [46] propose a set of characteristics such as response of harvesters to price signals, resource condition and consumer choice, that can help determine if a trade is dominated by supply or demand side factors.

Uncertainties can be pervasive in social ecological systems, particularly in data-limited contexts such as the present study, and can have significant impacts on decision making for conservation [32,52,63]. Uncertainty can be conceptualised in terms of whether it is important and controllable, where important uncertainty has a significant effect on management outcomes, and controllable uncertainty can be managed or minimised [48]. Understanding and identifying these dimensions can help prioritise which uncertainties to focus on in future research.

3. Study sites

Goa and Kakinada were selected for this study as they represent contrasting case studies with different spatial scales (a coastal state vs a single fishing harbour), different species and sizes of sharks caught, type of markets, local socio-economics, culture and historical context (Table 2). Shark fisheries and conservation have been poorly studied in both locations [29]. Goa is a small coastal state in western India with 41 fishing villages and 5 major fishing harbours [24]; Fig. 1, Table 2). While shark landings show an overall decrease over the last 20 years [24,23], anecdotal evidence and field observations suggest that a large portion of shark landings in the state are unreported. Goa hosts a major wholesale fish market at Margao, with retail fish markets of different sizes in most coastal villages and towns, and fish vendors unofficially operating along roads and highways. Fishers in Goa are relatively well educated and well off, with the lowest illiteracy rates amongst fishers in India and the lowest proportion of fisher families falling below the poverty line (Table 2).

Kakinada is a major fishing centre in the state of Andhra Pradesh, east coast of India. The town hosts two fish landing centres of which the Kumbabhishekam fishing harbour is the main hub for shark trade in the region. This harbour is dominated by motorised vessels such as gillnetters and longlines, some of which have been reported to traditionally catch sharks using bottom set gillnets and hook and lines [81]. Sharks landed in Kakinada and the surrounding villages are brought to this harbour and usually sold through an open auction. Outside of the harbours, there is a retail fish market in the town, and vendors also operate informally through bicycles and door-to-door. Shark stocks in this region have been found to be rapidly declining [47]. The state of Andhra Pradesh has the highest illiteracy amongst fishers in India and the highest proportion of families falling below the poverty line (Table 2). Fisheries in both sites are managed by the respective State Fisheries Departments, with similar management approaches across both but with some differences (e.g. the timing of the seasonal fishing ban period, Table 2).

Given these contrasting contexts, our research uses these two independent case studies, not necessarily to compare between them, but instead to illustrate the different ways markets can drive fishing dynamics, and how context-specific interventions are needed to improve sustainability [85].

Table 2
Top: Demographic and fisheries statistics for the two study sites, obtained from [16,15,24,47][24]. Bottom: Sample sizes and summary of interviews conducted at each site in the present study.

	Goa	Kakinada
Demographic and fisheries statistics		
Fisher population	12,651	16,211 (Active fishers)
Proportion of fisher families falling below poverty line	22 %	99 %
Illiteracy rate	14 %	66 %*
Total number of registered fishing vessels	2984	1240
Proportion of mechanised, motorised and non-motorised crafts**	Mechanised: 29 % Motorised: 62 % Non-motorised: 9 %	Mechanised: 18 % Motorised: 82 % Non-motorised: 0
Total marine fish landings in 2021 (metric tonnes)	121,469	Not available
Shark landings in 2021–22 (metric tonnes)	407	Not available
Marketing efficiency***	78.45 % (highest of all maritime states)	69.45 % (lowest of all maritime states)
Fisheries Management Authority	Goa Fisheries Department	Andhra Pradesh Fisheries Department
Seasonal fishing ban period for mechanised vessels	June 1 – July 31	April 15 – June 15
Summary of interviews		
No. of interviews	58	35
Type of respondents	Fishers: 29 (gillnets: 19, mechanised crafts: 7, multiple gear types: 3) Traders: 29 (Wholesaler: 10, Middleman: 3, Vendor: 16) Gender: 50 male, 8 female	Fishers: 23 (Boats operating gillnets and longlines: 12, operating gillnets only: 2, operating longlines only: 8, trawler: 1) Traders: 12 (Auctioneer: 2, Wholesaler: 6, Middleman: 1, Vendor: 3) Gender: 32 male, 3 female
Average years of experience in fisheries	24	24
Place of origin	Fishers: 93 % from Goa Traders: 62.1 % originally from other states, particularly Karnataka	Fishers: All from Kakinada or neighbouring villages Traders: 83 % from Kakinada, few from other parts of India

* indicate statistics that are for the state of Andhra Pradesh overall, not Kakinada specifically

** mechanised crafts are those with engines permanently fitted to the hull and use machine power for both propulsion and fishing operations. Motorised crafts are those with engines (inboard or outboard) that are used only for propulsion and not fishing operations, and non-motorised crafts do not use any kind of machine power for propulsion or fishing [17]

*** marketing efficiency is calculated as the percentage of the ratio of fish price at the landing centre to the retail centre. High marketing efficiency indicates better distribution of profits across the supply chain [15].

4. Data collection and analysis

Data were collected primarily through semi-structured interviews with supply chain actors in 2022 and 2023, particularly fishers and traders, at both sites (Table 2). The term 'fisher' hereafter refers to actors who harvest sharks from the sea, including small and large-scale fishers, boat owners (who actively fish) and crew members. 'Trader' collectively refers to all actors involved in the processing and sale of sharks and their products, including wholesalers, auctioneers, processors, and vendors. Interview questions were tailored to the type of actor being interviewed; in general, we collected information on respondent demographics, shark fishing and catch, shark trade and demand, prices, market structure and access dynamics (Supplementary 1 and 2). Since shark supply chains tend to vary based on the size of the shark (revealed through pilot surveys), we grouped questions into those covering large-bodied sharks (>1 m in Total Length TL) and small-bodied sharks (<1 m TL). In Goa, juvenile blacktip sharks (*Carcharhinus limbatus,* 60–80 cm TL) were an additional category for data collection and analysis as there was a separate fishery and supply chain that operated for these species. This separation simplified data collection and analysis whilst also avoiding errors in species identification (Supplementary 1).

Alongside the semi-structured interviews, we conducted informal interviews at both study sites with other supply chain actors (shark meat cutters, transporters, consumers) and key informants (local researchers and fisheries officers), adapting the same questionnaire and lines of inquiry as the formal interviews, depending on who was being interviewed (approximately 21 informal interviews in total). Data collected through these informal methods helped triangulate and contextualise information gained from interviews. This study received ethics approval from University of Oxford's ethics committee (Reference: R79807/RE001).

We analysed the data at three main levels – actor, inter-actor and market analysis – using descriptive statistics and illustrative quotes (details in Supplementary 1). We first describe the historical context of the shark fishery at each site, as it emerged as an important theme through the analysis. Actor motivations were categorised as instrumental, non-instrumental or mixed, whereas access was categorised as low, medium or high (Table 1). Supply chains of sharks were

constructed semi-quantitively for each site. We mapped the relative volumes of flow based on proportion of respondents that mentioned a particular connection in the supply chain (adapting the approach used by [35]). We investigated prices of shark products at different supply chain nodes. We further examined the own-price elasticities of shark supply, which refers to how the fishing and supply of sharks responded to changes in market price [67]. We used a qualitative approach, as there is a lack of objective market data for a quantitative econometric analysis.

Uncertainties present in our analyses and the results were qualitatively classified as high, medium and low based on the degree of uncertainty and level of priority (Table 1). Finally, data and evidence from our study were used to devise potential interventions at specific leverage points in the supply chains that could improve the sustainability of shark fishing.

5. Historical context

> "10 years ago (or even earlier, in my grandfather's time), people didn't really target sharks. They didn't have proper motors and gear to catch sharks, or much knowledge and awareness of them. This targeted fishing of sharks only started 5–10 years ago. So that's why shark catches are now increasing". A fisher in Goa

Key informants in Goa described a seasonal, targeted fishery for juvenile blacktip sharks (*C. limbatus*) that developed 10–15 years ago by small-scale fishers (most belonging to traditionally fishing communities). This fishery started due to emerging knowledge about the seasonal presence of these sharks nearshore. It was facilitated by the improving socio-economic conditions of local fishers that allowed better access to fishing craft and gear – specifically, a specialised bottom-set gillnet used to target sharks ('*Mori maag*'). While the number of fishers participating in this fishery has increased over the past decade, it remains limited to certain seasons and parts of Goa due to access and logistical factors. Hence while some fishers indicated an increase in shark catch in Goa over the past decade (fishers=3, 10 % of fishers), they participated in the targeted blacktip fishery and were referring to rising catches of these sharks. Most other respondents perceived a decline in shark catch overall, similar to other fish catch (fishers=21, traders=16, 64 % of respondents). Respondents also mentioned the declining catch of large-bodied sharks, which used to be encountered as bycatch and opportunistically taken in various fishing gears (fishers=6, traders=4, 17 % of respondents).

> "15–16 years ago, we used to only catch sharks. It was the only thing worth money back then. After the reliance oil rigs came [around 2008], we started fishing for tuna which was easier. For sharks we have to go 50–62 miles while for tuna we only have to go 30 miles". A fisher in Kakinada.

In contrast, targeted shark fishing was widespread in Kakinada 10–15 years ago. Large-bodied species like silky sharks (*Carcharhinus faciformis*) were targeted with specialised longlines ('*Saura thadu*') in motorised vessels. This shark fishery declined drastically due to multiple reasons: decline in shark catch (fishers=10, 44 % of fishers), shark fishing was considered difficult or dangerous, requiring longer travel offshore (fishers=9, 39 %), and tuna fisheries developed as a viable alternative (fishers=14, 61 %). According to the latter group of respondents, tuna became easily available due to the newly constructed offshore oil and natural gas platforms that appear to act as fishing aggregator devices (FADs). Tuna fisheries also developed through government schemes [47] and improvement of post-harvest facilities. Many fishers switched to tuna fishing over the past decade and reduced or even stopped targeting sharks. Nearly all respondents (fishers=22, traders=10, 91 % of respondents) indicated a decline in shark landings in Kakinada, as well as in the number of vessels targeting sharks.

6. Actor analysis

6.1. Main actors and motivations

In both sites, our interviews suggested that the main actors in the shark supply chain were fishers (both small and large-scale), traders (e.g. wholesalers, middlemen and vendors) and consumers (Table 3). Fishers in Goa included gillnetters who seasonally target juvenile blacktip sharks, and other fishers who use a variety of gears that capture other sharks species as bycatch throughout the year (Fig. 1). In Kakinada, fisher interviews largely focused on motorised boats that operate gillnets and lines and catch large-bodied sharks. We also interviewed a few trawl fishers who bycaught small-bodied sharks (Fig. 1). Traders in Kakinada also included auctioneers, who are not a major actor group in Goa.

Fishers were found to exhibit both instrumental and non-instrumental motivations for participating in fishing in general, and for sharks in particular (Table 3). The latter included shark fishing as a cultural or traditional practice (e.g., their fathers and grandfathers used to fish for sharks as well, Goa=23, Kakinada=19, 81 % of fishers in both sites), food and subsistence (sharks were take-home catch, Goa=14, Kakinada=14, 54 % of fishers) and social norms and influence (e.g., fishing for sharks due to the influence of friends or family, suggested by informal interviews).

Vendors (Goa=11, Kakinada=3, 74 % of vendors at both sites) also exhibited mixed motivations, as many of them belonged to fishing communities and traded fish for cultural/traditional motivations, and food. All other traders (auctioneers, wholesalers, middlemen, 54 % of traders across both sites) appeared to participate in fish and shark trade for instrumental reasons, specifically making money (Table 3). Many fishers in Goa had alternative livelihoods, particularly in the tourism industry, reducing dependence on fisheries. However, informal interviews suggested that fishing for sharks and other fish during the non-tourist season may be important culturally and for subsistence among small-scale fishers (Table 3). For most other actors across both sites, however, fishing formed their primary profession and they lacked alternative sources of income.

6.2. Access dimension

In Goa, wholesalers were identified as having high access to benefits from shark markets. They used a suite of mechanisms to maintain this access, such as capital, information on supply and demand, relationships with traders further downstream, and maintaining relatively high entry barriers (through social ties, for example, where wholesalers were often dominated by people from certain villages and communities). However, fishers, particularly from traditionally fishing communities, emerged as having increasing access and negotiation power in the system. Fishers had access to multiple trader types and could decide where to sell their catch based on the highest price. Fishers also exhibited improving socio-economic conditions due to their participation in the growing tourism industry in Goa, and appeared to have better access to capital. This lowered their reliance on traders for access to credit, with very few fishers taking loans from traders at present. Increasing access of fishers has been explicitly mentioned by all interviewed middlemen in Goa ($n = 3$), who stated that this has reduced their profits (Table 3).

Access dimensions were different in Kakinada, where fishers appeared to have the lowest level of economic benefit from the fishery. Fishers had limited knowledge of the market and prices, and little control over where and how their catch was sold, relying almost exclusively on auctioneers for trade. Auctioneers monopolised catch through provision of loans and contractual agreements with fishers. Wholesalers appeared to be the most significant economic beneficiaries, with access to different traders for each type of product, and access to and control of supply and demand for sharks (Table 3).

Table 3
Description of actor types in the shark supply chain: their roles, motivations and access. Quotes are provided to illustrate particular dimensions of the actors' motivations or access. Text in **blue** in the table indicates statements specific to Goa, text in **yellow** are statements specific to Kakinada, whereas text in **black** is statements relevant to both sites.

Actor	Description and role in the shark supply chain	Motivation	Access	Illustrative quote	Comments
Fisher	Different types of fishers (small and large-scale), male, who catch and land sharks using a variety of gear. In Goa, many boat owners are also directly involved in the sale of fish.	Mixed	Medium-high in Goa Low in Kakinada	*"My friend taught me about shark fishing a few years ago, that's when I started it. I only fish for sharks in the non-tourism season, as we have nothing else to do then"* – a fisher in Goa	Most fishers exhibited increasing access to benefits from shark markets in Goa.
Auctioneer	Closed group of approximately 30 men responsible for auctioning off all catch from boats to the highest bidder. Worked on commission of 10%. Provided loans to a certain number of boats and hence had fixed contracts with them.	Instrumental	High	*"Anyone can sell fish here, but outsiders are not allowed to auction. Only the set number of auctioneers have the right to auction fish here"* – an auctioneer in Kakinada	Auctioneers monopolise catch from fishers through provision of loans; this group also has high entry barriers.
Wholesaler	Trading companies that purchased whole sharks in large volumes from local vessels as well as markets outside the study sites, and distributed to multiple markets (locally and outside). Wholesalers also engaged in trade of specific products, such as fins and liver.	Instrumental	High	*"It's the wholesalers who control the market. They have the capital, and they don't allow anyone else to enter this business"* – a fisheries officer in Goa *"Fishing is a very lucrative business, we can make high profits"* – a wholesaler in Kakinada	Wholesalers in both sites control market prices, move shark products in and out based on demand, have access to specialised traders for different products (eg. fins), maintain access through social ties, with relatively high entry barriers.
Middleman	Small companies or individuals (generally non-local) who purchased sharks and fish from boat owners and distributed them outside of the state. In Kakinada, middlemen dealt with meat only, purchasing it from wholesalers or through the auction, processing and distributing it among local vendors and consumers.	Instrumental	Medium	*"Nowadays fishers are directly selling their catch to wholesalers, cutting us out. We're getting lower profits than before"* – a middleman in Goa	Middlemen in Goa claimed reducing access to catch as fishers had increasing negotiation power and access to sell their catch to the highest bidder. Middlemen in Kakinada had limited access to fin traders and hence could not benefit from that trade.
Vendor	Vendors purchased shark meat from fishers or different traders and sold it to local or regional consumers. Both male and female actors, who sold fish either through formal retail fish markets or through informal means such as door-to-door and roadsides.	Mixed	Varied/ medium	*"This is our traditional practice, my mother used to trade fish. My mother-in-law was in this business as well, I took over from her"* – a vendor in Kakinada	Limited control of prices. Maintained access through relatively high entry barriers, as this role is historically undertaken by vendors from traditional fishing communities.
Consumer*	Consumers of shark meat composed of native Goans (both Catholic and Hindu communities) and restaurants catering to foreign tourists in particular. Consumers were locals of Kakinada and surrounding villages such as Amalapuram, Pedapudi and Karapaka.	–	–	–	–

*Limited information on consumer motivations and access as they were beyond the scope of the current study.

7. Inter-actor analysis

7.1. Supply chain structure and flow of products

In Goa, meat was the primary traded product. Sharks were usually sold whole and fresh; only few respondents (fishers=2, traders=5, 12 % of respondents in Goa) stated that they processed (i.e. dried) sharks, and only when they were large-bodied, or unsold after some days. The upstream supply chains were diverse and localised, with many different channels that sharks moved through post-harvest (Fig. 2). Fishers would sell directly to different actors in the supply chain, depending on quantity of sharks; smaller quantities tended to be sold to vendors at local markets, or to consumers, while larger quantities were sold to wholesalers or middlemen as local markets lacked the capacity. Such supply chain structures are characterised as allowing a diverse actor group to participate, and hence potentially being an income generator for a larger group of people [82].

Small-scale fishers in the Canacona *taluka* in South Goa were

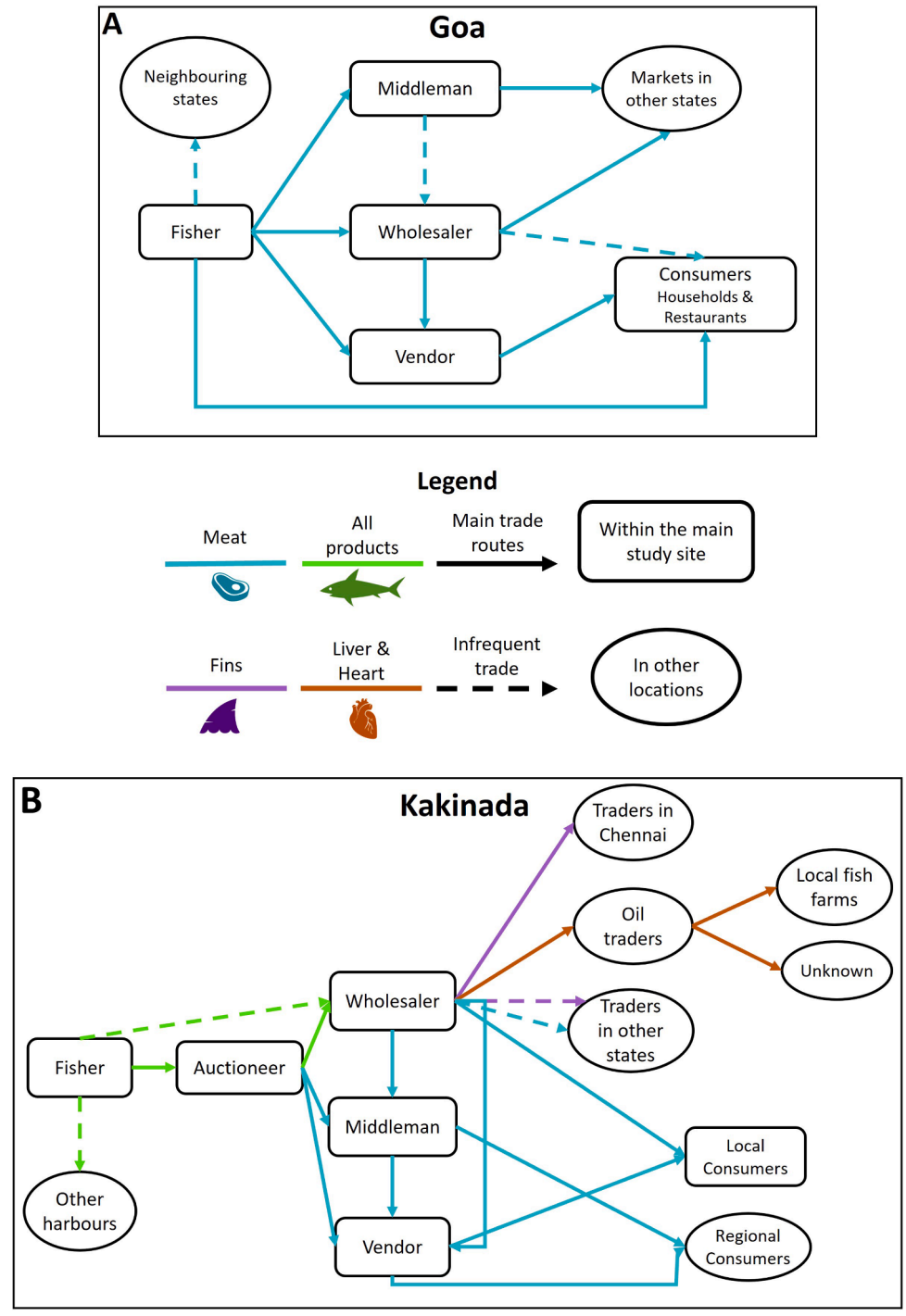

Fig. 2. The basic structure of the supply chain for shark products in Goa (A) and Kakinada (B). Relevant trade routes for different products (meat, fins, heart, liver) are shown, representing all species traded (small and large-bodied sharks). Solid lines represent main trade routes (mentioned by >50 % of respondents) while dotted lines are infrequent trade routes (mentioned by <50 % of respondents). Note that this diagram only maps sharks originating in Goa and Kakinada as these were the focus of our study; sharks landed in other places that are imported into the markets are not represented here.

identified as the biggest harvesters of sharks (particularly blacktips) within Goa according to respondents (fishers=6, traders=6, 21 % of respondents). However, there were no specialised shark fishers as all fishers operated multi-species gear. Similarly, there were no specialised traders for shark meat, and trade chains for different shark types and species were generally mixed (Fig. 2). The majority of locally caught sharks were sold and consumed within Goa, with both households and restaurants identified as end markets (Fig. 2). This was particularly the case for blacktip sharks, which were often sold to consumers directly by fishers. Wholesalers also brought in sharks from regions such as Maharashtra and Gujarat and distributed them within Goa as well as other regions. Outside of Goa, wholesalers and middlemen most often traded sharks to markets in Kerala, where they may be locally consumed (fishers=8, traders=2, 17 %).

Fins of large-bodied sharks used to be frequently traded. A specialised trader (hailing from the neighbouring state of Karnataka) would collect fins from fishers or from processers in markets, aggregate them in Mumbai, Karwar or other cities, and potentially export the fins

thereafter (fishers=4, traders=3, 12 %). Most respondents believed that fins were used for medicinal purposes, specifically to create surgical sutures (fishers=10, traders=11, 72 % of respondents who spoke of fins). Only 3 mentioned that they were used in shark fin soup. Fin trade has declined in the past decade, and fishers stated that they have not seen the fin trader in years. However, informal interviews indicated that fin trade still occurred sporadically when large-bodied sharks were caught.

In Kakinada, different parts of sharks were traded, including meat, fins, liver and heart. Fishers almost exclusively sold their catch through an auctioneer at the Kumbabhishekam landing centre (Fig. 2). Trade chains involved specific actors and channels through which the different products and shark species flowed (Fig. 2). Sharks appeared to be traded by multiple wholesalers, although the trade was monopolised by a few companies who purchased most of the sharks. These wholesalers hence may represent potential bottlenecks or 'gatekeepers' in the supply chain, as they controlled the distribution of different shark products [58,82]. Fins of large-bodied sharks were sold by wholesalers to dealers in Chennai (n = 7) and Mumbai (n = 1). Wholesalers believed that these products may be exported to Hong Kong and Singapore after that (n = 2). Few respondents believed that the fins were used for medicinal purposes (n = 2); most did not know or mention what fins would be used for. The liver and heart were extracted and sold to oil processors; oil extracted was used as supplements in local fish farms and other places, the end markets were uncertain (Fig. 2).

Wholesalers sold meat of large and small-bodied sharks to middlemen and vendors. Wholesalers sometimes also processed (i.e. salted) meat of large-bodied sharks and sold it in markets outside of Kakinada, in cities such as Hyderabad, especially when local prices of shark meat were low. Middlemen were from neighbouring villages such as Pedapudi and Karapaka, and sold shark meat at their villages to local vendors as well as consumers directly. Middlemen (and other actor types) had limited engagement with the fin trade – even when they purchased a large-bodied shark, they usually did not have access to fin traders to sell this product. According to key informants, most shark meat landed in Kakinada appeared to be consumed locally or regionally (within 100 km of Kakinada). Wholesalers also regularly imported small-bodied sharks from Mumbai (200–400 kg per day per wholesaler, n = 2) to cater to local demand for shark meat.

8. Market analysis

8.1. Prices of shark products

In Goa, sale prices of sharks estimated by fishers tended to be higher than prices (buying and selling) reported by traders (Supplementary 3). This may be because fishers sometimes sold sharks directly to consumers at high prices, but may also reflect overestimates from fishers. In Kakinada, fishers had limited information about prices and most data were obtained from traders. Hence, we compiled wholesale prices as a reference point to compare different species groups at each site (Fig. 3). Juvenile blacktip sharks sold for a higher price than small-bodied sharks in Goa. All sharks were more expensive than teleost fish like sardines (*Sardinella spp.*) and mackerel (*Rastrelliger kanagurta*) that are commonly consumed.

In Kakinada, small-bodied and large-bodied sharks were sold for similar prices, on average, and appeared to be more expensive than sharks in Goa. However, prices of large-bodied sharks were highly variable, going up to ₹600/kg ($7.2/kg USD) when sold to consumers and down to ₹100/kg ($1.2/kg USD) when sold for salting. Shark meat in Kakinada was more expensive than commonly eaten species like sardines and milk fish (*Chanos chanos*), and appeared to be more expensive than large yellowfin tuna (*Thunnus albacares*) that were a common target species (Fig. 3). Actors were mostly unwilling or unable to share prices of other shark products. One wholesaler stated that the heart and liver were sold by them to processers for ₹30/kg ($0.36/kg USD), but post-processing the oil could be sold for ₹120–130/litre ($1.45–1.57/litre USD). Fins were sold to fin traders in Chennai and Mumbai for ₹5000–6000 ($60.3–72.4 USD) per fin, depending on size and grade.

Shark price was determined by both demand-side and supply-side factors, and this varied seasonally. In Goa, market price fluctuated negatively with supply: prices decreased when supply of sharks was high, and hence prices were high in the off-season for shark fishing. Market price of sharks in Kakinada appeared to be less sensitive to quantities supplied, with very few traders mentioning this. Other price determinants included species, size, origin and quality. For instance,

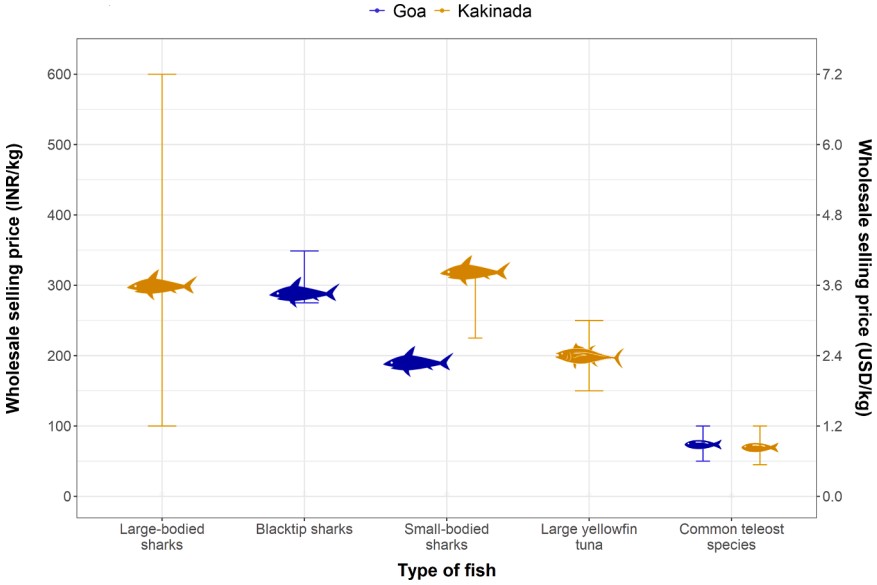

Fig. 3. Average selling price for meat at the wholesale of different shark types (small-bodied, large-bodied and blacktips) as well as other fish species at each site (Goa = blue, Kakinada = yellow). Minimum and maximum prices are also shown where possible. Large yellowfin tuna refers to *Thunnus albacares* (>20 kg) that are target species in Kakinada, common teleost species in Goa were sardines (*Sardinella spp.*) and mackerel (*Rastrelliger kanagurta*), and in Kakinada were sardines (*Sardinella spp.*), and milk fish (*Chanos chanos*). Prices are shown in Indian rupees (INR, left axis) as well as US dollars (USD, right axis). These data were compiled based on prices reported by wholesalers through interviews, and not from market records, and hence may have some margin of error.

locally caught sharks in both sites were higher valued than sharks brought from other regions to the markets for sale. Certain species like blacktip sharks and bull sharks (*C. leucas*) were preferred for consumption and higher priced, while hammerhead sharks (*S. lewini*) in Goa and tiger sharks (*Galeocerdo cuvier*) in Kakinada were less preferred for consumption and hence cheaper. In Kakinada, the grade of fins for large-bodied sharks was also a major price determinant, as was freshness, as sharks were often caught in multi-day fishing trips. In Goa, price varied with the trade channel, with fishers receiving higher prices when selling to local retail markets as compared to middlemen or wholesalers.

Nearly all respondents in Goa perceived an increase in shark meat prices and demand over the past 10 years (fishers=23, traders=12, 92 % of respondents who answered this question). In Kakinada, perceptions were mixed with some respondents (fishers=3, traders=4, 20 % of respondents) perceiving reduced prices of sharks over the past decade, due to the decline in the fishery. Respondents in Kakinada also mentioned that the value of shark meat has significantly increased (fishers=6, traders=4, 29 %), and sometimes was more valuable than fins, due to rising demand for local consumption.

8.2. Market dynamics

Shark supply from fishers at both sites appeared to be inelastic, with fishers behaving largely independently of price signals (Goa=19, Kakinada=18, 71 % of fishers at both sites). This was especially true for the blacktip fishery in Goa which was highly seasonal – hence in the season fishers would harvest sharks regardless of price. In Kakinada, fishers who had reduced or stopped targeted shark fishing stated that they would not target sharks again despite their market prices being high, due to the difficulty and risk involved in catching them. The shift away from sharks to tuna appeared to stem from the establishment of oil platforms and hence easy availability of tuna. These points suggest that fishing behaviour and shark catch at both sites were driven more by ecological (i.e. supply-side) rather than economic (i.e. demand-side) factors. Alongside inelastic supply, we also find evidence for resource limitation. Interviews at both sites indicate declining shark catch over the past decade, especially in Kakinada. In Goa, the seasonal nature of the blacktip fishery means that supply of this species for the rest of the year is very restricted. Hence, these factors indicate that shark fishing in both Goa and Kakinada are dominated by supply-side factors (Fig. 4).

However, another typical characteristic of supply-driven systems is that consumer choice is constrained by resource availability and price. This implies that consumption of shark meat and products would be declining and consumers may be switching to cheaper alternatives. This was not found to hold true as most respondents reported that shark meat consumption was rising in both sites despite increasing prices, especially in Kakinada (Fig. 4). This demand appears to be met by the market. At the trader level, shark supply and demand showed greater elasticity, with traders (wholesalers in particular) bringing sharks in and out of the study sites in response to price (Goa=18, Kakinada=5, 88.5 % of traders at both sites who answered this question). The role of demand-side factors can also be seen in the development and expansion of a market for tuna in Kakinada, which facilitated the shift from shark to tuna fishing (in combination with supply-side factors like the tuna availability at oil platforms).

9. Interventions for shark sustainability

9.1. Need for management interventions

> "Sharks have reduced in the water, because we don't let them breed. We go out and catch them when its their breeding season". A fisher in Goa.

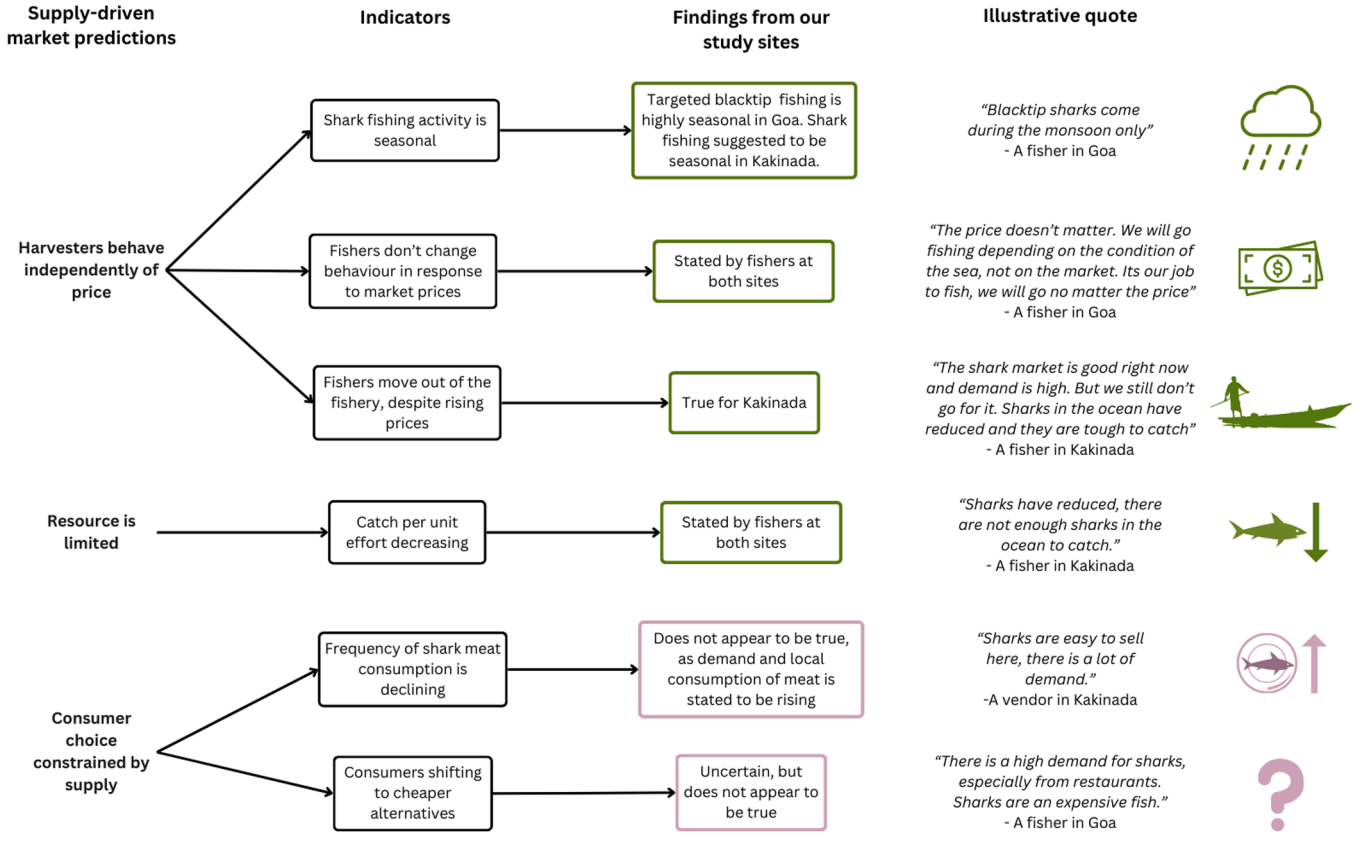

Fig. 4. Predictors and indicators of a supply-driven market and findings from the present study, based on the framework developed by McNamara et al. [46]. Green boxes = evidence suggests a supply-driven market, pink boxes = evidence unclear or suggesting market is not supply-driven.

"We used to get sharks 10 years ago, but not anymore. Sharks have gone extinct". A fisher in Kakinada.

Our findings support the local declines of sharks at our study sites. The majority of respondents reported declining catches of sharks, with some specifically mentioning diminishing populations in the sea. This aligns with national assessments that have found that shark and ray stocks were either 'declining' or 'less abundant' in most parts of India's coast [1]. For blacktip sharks specifically, although they are known to be a relatively productive species (producing up to 11 pups every 2 years) and may be capable of supporting a sustainable fishery [66,70], harvest rates of juveniles in Goa appear to be relatively high. Exploratory population models suggest that these levels of fishing are likely unsustainable (Gupta et al., in review). This is supported by previous research on India's west coast that found local blacktip shark populations to be likely overexploited or even collapsed [49].

Hence, our work highlights the potentially unsustainable nature of shark fishing and trade in Goa and Kakinada and emphasizes the need to intervene for sustainability. We outline a suite of interventions to address the specific drivers and patterns found within each site, which could improve the sustainability of shark fishing (Table 4; Fig. 5). These interventions include both policy and non-policy instruments at local, regional and national scales, and can be targeted at particular points in the supply chain (e.g. fishers, traders or consumers), or over the entire supply chain [30]. Our proposed interventions either work directly to manage shark exploitation (i.e. by regulating number or types of sharks fished), or indirectly by strengthening or regulating socio-economic drivers to enable a more sustainable and equitable fishery.

9.2. Fisher interventions

In Kakinada, we identify the need to improve the access of fishers to benefit from fish markets. Similar to many small-scale fisheries globally, fishers in Kakinada were found to have the least economic benefit of all supply chain actors [5,82]. In contrast, fishers in Goa displayed increasing access and negotiation power, which may be arising from multiple factors. Goan fishers have amongst the highest literacy rates and socio-economic status of fishing communities in India [16]. Most fishers work in the tourism industry, and hence have more diverse income sources and access to greater capital, while reducing reliance on fishing. Goan fishers mentioned benefitting from government policies that provided them the facilities to directly sell catch to different markets [24], these processes could be useful in Kakinada to improve fisher access. Other interventions include the provision of credit to fishers, which may provide them alternative means of raising capital and reduce their dependence on auctioneers [34,44]. Fishers in Kakinada appeared to lack access to information and knowledge about the trade, and prices of sharks and other fish products, indicating the need to develop information platforms aimed at these actors [30]. Fisher access can also be improved by strengthening local institutions, such as fisher co-operatives, which have been found to perform poorly for small-scale fishers within the state of Andhra Pradesh [56,62].

There may be a concern that increasing access and economic benefits of fishers may amplify fishing efforts to further benefit from the fishery (e.g. [68]). However, the declining shark resource in Kakinada, along with the perceived risk associated with shark fishing, suggest that this may be unlikely. Given the resource constraints, improving the benefits flowing to fishers may even reduce fishing efforts for sharks, especially when considering trade-offs with physical risk and social factors [30,54]. Furthermore, access and benefit sharing can have strong impacts on sustainability outcomes. Access theory finds that most of the benefits flowing from natural resources derive from the resulting market control, and not necessarily control of the resource itself [64]. Hence, increasing fishers' access to benefit from markets can provide fishers not only with the incentive to sustainably fish for long-term benefit, but also the

Table 4
Summary of findings from the present study at each site, with potential interventions to improve sustainability suggested for each driver or evidence of unsustainable shark trade. We also categorise and describe the degree of uncertainty, and prioritise uncertainties that need to be addressed based on how important the uncertainty is in impacting management outcomes, and how much the uncertainty can be controlled or mitigated.

Site	Key evidence	Level of analysis	Possible interventions	Degree of uncertainty	Prioritisation of uncertainties
Goa	Small-scale fishers targeting blacktip sharks seasonally, driven by supply-side factors, with relatively high access and negotiation power of fishers	All	Shark fishing regulated through social incentives, or even seasonal bans, and provision of alternative fish or income sources. (Gupta et al., in prep; [7])	**Low**: The targeted shark fishery is well understood, but effectiveness of and compliance with potential interventions are uncertain.	**High:** Uncertainty in compliance is important for management, and can be understood through predictive techniques and randomised control trials
Kakinada	Low access of fishers to benefit from the market	Actor analysis	Improve access mechanisms of fishers through provision of credit, increase access to market information, strengthen local institutions [19,30]	**Low**: Specific areas of low access, and types of interventions needed, can be better assessed.	**Medium:** Understanding access is important to determine type of intervention needed, but will be challenging in the socio-economic context.
	Wholesalers monopolise fin trade and are important actors in meat trade. High economic beneficiaries from sharks and high access the market, through mechanisms like social ties, knowledge, capital.	Actor and inter-actor analysis	Improve access of fishers to reduce power and monopoly by wholesalers. Increase proportion of benefits gained by fishers and other actors, improve licensing, registration and taxation [47,55]	**Medium**: Limited understanding of access mechanisms, price benefits & functioning of wholesalers	**Low:** Uncertainty in wholesalers may not have a big impact on management, and will not be controllable as wholesalers may be unwilling to share information.
	High local demand for shark meat which is being met by wholesalers importing meat from other harbours, potentially driving fishing and retention of sharks in these other sites.	Market analysis	Improving traceability in the supply chain to understand flow and end markets of shark products, to identify what management arrangements may be needed [31,39]	**High**: Quantities of shark products flowing through the system and supply-demand dynamics at other harbours unknown.	**High:** This will determine what trade restrictions are needed, and can be addressed through market surveys and specialised interview techniques
Both	Increasing demand and consumption of shark meat	All	Identification of alternative protein sources, demand-reduction campaigns over the long term to alleviate demand and consumption [37].	**Medium**: Limited understanding of consumption patterns, motivations and dependence on shark meat	**High:** This uncertainty can impact effectiveness of interventions. Can be addressed through consumer interviews.
	Fin trade and export persists despite the ban, especially in Kakinada	Inter-actor analysis	Implementation and enforcement of the fin ban needs to be directed towards trade and export hubs (like Chennai)	**High**: volumes, prices, and trade routes of fins unknown	**Low:** This uncertainty may not be important as fins are not the main driver of shark fishing, and may not be controllable as it is an illicit activity and difficult to monitor.

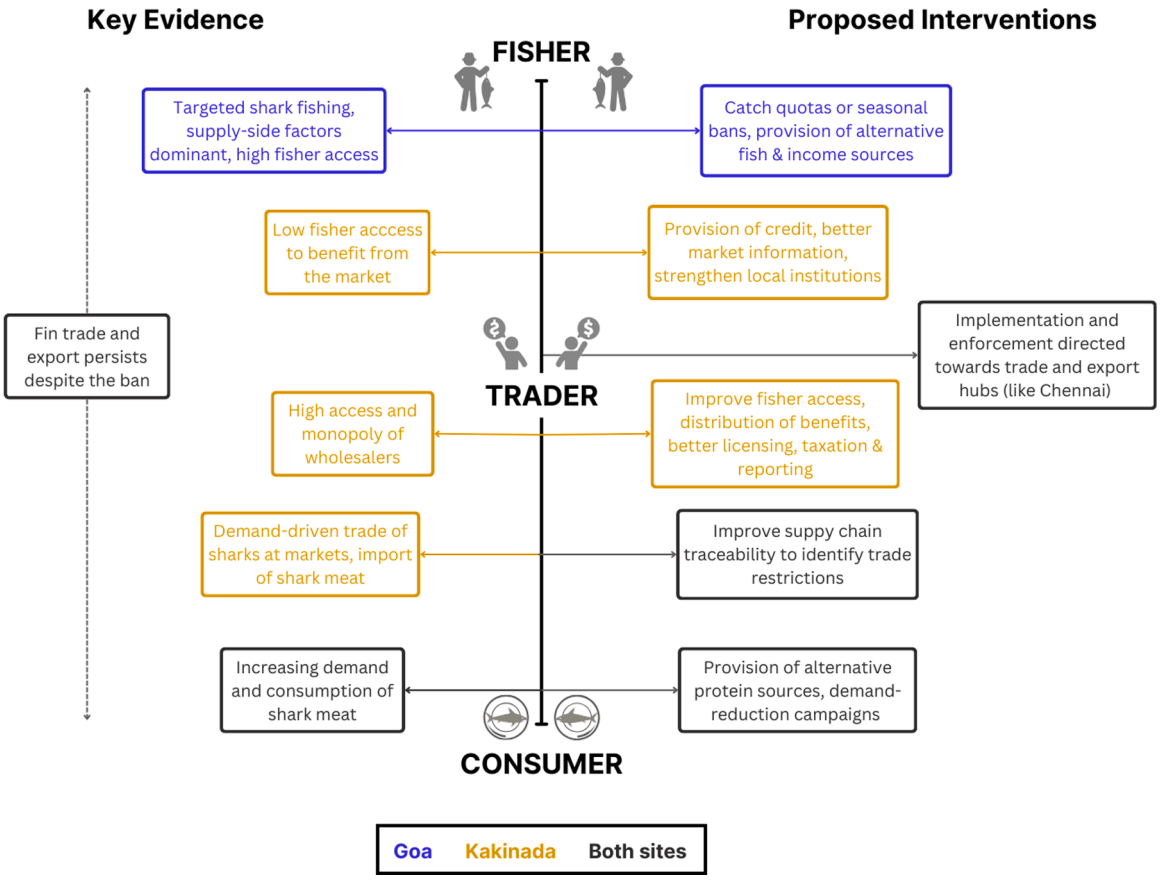

Fig. 5. Interventions proposed for each driver or challenge linked to unsustainable shark trade, at different leverage points in the supply chain, based on evidence from our study. Interventions for Goa are presented in blue, for Kakinada in yellow and interventions applicable to both sites in dark grey.

economic means to do this [64]. As such, fishers can show varied responses to changing catch and market structures, which may need close monitoring [13].

In Goa, fishers, particularly those targeting blacktip sharks, were identified as the actors with the most leverage (Table 4). With the blacktip fishery being predominantly driven by supply-side factors, and given the relatively high access and negotiation power of fishers, engagement with fishers could be the most effective in inducing positive change. This fishery is relatively nascent, and its seasonal nature and evidence from interviews indicate limited livelihood dependence on sharks. Hence, it could be regulated through mechanisms like community-based cooperative fishing with effort quotas, social incentives to reduce shark fishing, or even a complete ban on the targeted capture of these species (Gupta et al., in prep). It is crucial that any such interventions or policies are developed through participatory processes with fishing communities using existing local institutions, along with the provision of alternative fish or income sources [41,60]. Additionally, contextually-appropriate bycatch mitigation measures such as live release are needed to minimise the incidental capture of small-bodied sharks in other fishing gear used in Goa [28].

9.3. Trader interventions

Wholesalers emerged as a pivotal leverage group particularly in Kakinada, having the highest market access and potentially the highest economic benefits from the fishery. Wholesalers also display high connectivity with other supply chains: as the local meat demand grows but local shark supply diminishes, wholesalers meet this demand by importing sharks from other harbours. Hence, although we found that harvest of sharks was largely supply-driven, the market appears to be more complex and shows some demand-driven characteristics. This market may be exhibiting displacement effects [4], where wholesalers in Kakinada may be driving shark exploitation and retention in other fishing centres in India, hence displacing the impact. These findings highlight the complexity of supply-demand dynamics in wildlife trade, and the limitation of looking at a single supply chain in isolation. Interventions include better licensing and registration of wholesalers to improve reporting and transparency of shark trade, and ultimately implement better management controls over the supply chain [39]. Strong policies to improve the equity of profit distribution along the supply chain can also help mitigate the monopoly power of wholesalers [19,30,47,55].

9.4. Consumer interventions

Consumers may also be an important actor group for sustainability interventions. We find shark meat to be the sole traded shark product in Goa, and a major one in Kakinada. This provides strong evidence that meat, rather than fins, is an important driver of shark fishing. This is a narrative emerging globally [84], with prominent shark meat consumption found in several countries such as Brazil, Sri Lanka and Indonesia [10,18,6]. While this has not yet been quantified in India, significant domestic shark meat consumption has been reported in recent years, potentially driven by the rising prices of other marine fish [38,39]. Despite being among the top three shark and ray fishing nations in the world, India has never been identified as a major exporter of any kind of shark meat, not appearing in the top 20 exporting countries [22,84]. This suggests that majority of the shark meat landed in the country is consumed domestically [39]. Although the present study did not focus on consumers, our data suggests an increasing demand for, and consumption of, shark meat at our study sites which may play a role in driving fishing.

Our findings show that sharks appeared to be traditionally and regularly consumed in Kakinada, which contrast with reports of limited local shark consumption in the state of Andhra Pradesh [39]. This suggests that these trends seen in Kakinada may be unique within the larger region, and it also highlights the importance of comprehensive, local-level studies such as the present to supplement broader regional overviews. Local fishing communities at Kakinada are amongst the poorest in the country with known nutritional deficiencies [62], hence there may be a concern that shark meat is serving as a cheap and affordable source of protein [26,33,38]. However, our data show that shark meat was not a low-price fish in both study sites, and was considerably more expensive that commonly consumed teleosts. Shark prices in Kakinada were also found to be higher than the average retail shark price nationally [15]. Hence, it is unclear whether, and to what extent, sharks contribute to subsistence for low-income communities in and around Kakinada. In Goa, aside from traditional shark consumption within local communities, restaurants catering to tourists emerged as an end market for shark meat within the state. Karnad et al. [37] also found that foreign tourists were a newly emerging consumer group for sharks; this trend is concerning and needs close monitoring.

Interventions for consumers include demand reduction campaigns along with the provision of alternate protein sources [37,80]. Demand reduction interventions can be targeted at specific consumer groups to induce behaviour change, after first understanding consumer demographics, characteristics and motivations [53,79]. This may be most appropriate for tourist consumers. Given the potential local cultural and subsistence value of shark meat at both sites, it is crucial that alternative sources of protein are developed before implementing any restriction on shark trade and consumption by local communities. Alternative fish can include locally caught, underutilised and low-price species, such as small pelagics like sardines and anchovies that are predominantly used for fishmeal production [69,74].

9.5. *Supply chain interventions*

We find that export of shark fins persists despite the national export ban, particularly in Kakinada where fins remain a major price determinant of large-bodied sharks, suggesting poor effectiveness of the ban. Like previous studies, Chennai emerged as a major hub for the trade of fins [39,78]. As resources and capacity for enforcement are limited in India, it is crucial that they are used efficiently. For the export ban to be more effective, compliance and enforcement efforts need to be strengthened and directed towards hubs such as Chennai. Alongside this, we also highlight the need for improved monitoring and traceability along the supply chain. Better understanding of the flow of products can help in devising appropriate trade restrictions [1,31,84]. With a growing number of shark species listed under Appendix II of CITES [14], there is a need to develop systems and policies for monitoring and regulation of exports of different shark products from India.

10. Uncertainties and future research needs

By explicitly describing uncertainty in our data and evidence, we aimed to identify uncertainties that may have an impact on management of the system, and which can be addressed by future research (Table 4; [48]). In Goa, there remains some uncertainty regarding the impact of suggested interventions on local communities, and their compliance with these interventions. This can be addressed through predictive approaches to intervention design, where hypothetical interventions are tested with fishers ahead of implementation [77]. Across both sites, limited knowledge on the quantities of sharks and their products flowing through the system is a major uncertainty [39]. This information was challenging to obtain in our study due to the high variability of shark catch, and sometimes reluctance of traders to reveal this data. Improved catch monitoring and market surveys, along with specialised techniques like expert elicitation, can provide enough data for decision making while acknowledging that some uncertainty will remain in this area [3]. Demand and consumption patterns and motivations are further data gaps that need to be addressed in order to design behaviour change interventions for sustainability [51]. These points should be priorities for future work in this area, as they are dealing with important uncertainties and are feasible to address.

11. Study implications

Shark fishing in both Goa and Kakinada were found to be driven primarily by supply-side factors, but we also identified the importance of demand-side factors in influencing shark trade. We highlight diverse patterns of shark fisheries across the study sites, with Goa showing an emerging targeted shark fishery undertaken by small-scale fishers with relatively high market access, in contrast with a declining shark fishery in Kakinada where fishers exhibited low access to benefit from the market. Effective interventions will need to address specific drivers in each context, while considering the complexity and interactions within the broader system, as these fisheries are embedded within and interact with larger markets [42]. We propose a suite of possible interventions targeting key leverage points that could improve the sustainability of shark fishing at our study sites; it is crucial that these are further researched and trialled before implementation [7,77].

Our study underscores the importance of understanding the nuances and complexities of wildlife and fisheries markets. Policies for wildlife trade regulation are often implemented with limited understanding of market forces and dynamics, which can undermine conservation efforts [12]. Furthermore, assumptions are sometimes made regarding the importance of consumer demand and demand-side interventions, which do not hold true in all contexts as seen in this study and others [12,30,43,46,59]. Understanding the dynamics and drivers of unsustainable trade can help policymaking to be more proactive rather than reactive, by anticipating future shifts in the market trends. For example, the emergence of new markets for sharks, as seen in the present study and others [22,68], can be better managed.

We emphasize the need for a multi-actor approach, as specific interventions targeted at different types of actors can collectively improve sustainability while minimizing the risk of overlooking key drivers [20]. Polycentric governance approaches, which are characterized by decentralised governance with multiple authorities at different levels, may be useful here in improving power inequalities, addressing multiple socio-economic drivers, and hence enhancing the effectiveness of interventions [27]. We also illustrate the usefulness of the frameworks in this study [46,55], which facilitated the compilation of evidence from different levels and components to provide valuable insights over the entire system and its contextual intricacies. These frameworks can be particularly useful in the data-limited trade chains found in many global south contexts.

Lastly, our study demonstrates the value of mapping access and benefit sharing, which is relatively limited in applied ecology and conservation research. Sustainable management in social ecological systems can be challenging, especially in developing countries where there is limited capacity for monitoring and regulation, and the social costs of many market-based measures can be prohibitively high [76]. There is a need to develop practical solutions that can contribute to the combined goals of sustainable development, biological conservation and social equity [19,50,8]. Mapping access of actors, alongside understanding other market dimensions, can help devise interventions that address the drivers of unsustainable trade, and improve not just the sustainability but also socio-economic outcomes.

CRediT authorship contribution statement

Harsha Gaonkar: Investigation. **Tejaswi Abhiram:** Validation, Investigation. **Hollie Booth:** Writing – review & editing, Methodology, Conceptualization. **Rodrigo Oyanedel:** Writing – review & editing,

Methodology, Conceptualization. **Divya Karnad:** Writing – review & editing, Supervision, Conceptualization. **Trisha Gupta:** Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **E.J. Milner-Gulland:** Writing – review & editing, Supervision, Conceptualization.

Acknowledgements

TG was supported by funds from the Levine Family Foundation. DK was supported by the Bertarelli Foundation through the Bertarelli Programme in Marine Science. We thank Eswar Narayana from WCS-India, Dr Sreekanth from ICAR, the Goa Directorate of Fisheries, and Munib Khanyari for support and assistance during fieldwork, and Michael 't Sas-Rolfes for guidance with this study. We also thank the two reviewers for their comments that helped significantly improve this manuscript. We are grateful to the fishing communities and other stakeholders in Goa and Kakinada for their participation in this study.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.marpol.2024.106580.

Data Availability

Data will be made available on request.

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