Sustainable management of elasmobranchs in complex coastal fisheries

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Declaration

I declare that this thesis is entirely my own work. Contributions by other authors are stated in the Thesis outline section. None of the work has been submitted, in whole or in part, for any previous degree application.

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Abstract

Global trade and use of plants, animals and fungi forms one of the major drivers of biodiversity loss, but simultaneously support the lives and livelihoods of millions of people. Elasmobranchs (sharks and rays) are ecologically and socio-economically important, yet many species face extinction due to overfishing. In countries of the Global South like India, where there are high human populations and dependence on fisheries, the multi-species fisheries and complex socio-economic contexts create an urgent need for sustainable management of elasmobranch fisheries rather than exclusionary conservation measures. My DPhil aimed to understand how the sustainability of elasmobranch fisheries can be improved in such contexts, for the benefit of both biodiversity and people. I first conducted a scoping literature review of shark and ray research in India, identifying critical research gaps that need to be prioritised, such as the socio-economic dimensions of shark and ray fishing, trade and consumption. I examined fishing and trade motivations across the spectrum of elasmobranch catch, from low-value bycatch (like rhino rays) to high-value target species (like blacktip sharks) at two case study sites; Goa and Kakinada. My research uncovered diverse motivations and values underpinning people's use of elasmobranchs, including instrumental (economic) benefits, food, culture and tradition, which were enabled by mechanisms such as access to capital, social identity and knowledge. I investigated the ecological sustainability of a small-scale blacktip shark fishery, combining data from multiple sources including knowledge from fishers, and found that harvest rates need to be reduced to at least half for sustainability. Finally, I used participatory methods to explore potential conservation strategies and found that voluntary live release measures may be promising for rhino rays, whereas for blacktip sharks a complete exit from the fishery, through a combination of community-based agreements and state enforcement, may be the only option. My work has led to further research and to the design of live release interventions for rhino rays in Goa, which could serve as a scalable conservation model. My research contributes to developing robust approaches for conservation science and practice in data- and resource-limited contexts, and particularly highlights the importance of diverse knowledge systems, such as Local Ecological Knowledge, in ethical and effective conservation planning. I demonstrate the value of local-scale studies to inform the design of nuanced interventions targeted at contextual drivers. My DPhil hence contributes to a better understanding of marine sustainability to support more effective conservation action across scales, towards delivering on global biodiversity targets.

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Table of Contents

List of Figures

List of Tables

List of Acronyms and Abbreviations

CBD	Convention on Biological Diversity
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
CMFRI	Central Marine Fisheries Research Institute (India)
EAFM	Ecosystem Approach to Fisheries Management
FAO	Food and Agricultural Organisation
GBF	Global Biodiversity Framework
IPBES	Intergovernmental Panel on Biodiversity and Ecosystem Services
IPOA	International Plan of Action for Sharks
ISRA	Important Shark and Ray Area
IUCN	International Union for Conservation of Nature
LED	Light Emitting Diode (Fishing)
LEK	Local Ecological Knowledge
MPA	Marine Protected Area
MFRA	Marine Fisheries Regulation Act
NPOA	National Plan of Action for Sharks
PES	Payment for Ecosystem Services
SDG	Sustainable Development Goal
SES	Social-Ecological System
SSF	Small-Scale Fishery
ToC	Theory of Change
UN	United Nations
WLPA	Wildlife (Protection) Act of India

Chapter 1

Introduction

Galgibag beach, one of my study sites in Goa, at sunrise

1.1 Background

The world is currently facing an unprecedented biodiversity crisis. One million of the planet's 8 million species of plants and animals are threatened with extinction, driven by human activities, lifestyles and behaviours (Nielsen et al., 2021; IPBES, 2019). Exploitation and trade have been identified as one of the major drivers of biodiversity loss, and the primary threat to aquatic species, threatening over 6000 species with extinction globally (Maxwell et al., 2016). Hundreds of millions of people worldwide depend on the extraction, use and/or trade of wildlife to meet their needs, particularly (but not limited to) indigenous and local communities (Fromentin et al., 2023; Cooney et al., 2015). An estimated 70% of the world's poor depend directly on biodiversity and on businesses it fosters (UNCTAD, 2017; Cooney et al., 2015). These trade-offs for biodiversity and people are heightened by the mounting climate crisis (Habibullah et al., 2022). International frameworks and policies such as the Sustainable Development Goals (SDGs) and the UN Convention on Biological Diversity's Global Biodiversity Framework (GBF) have different goals and targets for the conservation and sustainable use of biodiversity, along with fulfilling people's basic needs and wellbeing (Obura et al., 2023; United Nations, 2024). To meet these targets, there is a need to harmonize conservation efforts with sustainable economic practices.

Marine ecosystems, particularly, are vulnerable to unsustainable exploitation, with seafood ranking as the top legally traded wildlife commodity globally (Andersson et al., 2021). Sharks and rays (collectively called elasmobranchs, a class of cartilaginous fish) are a commonly exploited and traded group globally. Elasmobranchs form one of the most threatened vertebrate species groups today, with over one-third of assessed species at the risk of extinction (Dulvy et al., 2021). Overfishing is the primary threat to these species; their conservative life history traits, such as slow growth, low fecundity and late maturity, make them vulnerable to overexploitation, and their populations have a limited capacity to recover from being fished out (Bonfil, 1997; Dulvy et al., 2021). Elasmobranchs are a highly diverse group, fulfilling important ecological roles and ecosystem services such as regulating trophic cascades, facilitating nutrient transfer through their migratory patterns and maintaining the health of coral reefs and benthic ecosystems, especially through the bioturbation effects of rays (Dedman et al., 2024; Ferretti et al., 2010; Flowers et al., 2021). Disappearance of shark or ray species has led to negative impacts for marine ecosystems (Dedman et al., 2024). These factors, combined with the fact that many elasmobranch species are seen as charismatic megafauna, have led to elasmobranchs receiving increased global attention in recent years, and forming a priority for conservation.

Various international frameworks support elasmobranch conservation, including the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), which regulates the global trade of numerous listed elasmobranch species, and the Convention on Migratory Species (CMS), which promotes international cooperation for the protection of migratory sharks and rays (CITES, 2024; CMS, 2024). Additionally, the United Nations International Plan of Action for Sharks (IPOA-Sharks) encourages nations to implement National Plans of Action (NPOAs) to ensure the sustainable management of shark populations (FAO, 1999). Despite these efforts, the conservation of elasmobranchs has a long way to go. Amongst other challenges, the varied socio-economic uses and values of these species complicates their conservation and management. Within fisheries, elasmobranchs encompass the spectrum of catch, from high-value targeted catch to unwanted, discarded bycatch, and hence show a plurality of values in different contexts (Booth et al., 2023a). Elasmobranchs and their products, including fins, meat, skin and others, make significant economic contributions that form a vital part of the livelihoods of many fishing communities around the world (Booth et al., 2019; Dulvy et al., 2017; Finucci et al., 2024). For example the global shark and ray trade between 2012 to 2019 was valued at US$4.1 billion (WWF, 2021). Shark and ray meat can serve as important food and nutrition sources, particularly as a cheap protein source for low-income communities (Jabado et al., 2018; Karnad et al., 2019; Temple et al., 2024). These species also hold important intrinsic and cultural values to many people and communities globally (Skubel et al., 2019).

Elasmobranchs are particularly important within coastal small-scale fisheries (SSFs) in the Global South, including countries like India and Indonesia, which are among the largest elasmobranch fishing nations (Davidson et al., 2016, Dulvy et al., 2017). SSFs, which support millions of fishers worldwide, can be understood through the framework of social-ecological systems (SES). SES are complex adaptive systems defined by the dynamic interactions and feedbacks between human and natural components (Gurney & Darling, 2017; Ostrom, 2009). Coastal resources like elasmobranchs support and sustain millions of fishers globally, but face increasing degradation due to overexploitation and other local and global pressures (Gurney et al., 2019). This in turn has detrimental impacts on the people and communities who depend on these biological resources. Sustainable management of these systems is vital not only for conserving biodiversity but also for ensuring the long-term wellbeing of the human communities that are a part of them.

I define sustainability here as the use of biological diversity in a way and at a rate that maintains biodiversity and ecosystem functions over the long-term, thereby contributing to the needs and wellbeing of present and future generations (CBD, 1992; Fromentin et al., 2023). Such a conceptualisation of sustainability encompasses biological, ecological and socio-economic considerations (Freese, 2012), and it is essential for guiding conservation strategies that balance human needs with biodiversity preservation.

1.2 Problem statement

The global discourse on biodiversity conservation is undergoing a fundamental shift, moving away from exclusionary, species-centric protection models toward a more holistic framework that integrates conservation with sustainable development and the needs of local communities (Büscher & Fletcher, 2019; Obura et al., 2023). This is reflected in the GBF's 2050 vision of a world where "biodiversity is valued, conserved, restored and wisely used, maintaining ecosystem services, sustaining a healthy planet and delivering benefits essential for all people" (CBD, 2024). Achieving these goals remains a major challenge in Global South countries where biodiversity conservation often conflicts with socio-economic development, particularly in the cases where wild species are directly exploited (Bawa et al., 2021). To reconcile conservation and development, transformative actions are required to address the underlying drivers of species decline while aligning conservation strategies with the socio-economic needs of local populations (IPBES, 2019; Bawa et al., 2021). At a minimum, conservation should do no harm to local people or the broader goals of sustainable development (Brittain et al., 2020).

My DPhil aims to explore this challenge and potential ways forward, through the example of elasmobranch fisheries. Elasmobranchs form a good model species group given their ecological and socio-economic significance (Dulvy et al., 2021; Temple et al., 2024). With strong science-based management, most shark species have the potential to support sustainable fishing (Simpfendorfer & Dulvy, 2017). However, many coastal fisheries in the Global South are poorly monitored with accurate assessments of elasmobranch mortality and biological characteristics missing, forming a barrier to sustainable management (Humber et al., 2017; Jorgensen et al., 2022). Furthermore, conventional conservation approaches for these species, such as marine protected areas (MPAs) or trade restrictions, rely on top-down regulatory mechanisms which tend to be impractical, unethical and ultimately ineffective in many Global South, fisheries-dependent contexts (Pascual et al., 2021; Booth et al., 2023b).

Ultimately, managing and changing human behaviour is key to conservation and sustainable use. Although research investigating human dimensions are growing, critical gaps remain in our understanding of what drives people to catch, trade and utilise elasmobranchs, particularly in the context of coastal, multi-species fisheries. Consequently, a major challenge remains in developing interventions or strategies to change human behaviour for sustainability. Evidence suggests that one-size-fits-all conservation approaches are insufficient, particularly in diverse social-ecological systems that involve a wide range of actors, species, and motivations (McClenachan et al., 2016; Ostrom, 2007; Salerno et al., 2021). Therefore, it is imperative to develop tailored interventions that consider the specific social, ecological, and economic contexts in which these fisheries operate (Salomon et al., 2011).

These challenges are exacerbated by an overall scarcity of data and knowledge in many regions in the Global South where resources and capacity for science and management are often limited (Amano & Sutherland, 2013; Sitas et al., 2009). Conservation science and practice for elasmobranchs need to be contextualised within this. Conservation efforts must prioritize the most pressing drivers of species decline and devise solutions that can operate effectively under conditions of uncertainty (Meijaard & Sheil, 2007;McCook et al., 2009; Schuster et al., 2023).

1.3 Aim and research questions

The overarching aim of my thesis was to understand how the sustainability of elasmobranch fisheries can be improved in coastal fisheries in a Global South context, for the benefit of both biodiversity and people. I worked towards this aim using selected case studies in India (Goa and Kakinada), where I explored the following research questions:

1. What are the gaps and limitations in data and knowledge for sustainability and conservation of elasmobranchs in India?
2. What drives and motivates people in multi-species, coastal fisheries to catch and trade elasmobranchs, and what are the underlying mechanisms facilitating this behaviour?
3. How can sustainability of elasmobranch fisheries be assessed within data-limited contexts?
4. What interventions can be used to conserve elasmobranchs and/or make their fisheries more sustainable within the broader social-ecological system? How do interventions

vary across the spectrum of elasmobranch catch (from low value bycatch to high value targeted catch) and across the supply chain (from fishers to traders and consumers)?

1.4 Study system

India is one of the world's megabiodiverse nations, ranks third in fisheries and aquaculture production globally and is among the top three elasmobranch harvesters, and currently has the world's largest human population with over 1.4 billion people, of which 12.9% live below the poverty line (FAO, 2024; World Bank, 2024). There are 4.9 million marine fishers in the country with millions more in the supply chain (Department of Fisheries, 2022) – all of whom will be directly or indirectly affected by biodiversity loss, as well as by conservation policies. With this background, India forms a priority for conservation and a relevant case study for my DPhil (Figure 1.1).

Like most other tropical, Global South countries, Indian fisheries exhibit a wide range of craft and gear types operating multi-species fishing in nearshore waters, where a diversity of marine species are captured and used. The majority of marine catch is from mechanized vessels like trawlers, contributing 82% of the catch volume (CMFRI, 2023). However, non-mechanized crafts, including artisanal fisheries, represent over 74% of all registered vessels, making them crucial to the livelihoods of millions of small-scale fishers (CMFRI, 2023). Fisheries in India are regulated by state-level Marine Fisheries Regulation Acts (MFRAs), but the sector continues to be governed by policies focused on maximizing extraction and yield rather than on biodiversity conservation or sustainable management (Gupta et al., 2019; Akhilesh et al., 2023; Gangal et al., 2023). Hence, most fisheries across India are poorly monitored and managed, compounded by issues such as data and resource scarcity, limited capacity, and weak governance.

At least 174 species of elasmobranchs have been recorded in Indian waters, of which 67% come under the threatened categories of the IUCN red list (Akhilesh et al., 2023). Historically, elasmobranchs were integral to India's artisanal fisheries (Kizhakudan et al., 2015). However, commercial harvest of elasmobranchs, particularly sharks, was seen from the mid-1970s, incentivised by global demand for shark fins. Elasmobranch landings peaked in 1998 at 75,262 tonnes, but have showed a steady decline since then – with 32,000 tonnes landed in 2022 (Kizhakudan et al., 2015; CMFRI, 2024). This reduction is despite increasing fishing effort, which suggests that elasmobranch populations are overexploited (Akhilesh et al., 2023). Elasmobranchs continue to be caught across the range of mixed-gear, multi-species fisheries, where the lines between target and bycatch become increasingly blurred as demand and market value for their meat and other products grow (Gupta et al., 2020a; Kizhakudan et al., 2024).

At the regional and international levels, India is a signatory to many conventions and commitments for conserving elasmobranchs, including the FAO-IPOA, CITES, CMS and the CDB. But India is still a long way from meeting global conservation commitments (Akhilesh et al., 2023). For instance, a draft National Plan of Action for sharks (NPOA) was submitted to the Ministry in 2015 but has not been approved and implemented to date. Most conservation policies for elasmobranchs in India are within the Wildlife (Protection) Act, 1972 – which includes 26 species under its schedules (Parliament of India, 2022). The harvest and trade of these listed species is prohibited, and the export of fins has also been banned. While these measures have met with some success (conservation of whale sharks, for example), on the whole their effectiveness is uncertain as illegal fin exports persist, alongside the (often incidental) harvest of protected species, and elasmobranch populations continue to decline (Kizhakudan et al., 2024).

A short-lived national-level blanket ban on elasmobranch fishing was imposed in 2001; this appeared to be implemented with little or no scientific guidance, and was revoked in a few months following opposition from fishing communities and traders (Vivekanandan, 2001). This incident strongly emphasises the need for sustainable elasmobranch management strategies that are science-based, economically viable and socially just, rather than blanket bans or similar exclusionary measures (Gupta et al., 2020a).

1.4.1 Case study: Goa

Goa, a state on the west coast of India, forms the primary study site for my research (Figure 1.1). Goa has a coastline of approximately 104 km, characterised by a number of estuaries and creeks, mangrove forests, patchy reefs, submerged rocks and sandy silt substratum (Velip & Rivonker, 2015). The state comprises two districts, North and South Goa. While Goa is one of the smallest fishing states, it hosts a diversity of fishing gear ranging from purse seines to non-motorised gillnets and artisanal nets, with 2984 registered fishing vessels (Goa Department of Fisheries, 2023). There are 5 major fishing harbours where both mechanised and motorised vessels land their catch. In addition, gillnets and other small-scale fisheries (e.g. shore seines) operate from the 41 fishing villages present along Goa's coastline (Goa Department of Fisheries, 2023). Mackerel (*Rastrelliger kanagurta*), sardines (*Clupeidae*) and carangids

(*Carangidae*) are the main captured species; however, like many other fisheries in India, the fishery in Goa is multi-species and a diversity of species is captured year-round.

There are 12,651 fishers in Goa, as well as a large population of migrant workers (CMFRI-FSI-DoF, 2020). Fishers in Goa are relatively well educated, with the lowest illiteracy rates (14% illiteracy) amongst fishers in India and the lowest proportion of fisher families falling below the poverty line (22% below poverty line). This may be attributed to development of tourism in the state. Aside from fisheries, Goa is also a major tourist destination with coastal tourism, with 3.8 million tourists recorded in 2023, hence forming a large part of the state's economy (Department of Tourism, 2024). A large number of fishers also work part-time in the tourist industry (Venugopalan, 2021).

My last two chapters focus on Canacona, a sub-district (*taluka*) in South Goa, with 11 major fishing villages and several smaller fishing centres. There are 6 mechanised, 230 motorised and 192 non-motorised fishing crafts registered in Canacona. The region supports a fisher population of 3,915, with approximately 700 of these being active fishers (CMFRI-DoF, 2020). The majority of the fisher population belongs to the Pagi community, a traditional fishing caste in this region (Dakshin Foundation, 2021). The Pagi fishing community is governed by the Akhil Goa Kshatriya Pagi Samaj (hereafter, *Pagi Samaj*), a local fishing institution that handles registration for boats and gear, distribution of subsidies, as well as mediation of conflicts and problems.

Goa forms the main case study for my DPhil, with Chapters 3 and 4 collecting data across Goa's coastline, while Chapters 5 and 6 focus on the Canacona region in South Goa. For Chapter 4, I included an additional case study of Kakinada, on India's East coast. Kakinada differs from Goa in terms of the type of fisheries operating within this site, species of elasmobranchs captured, type of markets, local socio-economics, culture and historical context, and hence formed an interesting contrast to illustrate the need for context-specific sustainability interventions.

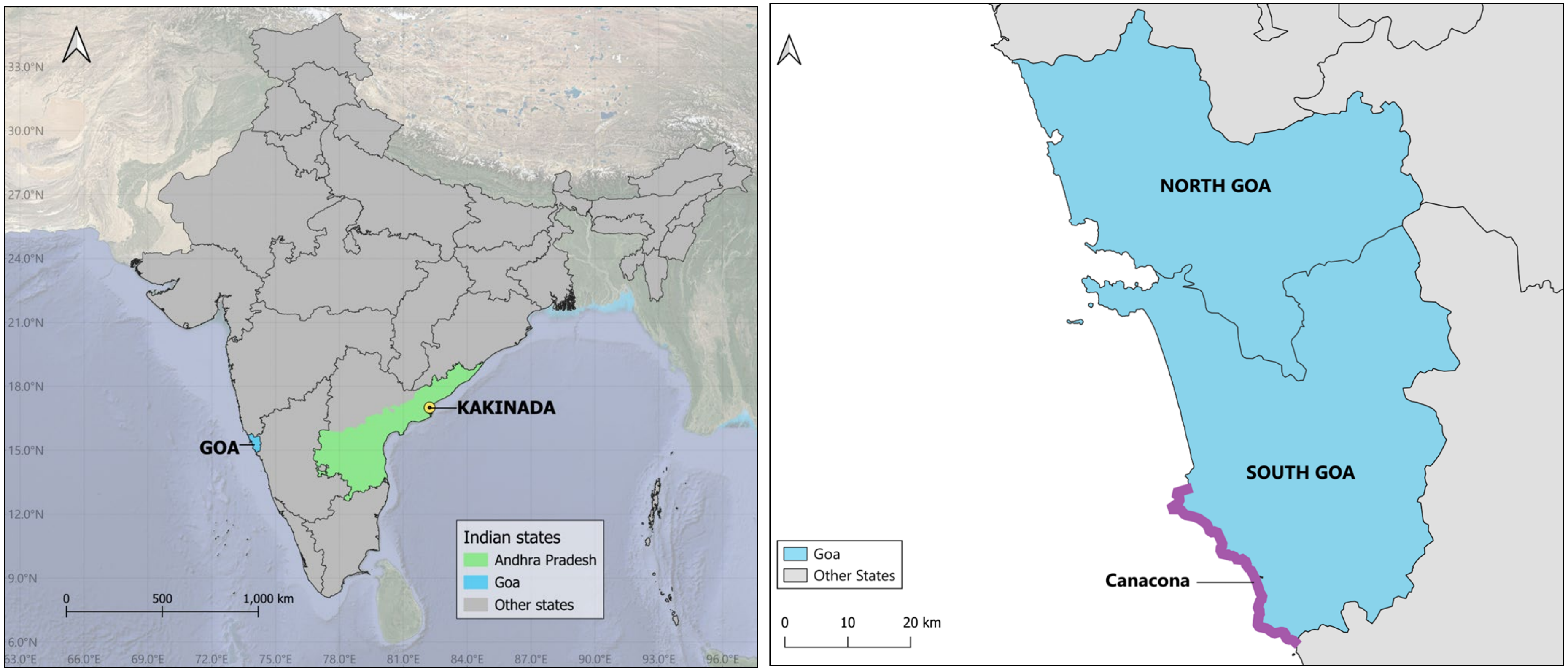

Figure 1.1: The study system for my DPhil. **Left**: Map of India showing the case studies of Goa (blue, on the west coast) and Kakinada (green, in the state of Andhra Pradesh on the east coast). **Right**: Map of Goa showing the two districts (North and South Goa) as well as the coastline of the sub-district (i.e. *taluka*) of Canacona where some of my research takes place.

Taking a case study approach to research allows in-depth, multi-faceted explorations of complex issues in their real-world context (Yin, 2009). Goa was initially selected as a case study based on the results of my scoping literature review (Chapter 2) that identified it as one of the least studied regions in India for elasmobranchs, as well as the seemingly unique presence and behaviour of rhino rays along Goa's coastline (Chapter 3). Through the latter study, patterns, themes and information emerged such as the presence of an undocumented targeted shark fishery, relatively high local demand for shark meat and tourism-driven shark consumption in Goa. This then formed the basis for my research on the social and economic dimensions of the fishery, presented in Chapters 4, 5 and 6. Overall, Goa as a site exhibited different types of elasmobranch fisheries, across the spectrum of catch and representing diverse values and motivations, making it an ideal candidate to address my research questions.

1.5 Thesis outline

In addition to this first introductory chapter, my thesis comprises a further six chapters, which includes 5 data chapters and a synthesis chapter, and an Appendix. Most of my data chapters are published or under review. They include the contribution of multiple co-authors, along with my supervisors, and I hence use the term 'we' instead of 'I' in my data chapters. All chapters were conceptualised by me, with assistance and inputs from my supervisors and additional collaborators. I conducted and coordinated data collection with the help of research assistants and analysed all the data. I led the writing on each chapter, with review and feedback from all co-authors.

The outline of these chapters is as follows:

Chapter 2: Scoping review of shark and ray literature in India: Gaps and ways forward. Here, we conducted a scoping review of shark and ray literature in India to assess the relevance of this research to conservation. This study identified important biases and gaps in elasmobranch research to date, such as the socio-economic dimensions, and emphasised the need to streamline efforts and use limited resources more effectively to produce more applied science that can inform conservation and management. This chapter set the basis for the rest of my DPhil research.

This chapter has been published as Gupta, T., Karnad, D., Kottillil, S., Kottillil, S., & Gulland, E. M. (2022). Shark and ray research in India has low relevance to their conservation. *Ocean & Coastal Management*, *217*, 106004.

Chapter 3: Drawing on local knowledge and attitudes for the conservation of critically endangered rhino rays in Goa, India. In this chapter, I focused on rhino rays, a highly threatened group of elasmobranchs that also represent a low-value bycatch species at my case study site. We drew on Local Ecological Knowledge (LEK) to understand the socio-ecological status of rhino rays, and investigated local attitudes towards the conservation of these species. This work demonstrated the usefulness of diverse knowledge sources like LEK, and provided a pathway for the conservation of threatened bycatch species like rhino rays within the local context, with community participation.

This chapter has been published as Gupta, T., Milner-Gulland, E. J., Dias, A., & Karnad, D. (2023). Drawing on local knowledge and attitudes for the conservation of critically endangered rhino rays in Goa, India. *People and Nature*, *5*(2), 645-659.

Chapter 4: Identifying leverage points for sustainability in India's shark supply chains. Here, we investigated the supply chain and market dynamics of shark fishing in Goa and Kakinada to identify leverage points for interventions. This study helped identify sustainability measures across the supply chain for high-value, targeted shark species, through interventions for individual behaviour change as well as broader interventions for contextual change, while explicitly accounting for uncertainties.

This chapter is undergoing minor revisions in Marine Policy as Gupta, T., Karnad, D., Oyanedel, R., Booth, H., Abhiram, T., Gaonkar, H. & Milner-Gulland, E. J. (IN REVIEW). Identifying leverage points for sustainability in India's shark supply chains. *Marine Policy.*

Chapter 5: Preliminary assessment of the ecological sustainability of a data-limited small-scale shark fishery. This chapter focused on the targeted, small-scale shark fishery in Canacona, Goa. We explored approaches to collect data and assess the ecological sustainability of this extremely data-limited fishery. We found that this shark fishery is likely unsustainable and highlight the need for urgent intervention to regulate this fishery for long-term sustainability. This study also highlights the usefulness of our approach, integrating data from multiple sources including expert elicitation interviews with local fishers, to build exploratory population models that can provide crucial information for preliminary decision-making.

This chapter is under peer review in Conservation Science and Practice as Gupta, T., Arlidge, W. N. S., Karnad, D., Kamath, A., Gaonkar, H. & Milner-Gulland, E. J. (IN REVIEW). Preliminary assessment of the ecological sustainability of a data-limited small-scale shark fishery. *Conservation Science and Practice.*

Chapter 6: Exploring interventions for shark conservation in small-scale fisheries. This chapter continued to focus on the targeted shark fishery in Canacona, Goa building up on Chapters 3 and 4, to explore measures for conservation. We built a Theory of Change and developed six plausible conservation interventions for sharks. Using scenario interviews with shark fishers, we examined their perceptions of the proposed interventions and their willingness to change behaviour. A complete exit from the shark fishery, co-designed with local communities, emerged at the most effective measure for conservation.

This chapter will be submitted for peer review in a journal like Oryx as Gupta, T., Karnad, D., Booth, H., Kamath, A. & Milner-Gulland, E. J. (IN PREP). Exploring interventions for shark conservation in small-scale fisheries.

Chapter 7: Discussion. Here I synthesised my 5 research chapters, outlined key findings and described how my work addressed my research questions. I identified and discussed several cross-cutting thematic patterns that emerged throughout my chapters and broader implications for conservation science and practice. Finally, based on my thesis research, I proposed a series of next steps for elasmobranchs in India, from research needs, conservation actions and interventions, and policy changes.

Additional Research

During my PhD, I undertook additional and related research (either as the lead or contributing author), which both contribute to the research narrative of this thesis and was influenced by it.

Gupta, T., Bashyal, R., Anagnostou, M., Dhanda, S., Djagoun, J., Feitosa, L. M., Hatten, C. E. R., Hunter., S. B., Mutezo, T. S., Nurbandi, W., Pizarro Choy, A., Sackey, H. N. K., Milner-Gulland, E. J., Oldfield, T. E. E., & Challender, D. W. S. (IN REVIEW). Resolving uncertainties in the legality of wildlife trade to support better outcomes for wildlife and people. *Conservation Letters*

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1.6 Researcher positionality

A researcher's worldview, philosophy and where they come from influence how the research is designed, conducted, and interpreted. The term positionality describes an individual's worldview and the position they adopt within a given research study and its social, cultural and political context (Holmes, 2020). In other words, it is inevitable that the personal characteristics and experiences of a conservation scientist inspire, influence and bias their research, for better or worse. In this section I reflect on my positionality as a conservation scientist, particularly in the context that I am currently working in, and how this may have influenced my DPhil research.

Like many conservation scientists, I come from a background of natural science with a master's degree in marine biology and training that is largely grounded in western science. I came into this field with a very positivist approach, believing in the existence of an objective truth that can be understood through quantitative and empirical scientific methods (Moon et al., 2019; Moon & Blackman, 2014). In addition, my motivations and goals at the start of my career were strongly focused on species and biodiversity 'protection' with little or no consideration of the human dimensions. However, my four years of work with a non-profit conservation organization in India significantly transformed my worldview and broadened my approach to conservation. I lived and worked in a coastal town conducting research on sharks, rays and fisheries, where I started to understand and sympathise with the needs and position of local communities and their role in conservation. Over time, I grew into an interdisciplinary researcher working with mixed methods and goals to understand social-ecological systems. This shift was crucial as it expanded my research focus beyond the traditional species-based conservation goals toward the inclusion of human well-being and community engagement in conservation efforts.

It was with this worldview and experience that I started my DPhil. While I did not consciously choose any particular theoretical lens for my research, I realise, in hindsight, that I applied a pragmatic and post-positivist approach throughout my DPhil. I used mixed methods and triangulation of quantitative and qualitative data and embraced the idea, to an extent, that there are multiple ways to interpret the world. In particular, my thesis followed the pragmatist view that research should be contextually situated and deliver practical outcomes (Moon & Blackman, 2014). Despite my growing experience with certain social science methods, I want to acknowledge here that I am not a social scientist and would not call myself one. I applied mixed methods, including robust social science methods, to the best of my abilities to answer my research questions in a complex social-ecological system. I do believe that research such as this can be strengthened through formal training in social science or anthropology disciplines (St. John et al., 2014).

I am aware of the potential biases that exist in my research and scientific process based my positionality and identity. Although I am Indian by nationality and ethnicity, and have conducted all my research in my country, I come from an upper middle-class family from a big city in India. I do not come from the regions that I worked in (Goa and Kakinada), nor do I belong to any fishing community, and hence I was very much an 'outsider' within the communities that I worked in. This can pose several challenges in terms of scientific rigour as well as ethics. From the start of my fieldwork, I was aware of the power dynamics and imbalances that existed between myself and my study participants. I did my best to acknowledge and resolve this by working with research assistants who were from the region, spending time within the communities I worked with to build relationships and trust, and immersing myself in the local culture and context. As my research aimed to gather and document the local ecological knowledge of fishing communities, I also became aware of the clash between my western-science perspective, and the perspective of local knowledge systems. This is not surprising given the starkly different value systems and epistemologies that usually exist between scientists and local communities. Bridging this epistemological divide required conscious reflection and a willingness to adapt my methodologies and thinking to incorporate local perspectives, and I worked towards this by spending time with the communities and learning their way of thinking as well as by drawing on existing literature on these subjects.

My research and personal objectives also sometimes represented a source of bias and conflict. As a conservationist, I am still working towards the conservation of threatened species. Although my DPhil aimed to align these conservation goals with the needs of local communities, or do no harm at the very least – these objectives or outcomes still conflicted at times. As a scientist, I am also biased towards conducting research and uncovering findings or results that are interesting or significant. I addressed these challenges by working with a diverse and experienced team of researchers and collaborators who helped mitigate any biases in the design, analysis and interpretation of my research, as well as in addressing the different moral and ethical issues that came up throughout my DPhil.

I aimed to acknowledge and reflect on my positionality throughout my DPhil, and particularly towards the end as I was writing up. I am aware of the mistakes I made and the challenges I faced in this particular aspect, and I have attempted to acknowledge some of them in my thesis. I am committed to learning from them, and hope that my mistakes and experiences can contribute to the learning and growth of my peers, and the conservation community at large.

Chapter 2

Scoping review of shark and ray literature in India: Gaps and ways forward

A diversity of fishing crafts on Malvan beach, a fishing centre in India

2.1 Introduction

Biodiversity is deteriorating at an alarming rate worldwide (Díaz et al., 2019). In order to conserve nature and its vital contributions to people, there is a need for research that combines novel and rigorous science with conservation-relevant questions (Cook et al., 2013). While conservation research has significantly increased in recent decades, this may not necessarily translate to policy and practice (Milner-Gulland et al., 2012; Williams et al., 2020). Biodiversity and conservation research has been found to make few direct contributions to real world conservation outcomes (Pullin et al., 2004; Williams et al., 2020). This has been especially documented in the Global South; despite having some of the most biodiverse areas and largest human populations, research in these regions seldom meets the needs of conservation practice (Gossa et al., 2015; Meijaard & Sheil, 2007; Sheil, 2002). With a view to promoting evidence-based conservation, there is a need to review existing research and if necessary, revise and re-focus future research efforts for conservation. Review and synthesis of literature has been valuable in identifying key data gaps, formulating research questions, guiding decision-making for policy, and forming the basis of horizon scans for future conservation issues (Haddaway et al., 2015; Muenchow et al., 2018; Wintle et al., 2020).

Sharks, rays and chimaeras, collectively called chondrichthyans, provide valuable contributions to people, through direct economic benefits from the fisheries and tourism industries, as important food sources in many parts of the world, and by playing critical ecological roles in aquatic ecosystems (Ferretti et al., 2010; Gallagher & Hammerschlag, 2011; WWF, 2021). However, chondrichthyans are one of the most threatened groups in the world, with over a third of all known species currently threatened with extinction due to overfishing and other anthropogenic activities (Dulvy et al., 2021). This situation is even more critical in the Arabian Sea region, where over half the chondrichthyan species have been assessed as Threatened on the IUCN Red List (Jabado et al., 2018). Bordering the Arabian Sea and the Bay of Bengal, India has a high diversity of chondrichthyans in its waters (at least 155 species, Akhilesh et al., 2014), and hosts one of the largest chondrichthyan fisheries globally (Dent & Clarke, 2015). Fisheries in India are also poorly regulated, making it one of the highest priority countries for the conservation of sharks and rays in the world (Dulvy et al., 2017).

An extensive body of literature exists on the biology of chondrichthyans in India. Taxonomic and species descriptions of sharks and rays from Indian waters began in the 18^{th} century, and a systematic fisheries database was started as early as 1947 (Jabado et al., 2018). Chondrichthyan research and conservation also appears to be receiving increasing interest and investment in recent years (BOBP, 2015). However, existing research may not be translating to action, as there has been little improvement in fisheries management on the ground and limited formulation of policies (Karnad et al., 2014; Karnad et al., 2019). India currently has few policies and regulations for the conservation of chondrichthyans and management of their fisheries, particularly in comparison to other Asian countries (Karnad, 2018). The policies that exist include the protection of 10 species under the Wildlife (Protection) Act (WLPA) in 2001, and the prohibition of shark fin exports in 2015 (Kizhakudan et al., 2015). These policies may not be entirely driven by scientific information; for instance, most of the 10 species protected under the WLPA are very rarely caught in fisheries, and a few of these species do not actually occur in Indian waters (Akhilesh et al., 2014; Tyabji et al., 2020). While poorly framed policies can be attributed to multiple factors, having a body of scientific research that addresses policy-relevant questions to draw on can aid in improving policy making.

When it comes to fisheries management, the conventional single-species management paradigm is largely followed in India on ground (Mohamed & Malayilethu, 2013). This approach has been critiqued for working on species in isolation, thereby neglecting ecosystem interactions as well as human interactions and societal objectives (NOAA, 2021); furthermore, it relies on data-intensive stock assessments which may be limited in the Indian context. The Ecosystem Approach to Fisheries Management (EAFM) is a newer and more holistic form of fisheries management that combines concepts of conserving biodiversity and ecosystems with those of fisheries management, food security and livelihoods (Staples & Funge-Smith., 2009). Although an ecosystem-based approach has been advocated in India's marine fisheries policy, it has not yet been implemented (Mohamed, 2013; Mohamed & Malayilethu, 2013). Understanding the availability and quality of existing data can support the updating and implementation of these management approaches.

These points highlight a need to review chondrichthyan research in India to understand the applicability of research to date, and inform future research and conservation efforts. We conducted a comprehensive scoping review of chondrichthyan research in India, with the larger aim of assessing the relevance of this research to conservation of these threatened species. We looked at the distribution and biases of chondrichthyan literature across research topics, taxa and locations. We assessed the availability of data and whether it could potentially contribute to different fisheries management frameworks. Specific research questions, and the rationale behind them, can be found in Table 2.1. Through this review, we identified the main research gaps and priorities that future efforts need to address in order to guide policy more effectively.

2.2 Methods

We conducted a scoping review of scientific and grey literature on chondrichthyans in India. Structured searches were first carried out using specific search terms (Table 2.2) for the abstract, title or keywords only, in order to only include literature primarily focused on chondrichthyans. Searches were conducted in English only, as most scientific literature in India is in English, and carried out on Google Scholar as well as a number of global and Indian databases (Table 2.2). Following this, supplementary, unstructured searches were conducted by reviewing the reference lists of the literature from the structured searches to compile a comprehensive list of published and grey literature. The latter included reports, theses, newsletters, bulletins and other unpublished work; media articles were excluded from this study, however. All searches were conducted in March and April 2021.

Findings from the first ten pages of results in Google Scholar and all findings from the other databases were screened for inclusion in the review. We adapted the flowchart from Haddaway et al. (2017) to organise the screening process (Appendix A1). The title and abstract of each publication were read, and those meeting the criteria for exclusion were recorded and removed from the review (Table 2.2). Duplicates, which refers specifically to the same publication appearing in multiple databases, were also recorded and excluded.

After screening, all included publications were downloaded and randomly divided amongst 3 reviewers. Each publication was read in full text and reviewed. Metadata such as study locations, study taxa, affiliations of authors and publication type (grey or peer reviewed) were extracted and stored. We then coded each publication for its main research themes, coding up to three themes per publication. Research themes were Biology, Ecology, Records, Taxonomy/Phylogeny, Fisheries, Socio-economic, Management/Policy and Other (Appendix A2). Publications were also coded for whether they provided explicit policy and/or management recommendations, and whether they contained data that could potentially contribute to the conventional single species fisheries management and to EAFM. The coding protocol and definitions can be found in Appendix A2.

Table 2.1: The main research questions that were addressed in this scoping review, hypotheses for each, and the rationale behind them.

Research Question	Hypotheses	Rationale
What are the main themes of chondrichthyan research in India?	Research will be dominated by fisheries landings and biology.	This trend was reported in the draft National Plan of Action for Sharks (NPOA; BOBP, 2015).
How is chondrichthyan research distributed across the different regions in India?	Research will be skewed towards regions of high chondrichthyan fisheries landings.	India has 9 coastal states (i.e. provinces) and 4 coastal Union territories; chondrichthyan research efforts will likely be distributed across these regions based on where fisheries for these species occur.
Which taxa have research efforts focused on?	Research will be dominated by charismatic species.	Globally, chondrichthyan research is biased towards charismatic species (Ducatez, 2019).
To what extent can the available data contribute to different management frameworks?	Overall applicability of research towards management frameworks will be low, but research will be more applicable to a single species management approach than EAFM	As the single species approach is largely followed in India, we expected that existing data will be more applicable to this approach than EAFM.
To what extent does existing literature provide recommendations for chondrichthyan management?	Few publications will provide explicit recommendations for chondrichthyan management.	Few policies and conservation measures for chondrichthyans exist in India, hence we expected a low proportion of publications providing management and policy recommendations.

How have the above listed characteristics of chondrichthyan research changed over time?	Chondrichthyan research is increasing over time; Research themes like socio-economics will be gaining prominence; Proportion of conservation-relevant research is increasing with time.	Globally, chondrichthyans are receiving increasing research attention, and conservation science is becoming more holistic (Booth et al., 2019).

Table 2.2: Search terms, databases, and exclusion criteria for the literature review.

Search Terms[1]		
(india OR gujarat OR maharashtra OR goa OR karnataka OR kerala OR tamil OR andhra OR orissa OR odisha OR "west bengal" OR lakshadweep OR andaman*)	AND	(*shark* OR stingray* OR whipray* OR elasmobranch* OR chondrichth* OR guitarfish* OR wedgefish* OR dogfish* OR skate* OR batoid* OR "sting ray*" OR wobbegong* OR hammerhead* OR bonnethead* OR carcharhin* OR dasyati* OR mobul* OR manta OR isurus OR alopi* OR sphyrn* OR sawfish* OR gymnur* OR chimaer*)

Search Databases	
Global databases	*Indian databases and repositories*
Google Scholar, Web of Science, Scopus and ProQuest	Central Marine Fisheries Research Institute (CMFRI), Central Institute for Fisheries Technology (CIFT), National Institute of Oceanography (NIO), Centre for Marine Living Resources & Ecology (CMLRE), Zoological Society of India (ZSI) and Shodhganga

Screening Criteria

The following types of publications were excluded:

- Paleontological publications and fossil records
- Parasitology publications
- Studies conducted outside India
- Studies not related to chondrichthyans
- IUCN red list pages
- Media articles

[1] – The Asterix * at the start and/or end of a search word is a wildcard of undetermined length, and guaranteed that all potentially relevant publications were considered

To test for reliability in coding amongst the 3 reviewers, the lead reviewer (TG) independently reviewed and coded 10% of the publications (16, selected at random) assigned to the second reviewer. The Cohen's Kappa test was then conducted for 5 variables coded by the two different reviewers. This process was repeated for the third reviewer. The test produces a coefficient that measures the agreement between two reviewers, with a score of 1 representing complete agreement. Any discrepancies found after the test were discussed and the process for coding was refined accordingly to maximise inter-reviewer consistency.

The coded data was analysed to calculate the number and proportion of chondrichthyan publications in each research theme, study state and taxonomic group. We also assessed the proportion of literature that was potentially relevant to policy for and management of these species. Finally, we looked at trends in chondrichthyan literature with time. The publication year was categorised into 4 time periods: before 1991, 1991-2000, 2001-2010 and 2011-2020, in order to assess decadal trends. We used chi-squared tests to assess temporal changes in themes within the chondrichthyan literature, taxonomic group under study, and a publication's relevance to policy and management. All data analyses were conducted on RStudio version 1.3.1093 (R Core Team, 2014; RStudio Team, 2015), while regional distribution of publications was mapped using QGIS version 3.16.3 (QGIS, 2021).

To identify gaps in chondrichthyan literature and provide recommendations, we drew upon global and regional literature (e.g. Dulvy et al., 2017; Jabado et al., 2018) as well as the draft NPOA for sharks in India (BOBP, 2015). We also took insights from shark and ray research and conservation in other developing, fisheries-dependent countries.

2.3 Results

2.3.1 Overview of chondrichthyan literature in India

Our searches produced a total of 1385 publications; a large number of these were duplicates or met the exclusion criteria and were screened out, resulting in 482 publications for review (Appendix A1, A2 and A3). The Cohen's Kappa test gave an average score of 0.8, ranging from 0.59 to 1 for the different pairwise comparisons across variables and reviewers, representing a fair level of reliability amongst reviewers. Most discrepancies were found in coding of the research themes; these were discussed and resolved wherever possible.

For most of the reviewed studies, lead authors were from governmental institutes (79%, n=385) such as the Central Marine Fisheries Research Institute (CMFRI), which is a research institute under the Indian Council of Agricultural Research. The number of journal articles were marginally less than the grey literature (47% and 51%, respectively); most were open access and easily available. Most publications contained some primary data (89%, n=431).

There was an overall increase in the number of publications on chondrichthyans with time (Figure 2.1). Nearly half of all chondrichthyan studies (46%, n=219) were published in the most recent decade (2011-2020, excluding publications from 2021). This was considerably higher than the previous decade (2001-2010), with only 90 publications (19%). Fewer studies were published between 1991 to 2000 (16%, n=74). Before 1991, we found a total of 88 studies on chondrichthyans (19%), with the earliest publication dating back to 1945. There was also a significant increase in the proportion of peer-reviewed publications with time, particularly from 2011 onwards (χ^2 = 72.10, df = 3, p-value < 0.001; Figure 2.1).

2.3.2 Research themes

The main theme of research on chondrichthyans in India was found to be Records (n=232, 48% of all publications), which are publications focusing on single observations or events (e.g. observations of morphological deformities in certain specimens, records of unusually high landings, strandings of whale sharks, etc.). This was followed by research focusing on Biology (n=127, 26%), and Fisheries (n=87, 18%). A few publications (6% of total) covered both Fisheries and Biology in combination, which generally consisted of research using landings surveys to assess species composition, fisheries characteristics, size, sex and other biological parameters of chondrichthyans. Contrary to *a priori* expectations, themes like Socio-economic and Taxonomy/Phylogeny were poorly covered, with less than 10% of publications on each. Socio-economic research included studies focused on the processing, utilisation, marketing and trade of shark and ray products. Very few publications (n=24, 5% of total) were in the theme of Management/Policy. The bulk of the research in this theme composed of non-detriment finding (NDF) reports, which assess whether international trade of a species will be detrimental to its survival in order to inform policy under the UN Convention on International Trade in Endangered Species (CITES; e.g. Kizhakudan et al., 2019; Zacharia et al., 2017), and documents related to the development of the draft National Plan of Action for Sharks (NPOA; BOBP, 2015; Kizhakudan et al., 2015; Zacharia & Vivekanandan, 2013). Other Management/Policy themed publications included literature on conservation campaigns and policy evaluations for the whale shark (*Rhincodon typus;* e.g. Premjothi et al., 2016a; Matwal et al., 2014).

Research themes were not equally distributed across the decades (<1991, 1991-2000 2001-2010 and 2011-2020), based on a chi squared test (χ^2 = 82.07, df = 21, p-value < 0.001). The themes of Records and Socio-economic appeared to decrease in proportion over time, especially between 2011 to 2020, despite an overall increase in number (Figure 2.2). By contrast, the proportion of publications on Management/Policy, Ecology and Taxonomy/Phylogeny appeared to increase across the decades (Figure 2.2). The proportion of Fisheries-themed publications increased in the 1990s but showed little change after that; Biology was also nearly constant in proportion across the time periods. On the whole, research themes have become more diverse with time, as seen by increasing proportions of the 'Other' category, which comprises themes like Ecotoxicology, Biochemistry, Checklists and Field guides (Figure 2.2). As there were a large number of publications that were only of the theme Records, with no other theme (n=187, 39%), these may be masking broader trends in chondrichthyan literature and were hence excluded from further analyses, unless specified otherwise.

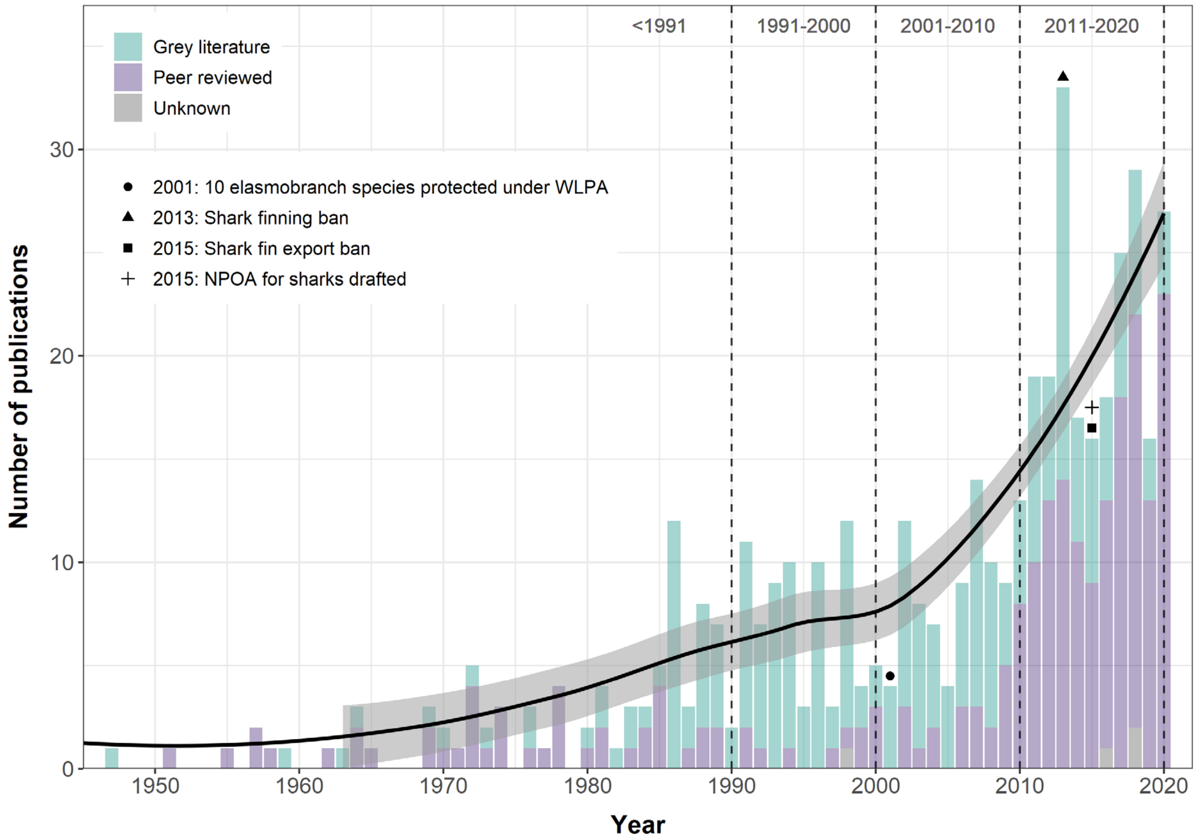


Figure 2.1: Number of publications over time, with proportions of grey (purple bars) and peer-reviewed (green bars) literature. The black line is the trend line of a linear model with the standard error in grey shading. The points represent key events for chondrichthyan policy and conservation in India. WLPA: Wildlife (Protection) Act, 1972. NPOA: National Plan of Action.

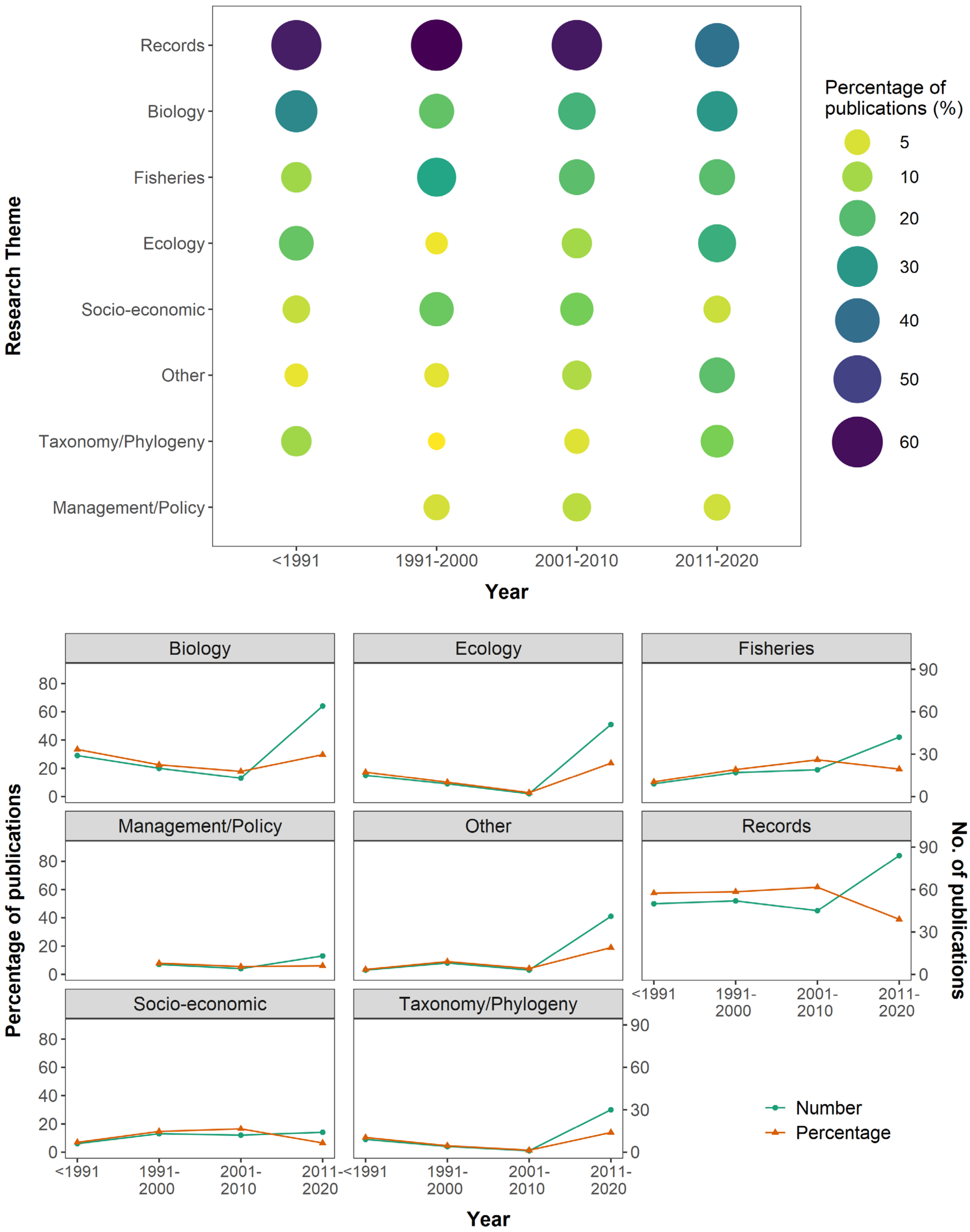


Figure 2.2: Main research themes of reviewed literature per time period (before 1991, 1991-2000, 2001-2010 and 2011-2020). Publications with more than one research theme are counted in each relevant theme. **Top**: Size and colour of the symbols represent the percentage of publications in each theme; larger and purple-coloured dots signify a higher percentage of that theme. **Bottom**: Total number of publications (green lines with circles, right axis) and percentage of the total (orange lines with triangles, left axis) for each research theme.

2.3.3 Research locations

The location of the data collection for chondrichthyan research was not equally distributed across the Indian maritime states (Figure 2.3). Excluding Records-only publications, Tamil Nadu, on the south-east coast of India, had the largest number of chondrichthyan publications (22%, n=65). This was closely followed by Kerala, on the south-west coast (20%, n=58; Figure 2.3). Research in both these states were dominated by the theme of Biology, followed by Ecology for Tamil Nadu and Fisheries for Kerala. Management/Policy was the least studied theme, with only 2 studies in each state.

The states of Goa (on the west coast) and West Bengal (on the north-east coast) were poorly studied, with only 6 and 7 chondrichthyan publications respectively. There was no research on the Management/Policy theme in these states. On the whole, less chondrichthyan research was conducted on the east coast than the west (Figure 2.3). Excluding Tamil Nadu, there were only 25 studies (9% of all publications excluding Records only) related to the remaining 3 east coast states combined. Excluding Kerala, the remaining west coast states were collectively represented in more than a quarter of chondrichthyan publications (27%, n=78).

These publication trends represented a mismatch between research efforts and chondrichthyan landings across India's coastline. States like Gujarat and Andhra Pradesh had proportionally less research despite having high landings, whereas research efforts in Kerala and Maharashtra were higher in proportion to the chondrichthyan landings in these states (CMFRI, 2019; Figure 2.3).

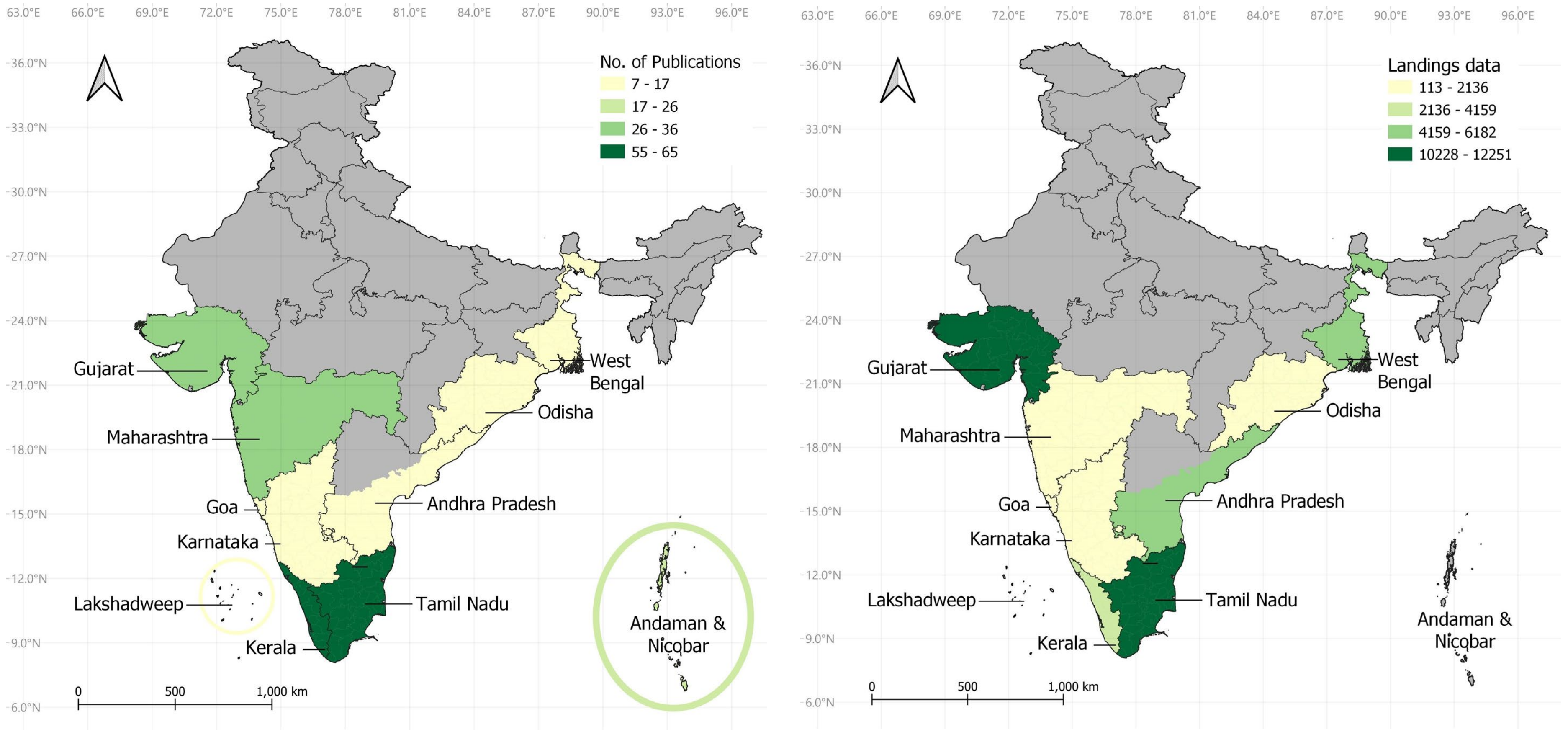


Figure 2.3: Total number of publications reporting research conducted in each coastal state (**left**; excluding publications that are Records only) and the total chondrichthyan landings per state in 2019 (**right**; CMFRI, 2019). No recent landings data for chondrichthyans were available for the Andaman and Nicobar Islands and Lakshadweep. Dark green colour indicates a higher number of publications at that state, and higher chondrichthyan landings, whereas light yellow indicates fewer publications and lower landings. Non-coastal states are marked in grey.

2.3.4 Researched taxa

Sharks (infraclass Selachii) were the main focus of research, represented in 79% of all publications (n=379). Rays (infraclass Batoidea) were studied in 32% of publications (n=156), while less than 3% of publications looked at chimaeras (class Holocephali, n=12). These groups are not mutually exclusive, and there are a number of publications that studied both sharks and rays (n=71). The whale shark (*Rhincodon typus*) was the most studied chondrichthyan species, with over 22% of all reviewed publications (including Records) focusing solely on this species (n=106). Other commonly researched taxa were mantas and devil rays (*Mobula sp.*), spadenose shark (*Scoliodon laticaudus*), requiem sharks (*Carcharhinus sp.*) and bramble shark (*Echinorhinus brucus*). Most of the literature studied sharks and rays at the species level (87%, n=416), with very few looking at them at the genus level or above.

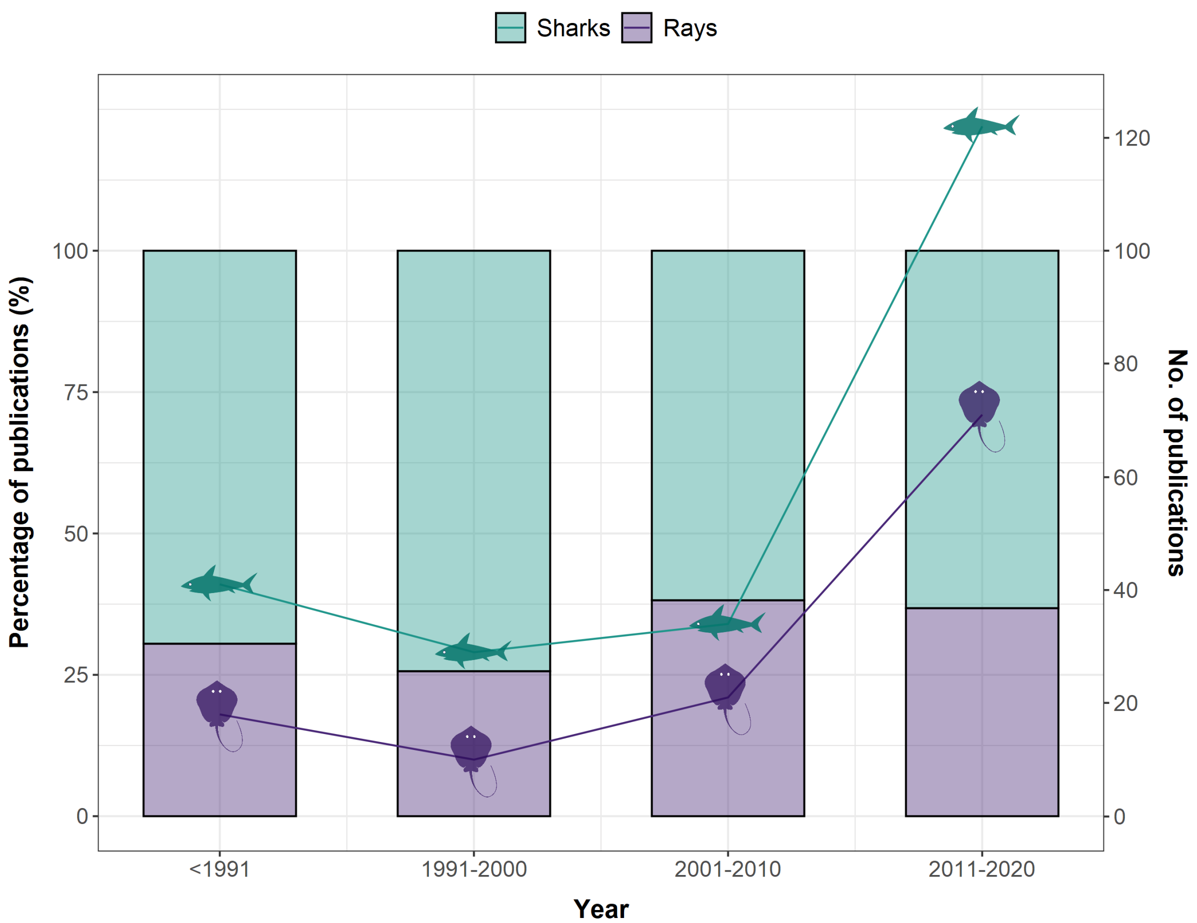


Figure 2.4: Number (right axis, line graph) and percentage (left axis, bars) of publications on each taxa (sharks, green and rays, purple) across the time periods. The data represented here excludes publications that are Records only. Publications studying both sharks and rays (n=71) are split and considered individual counts.

Nearly half of the shark literature was Records (48%, n=183), followed by Biology (26%, n=97). For rays, research was more evenly distributed across the different themes, with Records, Biology and Fisheries being the most common (33%, 32% and 26% respectively). Research on the theme Management/Policy was low for both sharks and rays (6% and 5% respectively). Although the number and proportion of ray-focused research increased over time, this increase was not significant (Figure 2.4, $\chi^2 = 2.54$, df = 3, p-value = 0.47).

2.3.5 Relevance of research for policy and management

Overall, the existing literature appeared to have low relevance and applicability in guiding policy and management for chondrichthyans. Only 12% of the reviewed publications (n=34) provided explicit policy and/or management recommendations for chondrichthyans and their fisheries. About 40% of the publications (n=110) contained data that could in principle contribute to a single-species management approach to chondrichthyan fisheries, while more than half contained data relevant to an Ecosystem Approach to Fisheries Management (EAFM; 56%, n=154). This was excluding publications that are just Records (n=187), as only 2 of these publications (1% of all Records) contained data that could contribute to single-species management and EAFM respectively, and none had any policy recommendations. On inclusion of research that only concerned Records, the proportion of publications relevant to policy and management decreased markedly.

The relative proportion of publications (excluding those that are only Records) with policy recommendations significantly increased with time ($\chi^2 = 9.01$, df = 3, p-value = 0.029). A similar trend was found for the proportion of publications with data relevant to EAFM ($\chi^2 = 9.64$, df = 3, p-value = 0.022), with significantly higher proportions of relevant publications in recent years. However, no significant change was observed for publications relevant to a single-species management approach with time ($\chi^2 = 3.56$, df = 3, p-value = 0.314; Figure 2.5).

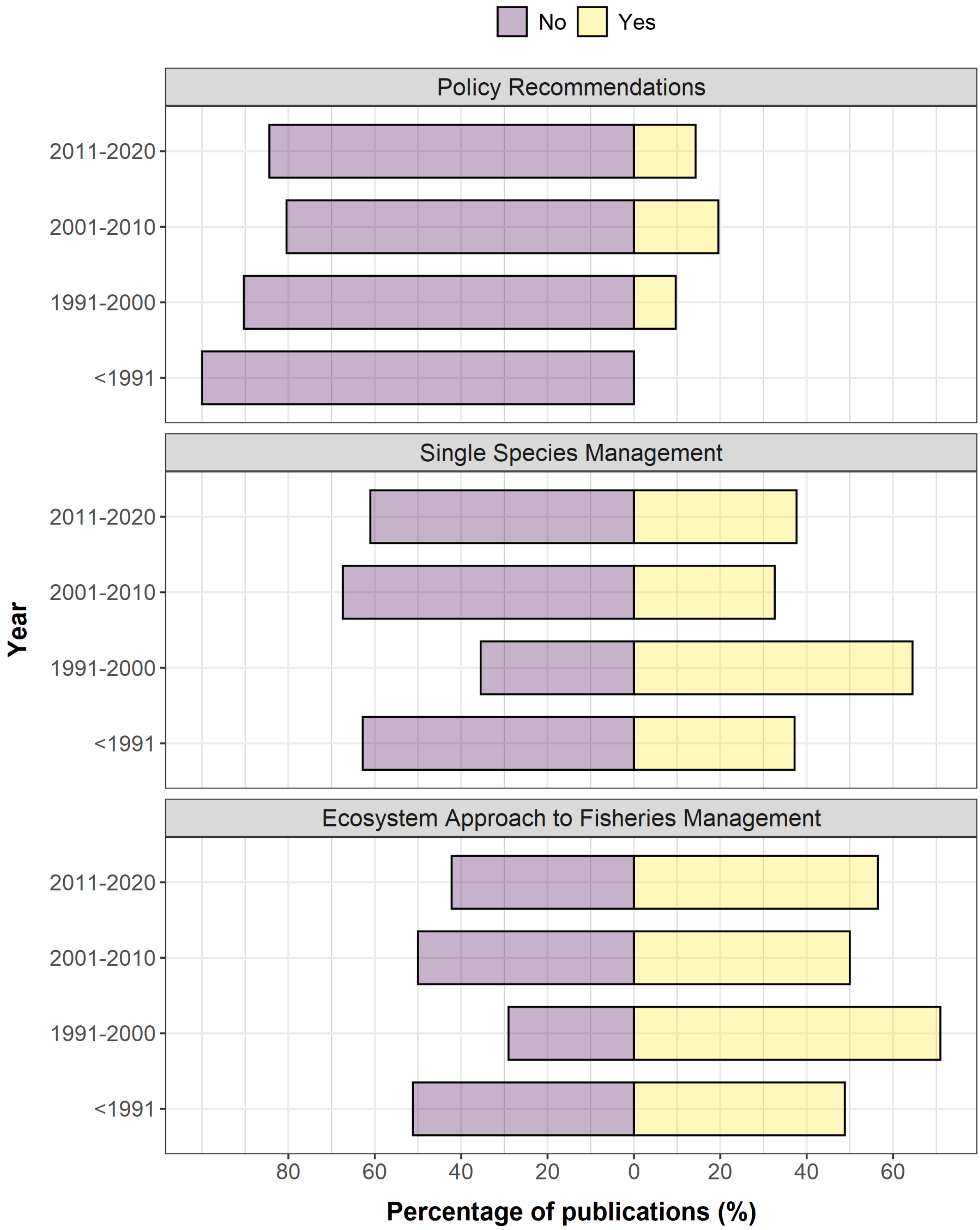


Figure 2.5: Relevance of publications to policy and/or management per time period (before 1991, 1991-2000, 2001-2010, and 2011-2020). **Top**: Number of publications that discussed the policy implications of their findings and provided policy/management recommendations; **Centre**: Number of publications with data that would be relevant to a single-species management approach; **Bottom**: Number of publications with data that would be relevant to an ecosystem approach to fisheries management (EAFM). The data represented here excludes publications that are Records only.

2.4 Discussion

This study shows that the research on chondrichthyans in India has significantly increased over time, and has especially grown in the last decade. In support of our hypotheses (Table 2.1), we found biases in research efforts towards certain states, taxonomic groups and topics. However, against our expectations, we found that chondrichthyan research remains strongly dominated by Records, with a paucity of literature on the socio-economic and management aspects. Overall, chondrichthyan research had little relevance for on-ground management or conservation policy-making. Although the field of conservation science has rapidly grown in India over the past few decades, particularly for terrestrial species (Bawa et al., 2021; Mishra et al., 2021; Thanuskodi & Venkatalakshmi, 2010), our findings highlight the need for improved conservation research for threatened marine species like sharks and rays.

2.4.1 Biases in chondrichthyan research

The dominance of Tamil Nadu and Kerala as sites for chondrichthyan research is likely to be due to the presence of governmental research institutes in these states (for example, CMFRI and CMLRE both have their headquarters in the Kerala, with major research centres in the Tamil Nadu), resulting in a large body of fisheries and marine research. Furthermore, Tamil Nadu is amongst the states with the highest level of chondrichthyan fishing (CMFRI, 2019), while Kerala is known to have a culturally high consumption of seafood, including sharks and rays (Salim, 2020). Research in other parts of the country remains patchy and scattered, particularly along the east coast, despite states like Andhra Pradesh and West Bengal having fairly high chondrichthyan landings and significant levels of local consumption (CMFRI, 2019; Karnad et al., 2024a).

Geographical bias in research efforts is not a new occurrence in conservation and biodiversity research, and has been noted for various different taxa and topics by global-scale reviews (e.g. Mas et al., 2021; Wraith et al., 2020) as well as within particular regions (e.g. Jamieson et al., 2019; Pitman et al., 2011; Suryawanshi et al., 2019). Bias in research locations can compromise conservation efforts through the neglect or under-representation of important biodiverse regions, and the development of conservation measures at a national scale that are inappropriate for the local or regional context (Marco et al., 2017; Muenchow et al., 2018; Teixido et al., 2020). Given the high cultural, socio-economic and political diversity across India, drivers of fisheries, utilisation and values of chondrichthyans are likely to vary with region (e.g. Jaini et al., 2018). Hence, this geographical research bias may be masking true patterns in chondrichthyan status, fisheries and trade, leading to poor decision making in conservation and management.

We found a similar bias in the taxonomic group under study, with research skewed towards sharks, and dominated by the whale shark (*R. typus*). Conservation science has long been plagued with a strong bias towards charismatic species, with non-charismatic yet ecologically important groups often overlooked in terms of research, policy and conservation (Donaldson et al., 2017). While the rationale is that charismatic species may serve as umbrella or flagship species for biodiversity conservation, this is not always the case (Zacharias & Roff, 2001; Wang et al., 2021). Extensive research and campaigns about the whale shark in India, combined with policy interventions, have led to the apparently successful conservation of this species (Bloch et al., 2019). However, it remains unclear whether this has led to positive outcomes for other chondrichthyan species. Rays are under-represented in Indian chondrichthyan literature, despite being more species-rich, widespread and threatened than sharks (Last et al., 2016). Rays also form a greater contribution to fisheries in India (59.5% of the total landed chondrichthyans in 2019; CMFRI, 2019) and are important for local food and livelihoods. Similarly, chimaeras are very poorly studied, which may be attributed to their deep-sea habitat and relative rarity in fisheries catch (Holt et al., 2013). Research efforts need to diversify and include a wider range of species, as a 'one size fits all' approach to chondrichthyan conservation will likely be unsuccessful given their high ecological and biological diversity (Dulvy et al., 2017).

2.4.2 Management of chondrichthyan fisheries

Fisheries management has been undergoing a paradigm shift worldwide from single species to an ecosystem approach (Townsend et al., 2019). While there have been advances in developing ecosystem approaches in India, its on-ground implementation is hindered by a multitude of operational challenges (Mohamed & Malayilethu, 2013). Our findings show that there is limited published information on chondrichthyan stock status and other parameters that are required for conventional management; this may be true for other commercially exploited species in India as well. Furthermore, contrary to *a priori* expectations, we found that the existing chondrichthyan literature might potentially contribute more to EAFM than single species management. While this result was surprising, EAFM is a broad and holistic framework that can integrate different types of data from various sources (Staples & Funge-Smith., 2009). Hence, we highlight the need to develop a feasible and locally appropriate framework for implementation of EAFM in India (Vijayakumaran, 2014).

2.4.3 Relevance of research for conservation

Overall, applied chondrichthyan research in India was limited, evidenced by the small number of publications in the Management/Policy theme, and equally few publications providing explicit recommendations for chondrichthyan conservation. A similarly small proportion of publications could contribute directly to fisheries management. Furthermore, although research is becoming increasingly diverse with time, it remains dominated by Records. While records have some value in understanding long-term trends, identifying shifting baselines and enabling the analysis of historical changes in socio-economic values (Baum & Myers, 2004; Monsarrat et al., 2019), we found that they have little direct relevance in guiding conservation and management of fisheries. The dominance of Records in the literature indicates that most published studies in our sample were largely incidental or opportunistic, with little directed and dedicated research on sharks and rays.

In the Asian tropics, conservation research priorities are often driven by the sources of funding, which are frequently external; this is further challenged by the social and economic priorities of governments, limited resource capacity, and conflict between development and conservation objectives (McNeely et al., 2009; Sheil, 2002). Conservation research in India has largely focused on terrestrial biodiversity, with significant attention given to charismatic land species such as the tiger and elephant; marine biodiversity has been relatively overlooked (Kuppasamy et al., 2013). Chondrichthyans are exceptionally challenging as they are both a threatened marine species group in need of conservation as well as a commercially valuable group that is regularly fished (Gupta et al., 2020a). As our findings show, most chondrichthyan research in India has been conducted by organisations under the Ministry of Agriculture and the Ministry of Fisheries, Animal Husbandry and Dairying of the Government of India, where these species are viewed through a fisheries resource lens. Very little research is conducted by the agencies under the Ministry of Environment, Forest and Climate Change, whose mandate is focused on wildlife and environmental conservation. Hence, chondrichthyan research tends to be production-oriented rather than conservation-oriented. This is not an issue confined to India; as a result, fish species are often neglected in wildlife conservation legislation globally (Vincent et al., 2014; Wyatt et al., 2021). There is a need for a pluralistic approach for sharks and rays, encompassing their different aspects and complexities in order to produce research relevant to conservation as well as fisheries management (Booth et al., 2019).

2.4.4 Key gaps and recommendations

We identified a number of critical gaps in chondrichthyan knowledge in India, that need to be addressed in order to make their conservation more effective. While there have been significant advances in documenting and describing the chondrichthyan species present in Indian waters, there is a need to assess the status of these populations, through species stock assessments or risk assessments (BOBP, 2015). Risk assessments will aid in identification of priority species and fisheries for conservation and management in India (Dulvy et al., 2017; Jabado et al., 2018). For instance, an adapted productivity-sensitivity analysis was conducted in Indonesia to identify at-risk shark and ray species; priority sites for conservation were also identified (Booth et al., 2018). Similar assessments would be highly valuable in India.

We also highlight a paucity of knowledge about critical habitats of sharks and rays. These species are known to use specific sites for spawning and nurseries, as well as for feeding, making them highly vulnerable to fisheries and other activities occurring at these areas (Heupel et al., 2007; Martins et al., 2018). Few studies in India have looked at the spatial ecology of chondrichthyans, with very few attempting to identify and characterise their critical habitats (c.f. Chembian, 2010; Kumari & Raman, 2010; Premjothi et al., 2016b; Gupta et al., 2020b). Knowledge of habitat use and aggregation sites can aid in the formulation of nuanced, area-based conservation measures (Barnett et al., 2019). Conventional methods for research on habitat use can be resource-intensive and may be a challenge for the Indian context. However, fisher knowledge (i.e. Local Ecological Knowledge and Traditional Ecological Knowledge) can be a crucial source of information in resource and data-limited situations. Fisher knowledge has been used to gain insights on shark and ray habitats in regions in Bangladesh (Haque et al., 2021), Mexico (Cuevas-Gómez et al., 2020) and Fiji (Rasalato et al., 2010), and could be used to address similar data gaps in India.

There is also a need for deeper understanding of the human dimensions of chondrichthyan fisheries, as they form complex social-ecological systems with important contributions to livelihoods and food security (Karnad et al., 2019). Chondrichthyan research needs to be inter- and multidisciplinary to address all elements of this system and guide holistic management. Social sciences are becoming increasingly mainstreamed into conservation science in general (Bennett et al., 2017), as well as into chondrichthyan research (Booth et al., 2019; Simpfendorfer et al., 2011). Social science can be used to understand attitudes, perceptions and values of sharks and rays and their use by local communities, in order to design appropriate and inclusive conservation strategies (Glaus et al., 2018; Mason et al., 2020; Sabbagh &

Hickey, 2020; Skubel et al., 2019). Against our expectations, we found alarmingly few publications on socio-economic themes in India, with no increase over time. With a large population of fisher folk (4.9 million; Department of Fisheries, 2020) and evidence of substantial local chondrichthyan consumption in the country (Karnad et al., 2019), understanding the socio-economic drivers of chondrichthyan fishing is a priority for India.

Finally, we propose that evaluation of existing policies and regulations for chondrichthyans in India is urgently needed. With the exception of the whale shark (e.g. Bloch et al., 2019), we did not find any policy evaluations that assessed their effectiveness for conservation of these species, which can be a hindrance to decision-making. It is essential that policies for sharks and rays in India are evaluated and strengthened based on scientific evidence. For instance, Collins et al. (2020) and MacKeracher et al. (2020) assessed effectiveness of and compliance with shark fishing bans in Sri Lanka and Myanmar respectively, to provide strong recommendations for improved outcomes. Similarly, Booth et al., (2020) developed a framework to evaluate the impact of regulations on manta ray trade in Indonesia. These approaches could be applied in the Indian context.

2.4.5 Limitations of this study

While every effort was made to ensure that we accessed and reviewed the entire set of chondrichthyan literature in India, such as using a comprehensive set of search terms and searching across numerous international and national databases, we acknowledge that we may have missed some relevant publications, particularly grey literature. Searching through a greater number of national databases, such as repositories of fisheries institutions, and in different regional languages, may yield more results. In person searches of research institute archives and libraries would no doubt have yielded some reports, theses and older journal articles that have not been digitised. However, as our main objective was to assess the conservation relevance of existing literature, publications that are not easily available online are unlikely to guide conservation policy-making. Lastly, we note that our assessments of the conservation relevance of chondrichthyan literature were based on the potential or hypothetical contributions to on-the-ground conservation or conservation policy. Assessing the actual real-world contribution made by each publication would be a significant challenge.

2.5 Conclusion

There is a substantial body of research for sharks and rays in India, increasing rapidly with time, which is a very positive sign for a data-limited region and taxonomic group. However, research on this group in India need to be refocussed towards producing data and evidence that can better support practical conservation and policy-making. Future research needs to focus on regional species risk assessments and knowledge of critical habitats to identify vulnerable species and areas for conservation. Understanding the socio-economic drivers and aspects of chondrichthyan fisheries must also be a priority, as it can be vital to developing successful management measures. Lastly, there is a need to review and improve existing policies for chondrichthyan fisheries and conservation. While implementation of conservation measures will remain a challenge in India due to limited capacity, political will, and other factors, strengthening the research and evidence base will help in developing science-based solutions to the challenges facing chondrichthyans. Our findings can help shape these future research efforts.

Chapter 3

Drawing on local knowledge and attitudes for the conservation of Critically Endangered rhino rays in Goa, India

Rhino rays in their nearshore habitats in Goa. Artwork by Sayan Mukherjee.

3.1 Introduction

In the context of global marine species declines and data paucity, useful information on the conservation status of species is being garnered from diverse sources. In particular, local knowledge systems provide insights that are complementary to ecological science, in terms of scope and content (Tengö et al., 2017). In coastal ecosystems, the knowledge and perspectives of fishers are valuable sources of information on historical and current trends in threatened marine species, especially in developing countries with limited scientific data (Drew, 2005; Haque et al., 2021). Local ecological knowledge (LEK) of fishers refers to the body of experiential knowledge including ecological, fishing practices, fishing communities, governance and markets, and their dynamic relationships, which is developed in a social-cultural and geographical context (Cowie et al., 2020). Alongside information on species, LEK systems provide insights for how and why social-ecological systems are governed, and for developing holistic solutions to resource management problems (Hazenbosch et al., 2022; Tengö et al., 2017). LEK can help understand how threatened species exist within local culture, in terms of their uses and values, and reveal attitudes towards their conservation (Cowie et al., 2020). Therefore, it is important to bring LEK together with the scientific mainstream to develop more holistic and equitable management and conservation plans (Drew, 2005; Haque et al., 2021; Nirmale et al., 2004).

Rhino rays are a data-limited and highly threatened group of elasmobranchs (sharks and rays). Comprising giant guitarfish (Family: *Glaucostegidae*) and wedgefish (Family: *Rhinidae*), 15 of 17 rhino ray species are Critically Endangered (Kyne et al., 2020). Rhino rays are slow-growing, long-lived, and display viviparous reproduction with long gestation periods and low fecundity (Moore, 2017). Most species are known to use nearshore bays, estuaries and lagoons as foraging, resting, mating and nursery areas (Chaikin et al., 2020; Farrugia et al., 2011; Martins et al., 2018; Whelan et al., 2017). These life history characteristics make rhino rays highly vulnerable to overexploitation by coastal fisheries, and their populations have a limited capacity to recover (Jabado, 2018). Most species are also endemic to countries where fisheries management and marine conservation are a major challenge (Kyne et al., 2020). Hence, there is a conspicuous lack of scientific information on their biology, ecology and socio-economic value, and rhino rays remain largely unmanaged (Moore, 2017).

Marine species can be utilised by coastal communities for a variety of purposes with different instrumental and relational values. Instrumental values are the values of an entity as a means to an end, generally including monetary and economic benefits (Arias-Arévalo et al., 2017; Pascual et al., 2017). In contrast, relational values are the preferences, principles, and virtues associated with relationships with nature, both interpersonal and as articulated by policies and social norms (Chan et al., 2016). In the case of rhino rays, their fins are important commodities in the international market and are the primary drivers for their capture and retention (Choy et al., 2022; Jabado et al., 2018). However, their meat is commonly consumed in countries like India and Bangladesh, where it can form a cheap source of protein for low-income communities (Haque et al., 2021; Nazareth et al., 2022). Skin, bones and other products have also been recorded to have ethnomedical uses in non-coastal regions of India (Singh et al., 2020). Therefore, local communities may have diverse values for rhino rays. Culturally-specific values underpin a community's relationship with a species, and hence can provide a local incentive for the conservation, but also exploitation, of the species (Marsh et al., 2021). For threatened elasmobranchs, understanding the historical or contemporary uses and culturally-specific values that these species have could inform the development of culturally appropriate conservation initiatives with the potential to achieve high levels of engagement and participation from local resource users (Grant et al., 2021).

Alongside values, it is important to understand attitudes of stakeholder groups toward biodiversity. Attitudes, which refer to an individual's evaluation of a person, concept, entity or action, can help predict human behaviour and determine participation in conservation activities (Ajzen, 1991; Solomon et al., 2012; Sponarski et al., 2014; Heberlein, 2012). The attitudes of fishers and the general public towards sharks present both challenges and opportunities for effective shark conservation (Ali et al., 2020; Drymon & Scyphers, 2017; Glaus et al., 2018; López de la Lama et al., 2018). Fishers also tend to perceive marine species holistically and as groups, rather than individual species (Karnad, 2022). Hence assessing attitudes of fishers towards rhino rays as a group, in the context of other threatened marine species groups, can help build a holistic understanding of how locals perceive and will respond to conservation measures.

India is among the top 3 elasmobranch fishing nations globally; 43,741 tonnes of landed elasmobranchs were recorded in 2019, of which approximately 481 tonnes were guitarfish and wedgefish (CMFRI, 2019). India is a hotspot for rhino ray species richness (Kyne et al., 2020), yet their ecology is exceptionally understudied (Gupta et al., 2022, Chapter 2). At the time of this study, one rhino ray species (*Rhynchobatus djiddensis*) was protected under India's Wildlife (Protection) Act (WLPA). Five more species have been recently listed under protection in the WLPA (*R. australiae, R. laevis, Rhina ancylostoma, Glaucostegus obtusus* and *G. thouin*; Parliament of India, 2022). The implementation of these policy changes will be challenging given that rhino rays are mostly bycaught in Indian fisheries, highlighting the need for practical and contextually appropriate mitigation measures. Furthermore, it is important to understand how fishing communities interact with these species and how conservation policies may impact them. (Tyabji et al., 2020)

Our study draws on the ecological knowledge of fishers (LEK) to understand the socio-ecological status of rhino rays in the state of Goa, on the west coast of India; an area with known populations of rhino rays and where a range of threats is present. We aimed to understand rhino ray habitat use and seasonality, and their interactions with fisheries, to get detailed insights into their ecology and associated fishing practices at a local scale, as well as to assess the level of ecological knowledge held by fishers in Goa for these species. We further described their socio-economic uses and relational values. Finally, we explored attitudes of fishers towards rhino rays, other threatened marine species, and their conservation.

3.2 Methods

3.2.1 Study site

This study took place across the coastline of Goa (Figure 3.1). Rhino rays are known to be captured by small-scale gillnets, coastal trawlers and other nearshore fisheries here (Hegde et al., 2014), most likely as bycatch (Sreekanth et al., 2021), with presence of two species (*Glaucostegus granulatus* and *Glaucostegus obtusus*) confirmed in Goa. However, at least 10 species of rhino rays (families *Glaucostegidae* and *Rhinidae*) have been recorded in Indian waters (Akhilesh et al., 2014). Based on distribution maps, it is likely that most of these species are present in Goan waters (Last et al., 2016). In addition, some rhino ray species are known to aggregate in the shallow coastal waters of a number of beaches in Goa (A. Jamalabad, personal communication; A. Lobo, personal communication). These sites may be serving as parturition, nursery or feeding grounds, but are poorly understood with sparse and anecdotal information. Aggregations of this type are susceptible to depletion due to fisheries, coastal development, pollution, tourism and other activities commonly occurring along Goa's coast.

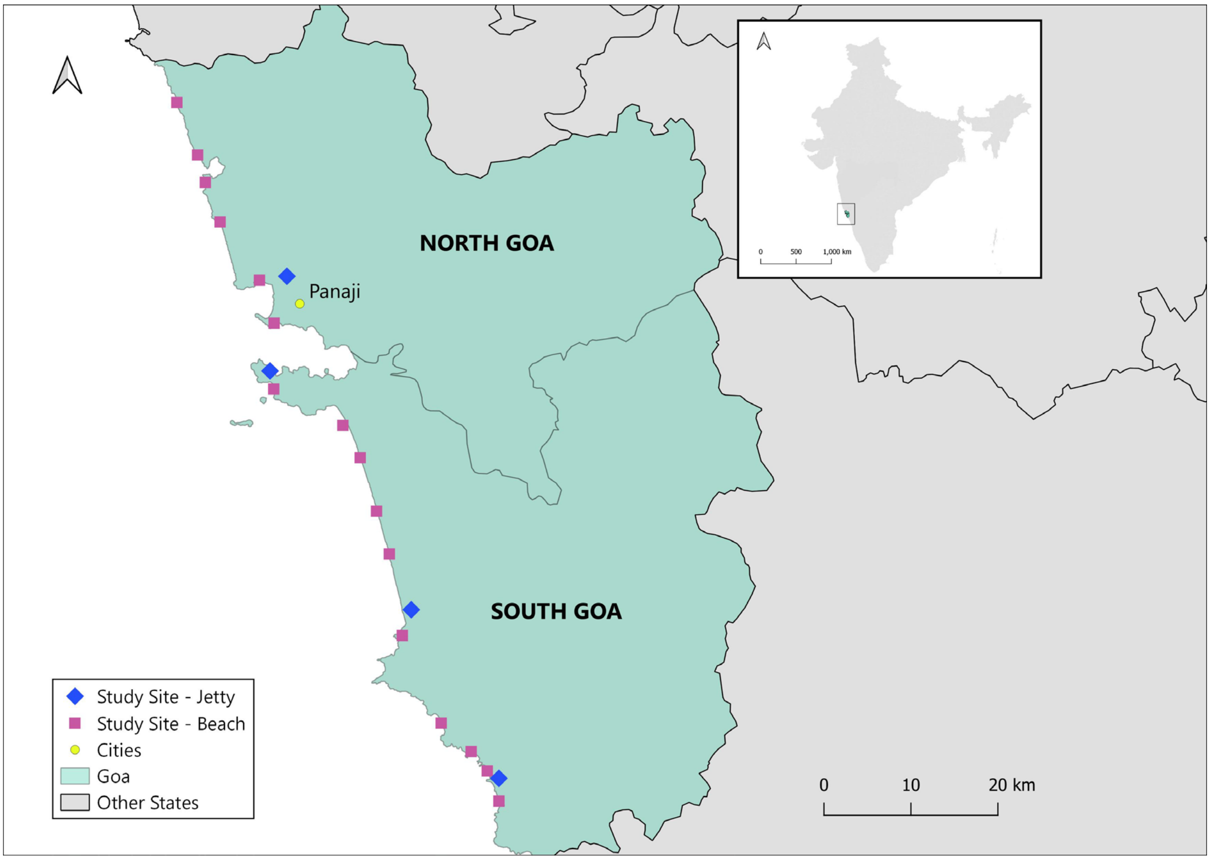


Figure 3.1: The study sites in Goa

3.2.2 Interviews

We used mixed methods, applying a combination of semi-structured interviews and key informant interviews. Study sites included 16 fishing villages and 4 major fishing harbours, randomly selected from a list of the major fishing sites in Goa (Goa Department of Fisheries, 2021; Figure 3.1, Appendix B1). We first conducted semi-structured interviews in February-March 2021, with fishers as they are the most likely to hold LEK for rhino rays and can also provide insights into the fishing and non-fishing threats to these species. At some study sites, we used a combination of convenience sampling, where available fishers were approached at the landing centre, and chain referral sampling, where interviewed fishers were asked to suggest other respondents (Newing et al., 2011). At other sites, we were introduced to the communities through respected members like religious leaders and used this to snowball and interact with a wider cross-section of the communities. Knowledge of the site and informal conversations with fishers indicated that we sampled the majority of active fishers at each site.

At the start of the semi-structured interviews, respondents were shown a photo of a rhino ray and asked if they recognised this fish. If yes, the researcher (AD) would introduce himself, explain the research objectives and asked if the fisher was willing to participate in the research.

Informed oral consent was obtained, rather than written consent, due to variability in literacy rates and fishers' comfort with reading and signing written documents. These interviews were conducted in Hindi or Konkani and lasted 20-30 minutes. Respondents were asked a mix of open-ended and closed questions on rhino ray ecology (local names, habitat use, seasonality, behaviour, breeding), fisheries (gear, catch rates) and post-harvest uses (Appendix B2). We also investigated perceptions of changes in rhino ray populations, and drivers of those changes. Pilot interviews found that fishers expressed significant uncertainty in distinguishing rhino ray species, particularly in the *Glaucostegidae* family. Hence our interviews looked at rhino rays collectively rather than at species level, to avoid any bias or errors in species identification. Nevertheless, any species-specific information mentioned by respondents was noted. This study received ethics clearance from Ashoka University's Institutional Review Board, following the code of ethics set forth in the Belmont Report (HHS, 1979).

While we aimed to interview individual fishers, this was not always possible. Respondents were often approached when they were sorting catch, cleaning their nets, or resting with other crew members. Even if a fisher was alone when approached, the interview process would often attract the attention of others in the vicinity. In these cases, group interviews were conducted, which differed from focus groups in that the individuals who formed the group were not invited intentionally, and these interviews were used to collect rather than confirm or contrast against data (Bernard, 2017). Demographic information was not collected for group interviews, and where more than one respondent contributed to a question, consensus in the answer given was confirmed before documenting it. As the aim of these interviews was to gather LEK and information on fishery characteristics, interviews conducted with small groups of collective fishers would not violate this aim (Grant et al. 2021).

Based on information obtained in the semi-structured interviews, we conducted qualitative interviews in October 2021, with key informants who were selected purposively because they had great expertise on fishing and could provide views that represented the community (Newing et al., 2011; Poggie et al., 1972). Key informants included fisher union leaders, community leaders, elderly fishermen and traders at the same study sites. They were identified based on our prior knowledge of the site, and through conversations with fishers and other community members, and approached at their homes, landing centres or markets. These interviews took 30-60 minutes and were conducted in Hindi by TG and AD. They primarily consisted of open-ended questions to get a better understanding of rhino rays and their conservation (Appendix B3). Key informants were first asked questions about their knowledge of and interactions with rhino rays to triangulate and better understand information gained from the semi-structured interviews. We then investigated attitudes towards the conservation of rhino rays and other threatened species like marine turtles and cetaceans. Key informants were asked to list marine species that to their knowledge are protected, and provide their opinions on the prohibition of harvest for these species. We then discussed rhino rays, asking key informants what would happen if these species were similarly protected, and their attitudes towards rhino ray conservation.

3.2.3 Data analysis

Interview data addressed four pre-decided themes: (1) Ecological characteristics (habitat, seasonality and behaviour), (2) Socio-economic characteristics (fisheries, uses and values), (3) Population trends and (4) Conservation. Data from the semi-structured interviews were used to address sections 1 to 3. Key informant interviews were used to triangulate these data and explain some of the trends obtained. Section 4 was designed based on information obtained in the semi-structured interviews, and hence was addressed entirely by key informants.

The closed, quantitative data were entered into Microsoft Excel and analysed using RStudio to produce descriptive statistics. The open-ended, qualitative data were thematically analysed on NVIVO. We used a hybrid approach, with both deductive and inductive coding. For example, responses on rhino ray habitat and seasonality were deductively coded based on a priori codes. However, emerging and unexpected themes, such as feeding behaviour, were inductively coded from the responses. Statements and knowledge about rhino ray ecology were compared with information from the scientific literature. We reviewed information for the rhino ray species that possibly occur in this region in databases like Rays of the World (Last et al., 2016) and FishBase (Froese & Pauly, 2022), as well as scientific papers. This was not intended to be a comprehensive literature review, but was done to understand how LEK and scientific knowledge complement and contradict each other (Tengö et al., 2014). We also aimed to identify and gain new insights for rhino ray populations in this region.

Different values for rhino rays were observed in interview transcripts and appeared to emerge as an important theme. Therefore, these values were captured and analysed using the relational values framework described by Chan et al. (2016, also see Arias-Arévalo et al., 2017). Coding was done by TG and checked by AD. To understand attitudes towards conservation, responses of key informant interviews were coded as positive (attitudes that favoured conservation) and negative (attitudes that did not favour conservation).

The term 'respondents' is used to refer to the semi-structured interviews, whereas 'key informants' refers to the key informant interviews. The results are presented in terms of percentage of total respondents/key informants, and ranges, means and medians are presented as appropriate. We also present specific quotes from the interviews to better explain our findings.

3.2.4 Positionality

All fieldwork and interviews were conducted by AD and TG. We are both Indian nationals but are not residents of Goa nor belong to any of the fishing communities with whom we worked. We are western-trained early career natural scientists, with additional training in interdisciplinary conservation science. Therefore, our lenses are shaped as well as limited by our identities and training. We mitigated our position as outsiders by building a rapport with our interviewees and reassuring them about the confidentiality of the information they provided. As a measure of the trust built, fishers voluntarily revealed some sensitive information such as illicit fishing activities. We also acknowledge that our positionality may have biased the way we collected, transcribed, and interpreted the data. We have strived to represent the knowledge of the interviewed fishers as authentically as possible and remain true to the words used by the fishers themselves. However, our work does focus on specific dimensions of LEK and hence represents a partial understanding of the vast ecological knowledge held by fishers in Goa.

3.3 Results

We conducted a total of 66 semi-structured interviews, with gillnet fishers (59%), mechanised fishers (35%) and other small-scale fishers (21%). Respondents were mostly from Goa (66%), with some migrant fishers. Just over half of these were group interviews (53%), hence we did not record demographic details such as age and years of fishing experience. Additionally, we conducted 22 key informant interviews, again focusing on gillnet and small-scale fishers (91%) with a few mechanised fishers. All key informants interviewed were locals from Goa, with an average of 28 years of fishing experience.

3.3.1 Ecological Characteristics

Rhino rays were recognised by nearly all the interviewed fishers (97% of respondents). Only 2 respondents, both migrant fishers, did not recognize rhino rays and were hence not asked further questions. Presence of rhino rays in shallow coastal waters was confirmed in all the study sites; respondents also mentioned finding these species all along Goa's coastline, as well as in the neighbouring states of Karnataka and Maharashtra where they have also fished or resided. We recorded 8 different local names for rhino rays across the Goan coastline. In the South, rhino rays were most often referred to as “Ellaro” whereas in the North, they were called “Phadke” or “Kharra”. There were no separate names for different species, with a few exceptions (Appendix B4).

Overall, fishers were able to provide insights into the ecology of rhino rays at a broad resolution. Responses were provided to most questions and there were only a few occasions where fishers stated that they did not know. Rhino rays were stated to inhabit sandy sea floors (86% of respondents), near or in between rocks (48%) and in the mouths of rivers and creeks along Goa’s coastline (44%). They were observed in shallow nearshore waters (up to 5m depth, 79% of respondents), but showed ontogenetic shifts with juveniles and pups occupying shallow waters and moving offshore as they grow bigger (24%). This LEK aligned with information on rhino rays in the scientific literature (Table 3.1).

August and September, right after the monsoon season, were identified as months of highest sightings nearshore (61%, Figure 3.2). On the contrary, the summer months of April and May were stated to have little or no presence of rhino rays in nearshore waters (24%). Respondents believed that rhino rays bred nearshore, particularly around the river mouths (30%), during the monsoon (24%), or just after the rains (9%). Such insights into seasonal habitat use and movements has not been reported in literature for this region and hence adds new information to the scientific knowledge base (Table 3.1).

Some respondents also mentioned unique behavioural observations for rhino rays (Table 3.1), although sample sizes for these were low. Certain species-specific insights were also noted: the bowmouth guitarfish (*Rhina ancylostoma*) was only found in deeper waters and not observed nearshore. Some respondents suggested that the sharpnose guitarfish (*G. granulatus*) was less common than the widenose guitarfish (*G. obtusus*). The former was found in deeper waters and was generally found alone while *G. obtusus* was found in groups.

Table 3.1: Fishers' LEK of rhino rays, along with an example quote from the interviews and references from the scientific literature, if present. The green colour indicates that the local knowledge aligns with scientific literature at a broad resolution; blue indicates that this information is not reported in scientific literature (to our knowledge) but is consistent with biological characteristics of rhino rays or literature for species not found in this region; orange indicates information given as personal interpretations by fishers, which does not align with scientific literature or biological characteristics.

LEK from fishers (% of respondents)	**Aligns with scientific literature? (Reference)**	**Example quote**
Habitat use		
Rhino rays inhabit sandy sea floors (86%), near or in-between rocks (48%)	Yes (Last et al., 2016)	*"They prefer sandy waters so they can bury themselves under the sand. They also like to be near rocks and caves sometimes."*
Found in the mouths of rivers and creeks (44%). The following rivers in Goa were specifically mentioned (n >1): Betul, Talpona, Agonda, Chapora, Zuari and Mandovi	Yes (Last et al., 2016; Froese & Pauly, 2022). Use of brackish and freshwater habitats is poorly studied for most species, however.	*"Sometimes you even find them going 1-2 km upriver in certain rivers and going back out to sea. This happens during the rainy season, as the water level is higher"*
Rhino rays are found in shallow, nearshore waters (up to 5m depth, 79% of respondents), and in offshore waters, up to 110m depth and 80km offshore (29%)	Yes (Last et al., 2016)	*"You can find them in ankle deep water as well as deep water, 50-60km from shore. They are bottom dwelling fish."*
Ontogenetic shifts in rhino rays, with juveniles and pups occupying shallow waters and moving offshore as they grow bigger (24%)	Yes (Last et al., 2016)	"*The bigger ones are mostly in the deep side. The babies come to the shallows to feed, so we see them more*"
Seasonality		
Maximum sightings of rhino rays nearshore are in August and September, right after the monsoon season (61%)	No. Consistent with trends reported by Nazareth et al. (2022) in the Andaman Islands, India	"*The festival of Ganesh Chaturthi, during the rains, is the season for these fish. That and after the rains is the best time to come spot them.*"

Little or no presence of rhino rays in nearshore waters in the summer months of April and May (24%)	No	*"In summer, the water becomes too hot for these fish. They go to deeper, cooler waters"*
Breeding takes place during the monsoon (24%), or just after the rains (9%)	No. Consistent with literature for species not found in this region (Last et al., 2016; Chaikin et al., 2020)	"*The rainy season, July and August, is the time their populations increase."*
Other behavioural observations		
Rhino rays come to the shallow waters on the shoreline, or upriver, to feed on fish and crabs (23%)	Yes (Last et al., 2016; Sreekanth et al., 2021).	*"They come to the very edge of the shoreline because they eat the small white crabs that run on the shore. To catch the crabs, they have to take a risk and come to the edge of the shoreline where the waves break."*
Rhino rays are found in pairs or groups of up to 5 individuals, especially juveniles (12%).	No. Consistent with literature for species not found in this region (Chaikin et al., 2020)	*"These fish travel in pairs. They travel together to feed and rest. It could be possible that they could be from the same mother. As they get bigger they split up."*
Rhino rays are sometimes predated on by crows and other birds in the shallow nearshore waters (3%)	No. Predation of rhino rays by birds does not appear to be previously published and needs further examination	*"Sometimes you find the small ones near the river mouth but they go back quickly into deeper water because birds trouble them. Crows and fish-eating birds like pond herons can pick up the lighter ones and eat them."*
Rhino rays come to the water surface to 'breathe' (6%)	No. Does not align with published biological characteristics, needs further investigation.	*"They are bottom dwelling fish. They sometimes come to the surface upside down, take a gulp of air and go back down"*

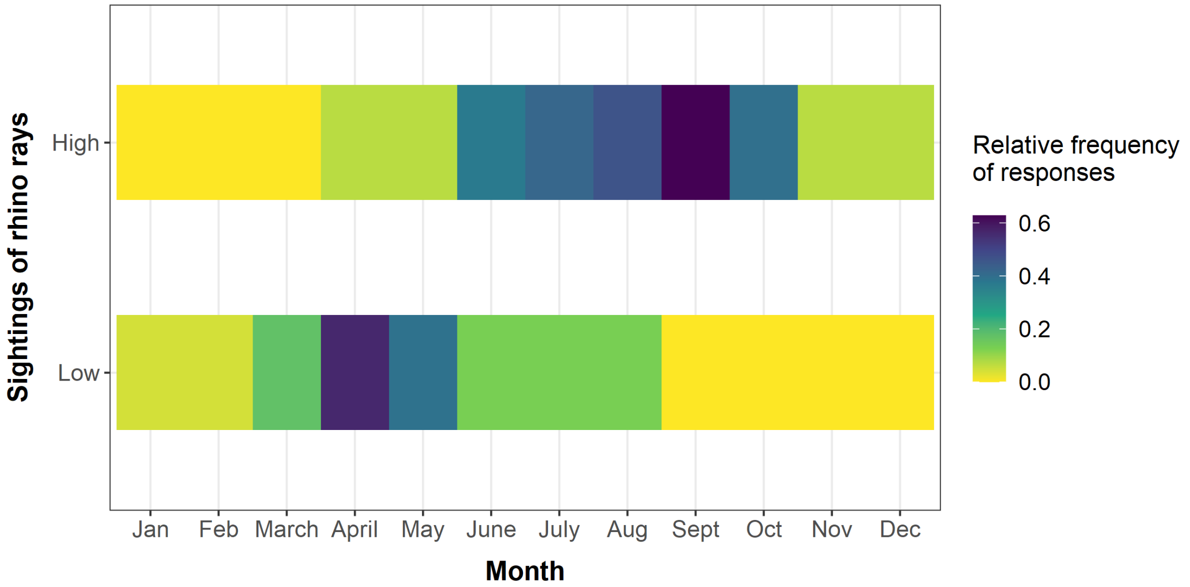


Figure 3.2: Seasonality of rhino ray sightings expressed as relative frequency for each month. Relative frequency was calculated as the number of responses for high (top) and low or no (bottom) sightings of rhino rays for each month, divided by total number of responses for this question (Tanna et al., 2021).

3.3.2 Social and economic relationships between fishers and rhino rays

Fisheries

Rhino rays are caught as bycatch; no respondent stated that they targeted these species. However, according to a key informant from South Goa, rhino rays used to be targeted several decades earlier (*"In August to October, lots of rhino rays used to come in the nets, especially big ones. Fishermen used a special net, 400mm, for rhino rays. This was about 40 years ago. My father used to fish them"*). Previous targeting of rhino rays was also mentioned in some informal interviews with other fishers in South Goa. In contrast, more than a third of respondents (38%) listed sharks as one of their target species, especially in South Goa (67% of respondents from the south). Key informants explained that sharks were seasonally targeted by many gillnet fishers in Goa.

Most respondents said that rhino rays were captured in bottom-set gillnets for crabs (61%), followed by trawl nets (26%) and shore seines (21%). The bowmouth guitarfish (*R. ancylostoma*) was stated to be caught only in trawl nets whereas the other species were captured across all gear. Rhino rays of less than 2 feet (61cm) in length were captured most frequently (73% of respondents), which were likely to be juveniles or even pups. Nearly half (44%) said they also caught medium-sized individuals of 2-4 feet (61-122cm). Very few respondents caught large rhino rays bigger than 4 feet (122cm, 8%). The smallest sizes were seen in shore seines, where 82% of shore seine fishers caught individuals less than 2 feet. The size distribution in trawl nets was larger, with all sizes of rhino rays captured. Reported bycatch rates were highly variable, ranging from 1 rhino ray per year to 15 per month. On the whole, bycatch rates were higher in the south, with 4 rhino rays caught per month being the most common response (18% of respondents in the south), whereas in the north less than once a month was the most common response (21%). Some respondents did not provide a bycatch rate, stating that it was too variable.

The months of September (59% of all respondents) and October (47%), right after the monsoon, were stated to have the highest rhino ray bycatch. This aligned with information provided about their seasonality and months of highest occurrence (Figure 3.2). Gillnet fishers in particular stated that in post-monsoon they could catch multiple rhino rays each time they cast their net ("*After the rains, they come inland a lot more. We can catch close to 5-10 per week, sometimes more*.")

Post-capture uses

Post-capture, rhino rays were sold commercially at local markets (71% of respondents), taken home for consumption (58%), or discarded (dead or alive, 65%). Most respondents had multiple uses, depending on size and number of rhino rays caught, the quantity and quality of the remaining fish catch, market price and other factors. On average, rhino rays were sold for Rs. 66 ($0.87) per kilo, with sale price ranging from Rs. 13 to Rs. 150 ($0.17-$1.98) per kilo. In comparison, Indian mackerel (*R. kanagurta*), one of the most popular and common species in this region, is generally sold for between Rs. 150 to 200 ($1.98-$2.62) per kilo. Most respondents stated that they believed that the rhino rays they sold were used locally for consumption, with some stating that they were also traded to other parts of India, particularly the state of Kerala.

Post-capture use of rhino rays varied with district (Figure 3.3). In the north, most respondents (91% of respondents in the north) discarded them, followed by selling them in the market (70%) and consuming at home (58%). Size appeared to be the deciding factor, as only large-sized (i.e. adult) rhino rays were sold or consumed. No respondent sold or consumed juveniles, which were all discarded as they were considered to have less meat or be very "bony" and not favoured for consumption (45%), and because of their lack of market value (27%). This contrasts with fishers in South Goa, who primarily sold rhino rays in markets (73% of respondents in the south, Figure 3.3) followed by consumption (58%). Most of these respondents stated that they sold or consumed all sizes, including juveniles. Only a few respondents discarded rhino rays (39%); this was done largely due to their lack of market value (27%) and if they had too many (9%).

According to key informants, these observed differences could be due to tourism. Tourism is highly developed in North Goa, hence fisher behaviour may be adapted to catching and selling species that are popular among tourists. In the South, with less commercial tourism, fishing behaviour was more based on tradition and on local market demands. Therefore, fishers in South Goa exhibited higher capture and retention rates of rhino rays.

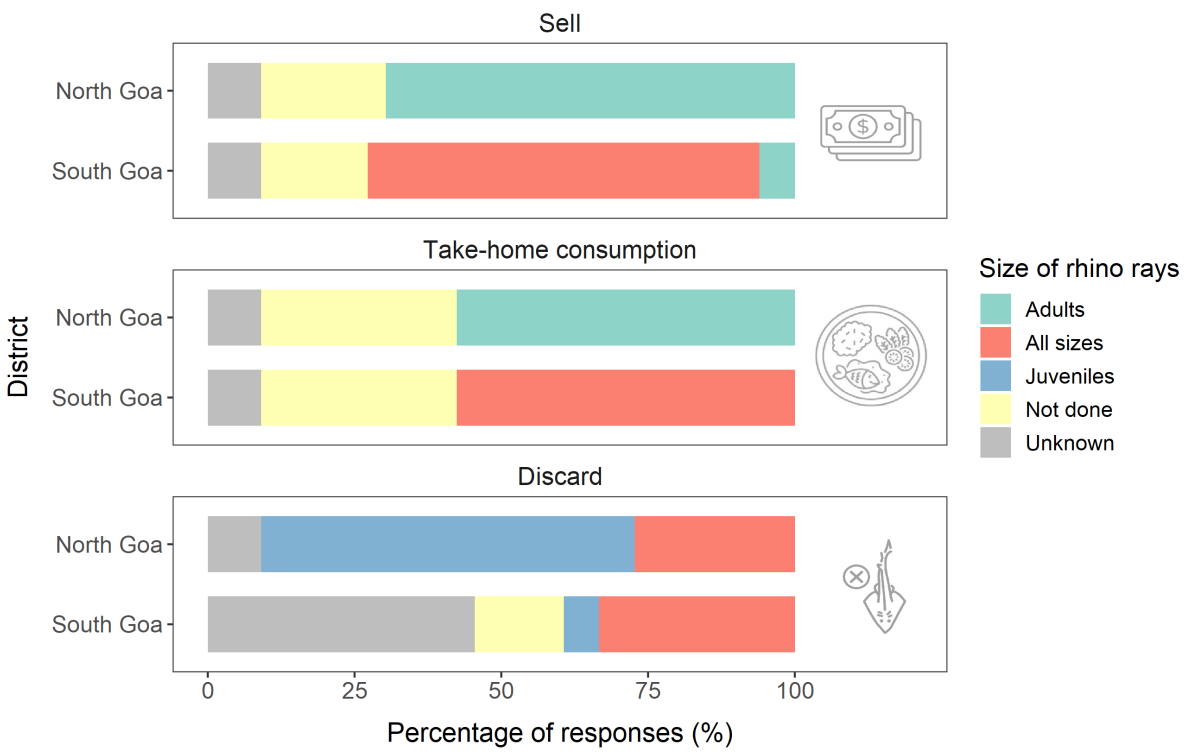


Figure 3.3: Post-capture uses of rhino rays in each district of Goa. The colours indicate the size of rhino ray individuals for each use. Graphics courtesy of The Noun Project (2014).

Values

In addition to instrumental (monetary) and subsistence uses, we coded 22 responses expressing relational values for rhino rays. These ranged from recreation (rhino rays are consumed and enjoyed with alcohol) to symbolic values (rhino rays were considered lucky) and others (Table 3.2). Some respondents also expressed negative values for rhino rays, considering them to be a bad omen, and not suitable for consumption.

It should be noted that although most respondents sold rhino rays in markets, these species were generally considered to be low value catch and did not fetch high profits ("*We sell it, but there is not much value for this fish. Only locals eat it.*"). Similarly, while more than half of the respondents consumed rhino rays, consumption was infrequent (1-2 times a month, on average) and hence it is unlikely that these species form a staple food source.

Table 3.2: Values for rhino rays expressed by fishers in Goa, through the semi structured interviews, categorised following the values framework described by Chan et al. (2016), and adapted by (Arias-Arévalo et al., 2017).

Type of Value	Articulated value	No. of responses (% of total)	Example quotes
Instrumental The value of an entity as a means to an end.	Monetary benefits (guitarfish are sold for profit, albeit for a low value)	47 (71%)	"*Whatever is caught and can be sold, is sold in the market*"
Relational The importance attributed to meaningful relations and responsibilities between humans and between humans and nature.	Subsistence (used for take-home consumption)	38 (58%)	"*We eat any size of guitarfish. Even if we have caught small guitarfish of 1 foot size, sometimes we take that home and make curry and eat it"*
	Recreation (Consumed along with alcohol)	9 (14%)	*"It has got a very sweet tasting flesh. After a rough day's work, it goes well with our evening drink"*
	Non-fishing experiences	6 (9%)	*"When I was a child, we would try to spot these fish as*

	(eg. Childhood memories, observations of them playing in the water)		*competition to see who would make a better fisherman"*
	Symbolic value (Rhino rays are considered to be lucky because of their rarity)	4 (6%)	*"It's a super rare fish, but you can see it on the shore. If you see it on the shore, means your stars are lined and you are very lucky"*
	Social cohesion (large guitarfish catch is shared with the community)	3 (4%)	*"If the guitarfish is big and too much for our household, we cut and share it with our neighbours."*
	Negative (considered to be a bad omen or not fit for consumption)	3 (4%)	*"I tried this fish once and it upset my stomach. I tried feeding the leftover meat to my cat and the cat also rejected it. After this, I never dared to consume it again, I throw it back into the water."*
Intrinsic The value of nature, ecosystems, or life as ends in themselves, irrespective of their utility to humans.	Not expressed	-	-

3.3.3 Population Trends

Most respondents (53%) believed that there had been no change in rhino ray populations since they started fishing. Some perceived a decrease (18%) or increase (18%) in rhino ray populations. These patterns were not confirmed by key informants, most of whom perceived decreasing populations (58% of 16 key informants who answered this question). We did not find any clear patterns in responses between North and South Goa.

We prompted key informants to provide the reasoning behind their own perceptions, as well as the possible reasons for other respondents' perceptions (Figure 3.4). Key informants who perceived decreasing trends stated that they had observed a reduction in the number and/or size of rhino rays caught in their nets compared to when they first started fishing, and could provide concrete examples for this ("*Earlier we used to get a lot more, especially large ones. When we would catch lots of rhino rays, they would be dried and stored to be consumed later. Now we don't get that many, so we don't dry them anymore*"). Some also mentioned the disappearance of particular species, such as white spotted wedgefish (*Rhynchobatus spp.*) and sawfish (*Pristis spp.*).

The reasoning provided for why populations might be perceived as increasing was that fishers noted higher catches of rhino rays in their nets, or increasingly observed them in the nearshore waters ("*We keep getting them in our nets, we get them every day. Their populations are increasing*"). Reasoning behind perceptions of 'no change' were that these species were low in number to begin with and were not targeted for fishing ("*This fish was always low in number, right from the start. They haven't changed because no one catches them much*"). For both these potential reasons, however, key informants were unable to provide concrete examples or evidence.

Capture of rhino rays by mechanised fishing vessels, and general overfishing, were cited as possible drivers for the decline in rhino ray populations by a few key informants and respondents. Non-fishing activities as such pollution and tourism (including dolphin watching tours and water sports) were also suggested as potential drivers of declines. These activities were believed to cause declines in nearshore fish populations generally, or drive fish offshore and away from the coast.

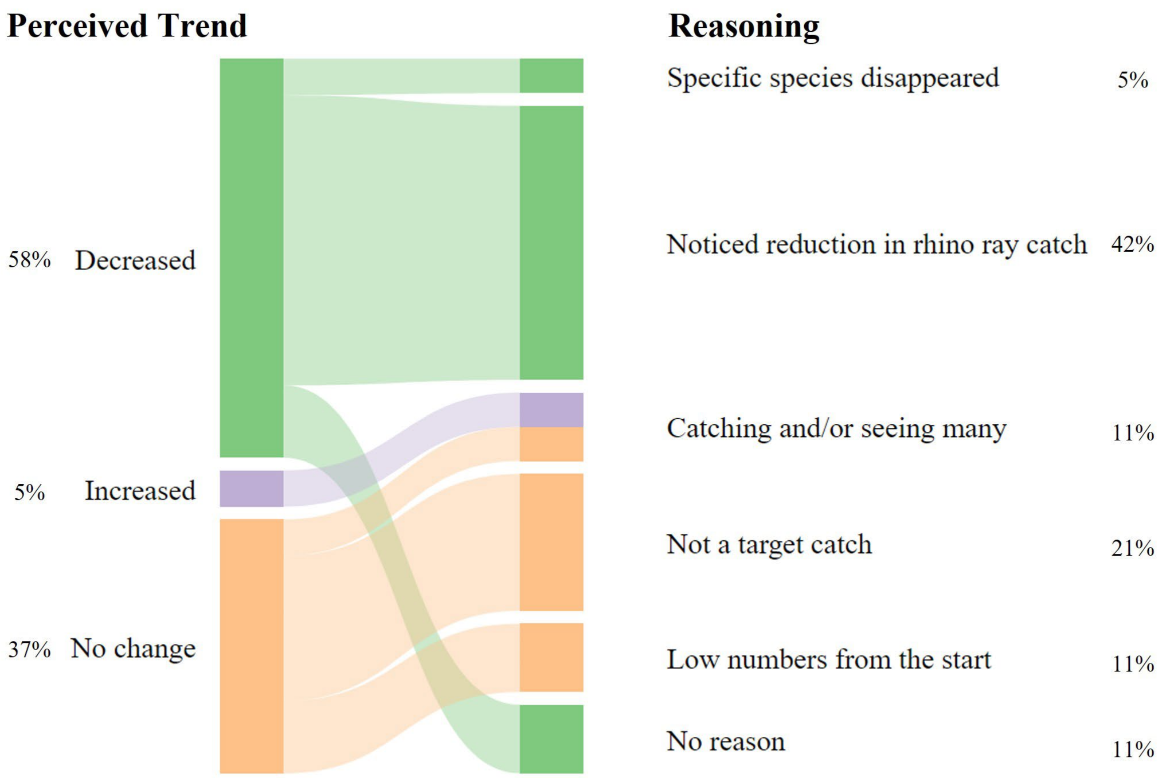


Figure 3.4: Perceived population trends of rhino rays by key informants, and the rationale or reasoning behind each perception

3.3.4 Conservation

Knowledge of and attitudes towards protected marine species

At the time of the study, 10 elasmobranch species, all marine mammals and marine turtles were protected under Schedule I of the WLPA in India, their harvest prohibited (Kizhakudan et al., 2015). Most key informants listed dolphins (91%) and turtles (82%) as protected marine species; a few mentioned 'big sharks' (18%) and stingrays (9%) as well.

While these bans were generally complied with, some key informants (50%) admitted that protected species were still occasionally captured by themselves or other fishers in their community, and sometimes consumed or sold. Many (59% of informants who answered this question) held negative attitudes towards the protection and ban on catching these species, particularly dolphins, stating that they 'stole' fish from their nets and caused a lot of damage (Figure 3.5). This was particularly the case in North Goa. However, some positive attitudes towards protecting these species were also expressed (41%), particularly for turtles as they were considered holy by Hindu communities. These positive attitudes were expressed mainly in South Goa.

No compensation, monetary or other, was provided to fishers for the damage caused to their net when releasing a protected species. Some key informants (62% of informants who answered this question) believed that such compensation was not needed, whereas others (38%) stated that the government should provide them with some compensation for their damaged nets and mentioned that this would also incentivize fishers to release protected species (Figure 3.5).

Attitudes towards rhino ray conservation

We then asked key informants what they would feel if rhino rays were similarly protected. All key informants held positive attitudes about this, stating that a ban on these species would have little to no impact on fisher earnings (Figure 3.5). Key informants mentioned that avoiding capture of these species would be challenging, though, as they co-occur with target species such as crabs and are hence bycaught. However, many suggested that live onboard release would be possible, and stated that rhino rays were usually alive in their nets and would survive if released immediately. One key informant mentioned the need to enforce any ban at the level of the market, as de-valuing the species would encourage fishers to release them. Another stated that fishers would be more willing to release rhino rays if they better understood the role these species play in the ecosystem.

In contrast, negative attitudes were expressed about any potential restriction on shark fishing (63% of informants who answered this question). Sharks were considered high value catch and were seasonally targeted; many key informants believed that a ban on shark fishing would affect their earnings and that they would be unlikely to comply (Figure 3.5).

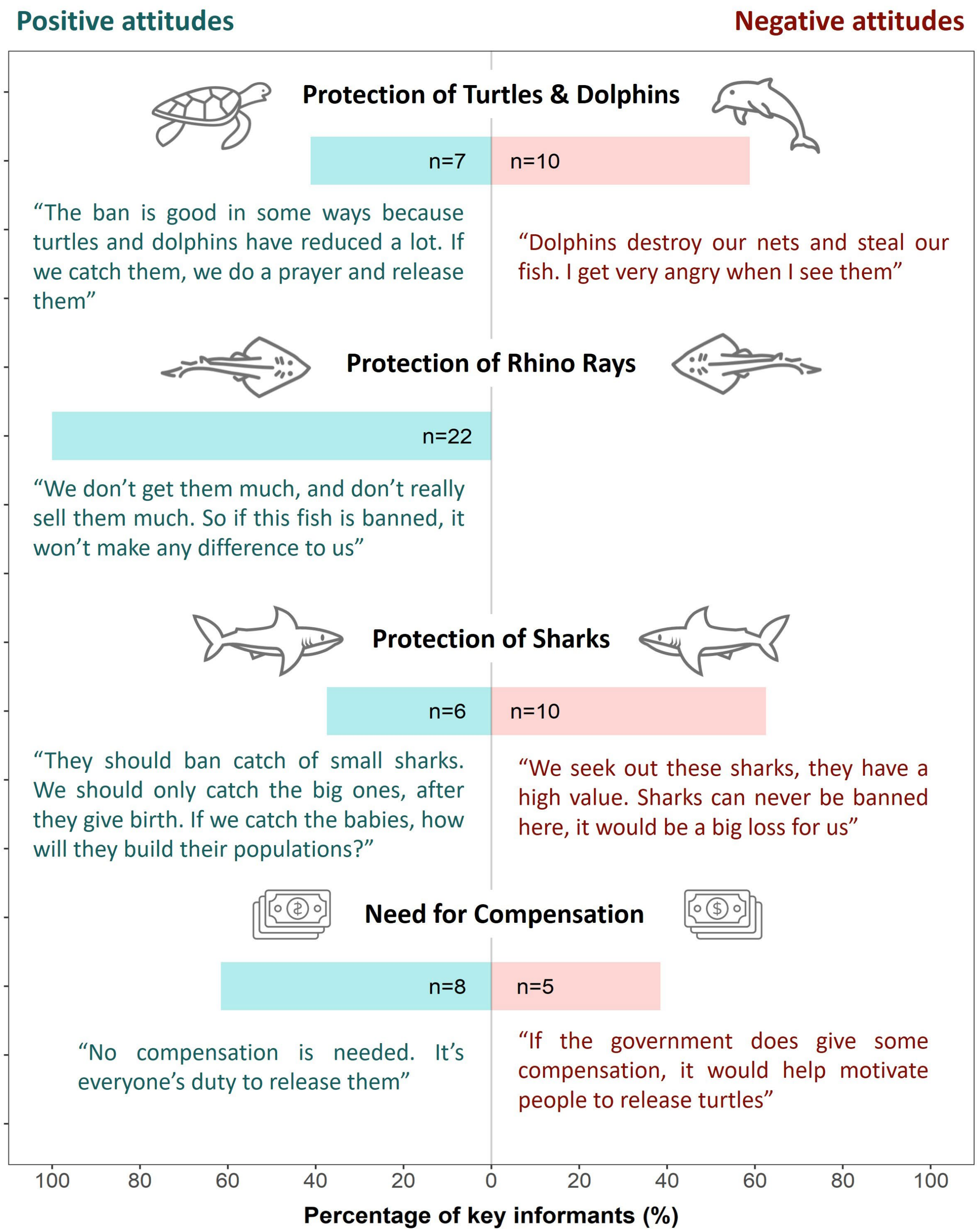


Figure 3.5: Attitudes of key informants on the protection (i.e. fishing ban) of dolphins and turtles, on the hypothetical protection of rhino rays and sharks, and on the need for monetary incentives to compensate for a species being protected. Attitudes are classified as positive if they are favourable towards conservation, and negative if they do not favour conservation. Not all key informants provided responses to all questions, hence percentage (x-axis) is calculated based on total number of responses for each section. Quotes from the interviews are provided as an example for each attitude. Graphics courtesy of The Noun Project (2014).

3.4 Discussion

3.4.1 Fisheries and threats to rhino rays

Targeted fishing of rhino rays has been recorded in many parts of the world for their high-value fins used in shark fin soup (Chaikin et al., 2020; Haque et al., 2021; Jabado, 2018). Our interviews revealed the targeted capture of large-bodied rhino rays by gillnet fishers in Goa in the past, for their fins as well as meat. This is no longer practiced, as rhino rays appear to be entirely bycaught and their catch dominated by juveniles. Furthermore, we did not find any evidence of trade in fins at present and these species are used only for local or regional consumption. Disappearance of this targeted fishery and shift in the socio-economic valuation by fishers may reflect a decline of rhino rays in this region. However, fin trade may still represent a future threat on the horizon, as there is a growing market for small, low-value fins in Southeast Asia for inexpensive shark fin soup (Cardeñosa et al., 2019). Regular monitoring is needed to ensure that this trade does not develop in coastal fisheries such as in Goa, as it may incentivise the exploitation of juvenile rhino rays. Our study also revealed that a seasonal targeted fishery does exist for sharks in this region. Further research is needed to understand the drivers of this fishery.

Goa has undergone rapid development and change in recent decades, and marine biodiversity may be facing a range of threats from different sources, not just fisheries (Bhagat, 2022). Tourism is highly developed in the north, but relatively less so in the south, and may therefore explain the differences in interactions with rhino rays between these two districts. Tourism may shape fisher behaviour in the north, incentivising trade in more popular and commercial species, and causing a decline in traditional fishing and consumption practices (de Madariaga et al., 2019). This may have a positive outcome for threatened rhino rays that are now discarded more often and can support the implementation of conservation measures. However, tourist demand patterns can also be responsible for driving overexploitation and trade of threatened wildlife (Arias et al., 2020; Garcia Rodrigues & Villasante, 2016). Respondents suggested that tourism activities like dolphin-watching, water sports and beach shacks can have negative impacts on nearshore fish populations. For the biodiverse coastline of Goa where livelihoods are highly dependent on tourism and fishing (Venugopalan, 2021), it is crucial that impacts of tourism and coastal development on marine ecosystems are better understood.

3.4.2 Importance and limitations of local ecological knowledge

Our study adds to the growing body of evidence acknowledging the importance of fishers' LEK in characterizing fisheries, evaluating species abundance, population trends, assessing threat and extinction probability, and supporting effective fisheries management decision making (Beaudreau & Levin, 2014; Drew, 2005; Farr et al., 2018; Haque et al., 2021; Nazareth et al., 2022). Despite the elevated extinction risk they face, rhino rays have been poorly researched and there remain conspicuous gaps in our knowledge of their ecology and fisheries, particularly in developing countries like India that fish them the most (Kyne et al., 2020). LEK can help address some of these gaps in Goa, contributing to our understanding of the habitats used by rhino rays and the seasons they use them in. Insights from fishers confirmed our hypothesis that nearshore habitats in Goa around river mouths and estuaries form important nursery grounds, particularly for species like *G. obtusus.* Given their slow growth rates and low fecundity, juvenile survivorship is one of the most crucial features for sustaining elasmobranch populations, highlighting the importance of nursery grounds (Heupel et al., 2019; Martins et al., 2018). LEK helped identify prospective nursery sites in Goa, which need further assessment and long-term research.

A concerning finding that emerged from fisher's LEK is the possible disappearance of white spotted wedgefish (*Rhynchobatus spp.*) and sawfish (*Pristis spp.*). While there is considerable evidence for the decline of sawfish in south Asian waters (Fordham et al., 2018; Haque et al., 2020; Tanna et al., 2021), little information exists for guitarfish and wedgefish. Elasmobranch landings are often not recorded at the species level in many parts of India, making it challenging to assess long-term trends for threatened species like rhino rays. In such contexts, LEK can be the sole source of information to monitor populations of threatened species (Valerio-Vargas & Espinoza, 2019). Substantial declines in *Rhynchobatus spp.* have been reported by fishers in Bangladesh (Haque et al., 2021). Although some *Rhynchobatus* species have been found to be relatively productive (D'Alberto et al., 2019), these findings indicate that depletion exceeds population recovery time for wedgefish in South Asia compared to other elasmobranch taxa. Wedgefish populations may especially be in crisis and need urgent action.

As a result of profound economic, cultural and environmental changes local and indigenous knowledge is being weakened and eroded globally, particularly when pertaining to ecology (Aswani et al., 2018). It is thus interesting to see the levels of LEK displayed by fishers in the present study, where most respondents could recognise rhino rays and were able to provide responses to most questions at a broad resolution, even though these species have low commercial values. In contrast, Tanna et al. (2021) found that less than half of interview respondents could identify and provide information about sawfish in Sri Lanka, indicating shifting baselines and loss of knowledge (Turvey et al., 2010). This ‘societal extinction’ of a species from a culture can weaken pro-environmental attitudes and even accelerate biological extinction (Jarić et al., 2022). In Goa, existence of LEK for rhino rays indicates their continuing presence in nearshore waters and suggests that these species are embedded within cultural values, which were also recorded by our study. It is important that this knowledge is preserved and strengthened to prevent societal extinction. Fishers’ LEK must be brought into the scientific mainstream and incorporated into policy and management, which can be done through various participatory approaches and frameworks (Tengö et al., 2017).

While discussing the use and benefits of LEK, it is equally important to acknowledge its limitations. Insights of fishers can be biased by their own practices, habits and experiences (Turvey et al., 2010; 2014). For instance, higher sightings of rhino rays in the post-monsoon months can be a result of increased fishing activity during this period. Inaccuracies can also be seen in the contrasting information obtained from respondents and key informants on population trends. This emphasizes the need to work with local key informants and not only randomly selected individuals in ecological studies that incorporate local knowledge (Chalmers & Fabricius, 2007). There can also be challenges in getting precise spatial information through LEK (i.e. “fuzziness”; Karnad 2022), due to different conceptions of scale and space between local residents and scientists. In the present study, respondents could describe rhino ray habitats at a broad resolution but could not provide nuanced information on specific locations. Another significant limitation is the absence of species-level data for rhino rays, due to misidentification by respondents. We also acknowledge that although we aimed to sample as comprehensively as possible, our study relied on key informants and convenience sampling and that might have affected our findings.

Most of these shortcomings can be addressed through combining LEK with other sources of information. Many studies have successfully synthesised LEK with scientific information through ecological surveys for more effective decision making in conservation and management (Lopes et al., 2019; López-Angarita et al., 2021; Mason et al., 2019).

3.4.3 Harnessing values and attitudes for conservation

There has been considerable research on the relationship between human values, attitudes and behaviours. Values can underpin and influence the manifestation of pro-environmental attitudes and behaviours, and therefore can be leveraged for conservation (Ihemezie et al., 2021). In the present study, we identified diverse values for rhino rays, from subsistence to recreation and social cohesion. As we coded values that were naturally expressed during interviews without direct questioning, our sample size is small. Nevertheless, it offers insights into the different relationships that fishers can have with low-value bycatch species like rhino rays. Moreover, key informants exhibited positive attitudes towards rhino ray conservation. According to the Theory of Planned Behaviour, a favourable attitude towards a behaviour is linked to a stronger intention to perform the behaviour (Ajzen, 1991). This suggests that fishers in Goa have a higher likelihood of participating in conservation interventions for rhino rays. Fostering pro-environmental values (e.g. symbolic values, where rhino rays are considered lucky) can reinforce these positive attitudes and support the implementation of interventions for sustainable fishing and conservation (Ihemezie et al., 2021; Skubel et al., 2019). For example, sacred values for turtles have strengthened their conservation in many communities in India (Phillott & Chandrachud, 2021; Tripathy & Choudhury, 2007). In our study, we also found positive attitudes towards and compliance with marine turtle conservation.

3.4.4 Live release interventions for rhino rays

With more rhino ray species recently listed under protection in India's WLPA, it is necessary to develop practical measures to mitigate their capture and fisheries, particularly in the case of bycatch (Booth et al., 2019; Gupta et al., 2020a). Our study suggests a pathway for the on-ground implementation of this legislation in places like Goa, where the release of live rhino rays, on board or from the shore, may be a feasible solution. While avoidance of capture would be ideal to conserve threatened bycatch species (Milner-Gulland et al., 2018), it would be challenging here due to the relatively low selectivity of gear and shared habitats with target species. Release can be an effective and low-cost conservation measure in tropical, mixed species fisheries, especially when measures like spatial closures or gear modifications are not feasible (Gupta et al., 2020a; Wosnick et al., 2022). Although poorly studied, some studies have noted moderate to high survival rates post-capture for different rhino ray species (Fennessy, 1994; Prado et al., 2021; Stobutzki et al., 2002); high survival has also been observed by fishers in our study site.

Live release interventions have been successfully implemented for rhino rays in various parts of the world, such as Brazil (Wosnick et al., 2020) and Indonesia (Hollie Booth pers. comms.), where economic payments were used to incentivise releases. Although such economic incentives, or even disincentives like fines or sanctions, are a commonly used tool in conservation, they could have unintended consequences in certain contexts (Booth, 2021; Travers et al., 2016). Social norms, culture and institutional arrangements can also shape individual behaviour, and can be an entry point for conservation (Booth, 2021; Ostrom, 1990). Our research suggests that voluntary release measures implemented through norms-based approaches and community participation, rather than economic payments or top-down enforcement, might be successful in Goa - given the low commercial values of rhino rays, positive attitudes towards their conservation and possible relational values. We identified the fishing gear, regions and seasons in Goa that should be targeted for a release intervention. Prior to designing and implementing this, however, further research on attitudes, behaviour, social norms and other human dimensions is necessary (McDonald et al., 2020; Veríssimo, 2013), alongside ecological studies of capture and survival rates.

3.5 Data Availability

All data used in this paper, except the interview transcripts as we do not have the required consent to archive these, are either presented in the main text through figures and tables or available on the data dryad repository at https://doi.org/10.5061/dryad.vt4b8gtwq

Chapter 4

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

Bull sharks at a landing centre in Kakinada, their fins have been removed for trade

4.1 Introduction

Wildlife trade is a major driver of biodiversity loss globally, contributing to extinction risk in over 14,000 species (Challender et al., 2023; Maxwell et al., 2016), yet millions of people depend on this for their livelihood and sustenance (Cooney et al., 2015). Endangered species like sharks are part of this trade, with 36% of sharks and rays threatened with extinction due to overexploitation (Dulvy et al., 2021). Sharks hold important subsistence, economic and cultural values for many communities globally, highlighting the need for sustainable and equitable fisheries management (Temple et al., 2024; Jabado et al., 2018; Skubel et al., 2019). Conservation efforts for sharks include supply-side interventions such as domestic fishing regulations and habitat protection (Shiffman & Hammerschlag, 2016); 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 (CITES, 2024); and demand-side interventions, such as demand reduction campaigns (e.g. for shark fins, Whitcraft et al., 2014). 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 (Haque et al., 2023; Challender et al., 2015; Booth et al., 2021).

Markets can be described as the combination of institutions, processes, infrastructure and social relations where parties engage in exchange (Crookes & Milner-Gulland, 2006; Oyanedel et al., 2021). 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 (Phelps et al., 2016; WWF, 2021). For example, analysis of the structure of live reptile markets in Indonesia identified a small number of ‘gatekeepers’ who controlled the market (Phelps et al., 2016). 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. (2016) 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. (2023) 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 (McNamara et al., 2016; Oyanedel et al., 2021).

India is amongst the top three shark and ray harvesting nations globally; shark fishing in the country is largely unmanaged (Karnad et al., 2024a). Targeted shark fishing was prevalent in the 1980s and 1990s, driven largely by the international demand for fins (Kizhakudan et al., 2015). Landings have declined since then despite increasing fishing effort, suggesting that shark populations are overexploited (Akhilesh et al., 2023). Twenty-six shark and ray species are currently protected under India's Wildlife Protection Act, and shark finning and fin exports are prohibited (Parliament of India, 2022; Akhilesh et al., 2023). 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 (Kizhakudan et al., 2024). Additionally, there are currently no regulations for the harvest and trade of non-protected species and non-fin products (Akhilesh et al., 2023). 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 (Kizhakudan et al., 2024). 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 (Figure 4.1). We adapted methods and frameworks by McNamara et al., (2016), Oyanedel et al., (2021) and Milner-Gulland & Shea (2017) 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 4.1). 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.

4.2 Analytical frameworks

Following Oyanedel et al. (2021), 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 4.1; Arias-Arévalo et al., 2017; Ramcilovic-Suominen & Epstein, 2012). Access refers to the ability of actors to operate in, and collect benefits from, a market, via formal or informal mechanisms (Ribot & Peluso, 2003).

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 (Haque et al., 2023; Oyanedel et al., 2021). 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. (2016) 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 (Holden et al., 2019; Regan et al., 2002; Nuno et al., 2014). 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 (Milner-Gulland & Shea, 2017). Understanding and identifying these dimensions can help prioritise which uncertainties to focus on in future research.

Table 4.1: The different components of the present study, adapted from frameworks developed by McNamara et al., (2016), Oyanedel et al., (2021) and Milner-Gulland & Shea (2017).

Study component	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 (Haque et al., 2023). 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.

4.3 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 4.2). Shark fisheries and conservation have been poorly studied in both locations (Gupta et al., 2022, Chapter 2). Goa is a small coastal state in western India with 41 fishing villages and 5 major fishing harbours (Goa Department of Fisheries, 2023; Figure 4.1, Table 4.2). While shark landings show an overall decrease over the last 20 years (Goa Department of Fisheries, 2016; 2023), recent studies and anecdotal evidence suggest that a large portion of shark landings in the state are unreported (Gupta et al., 2023, Chapter 3). 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 4.2).

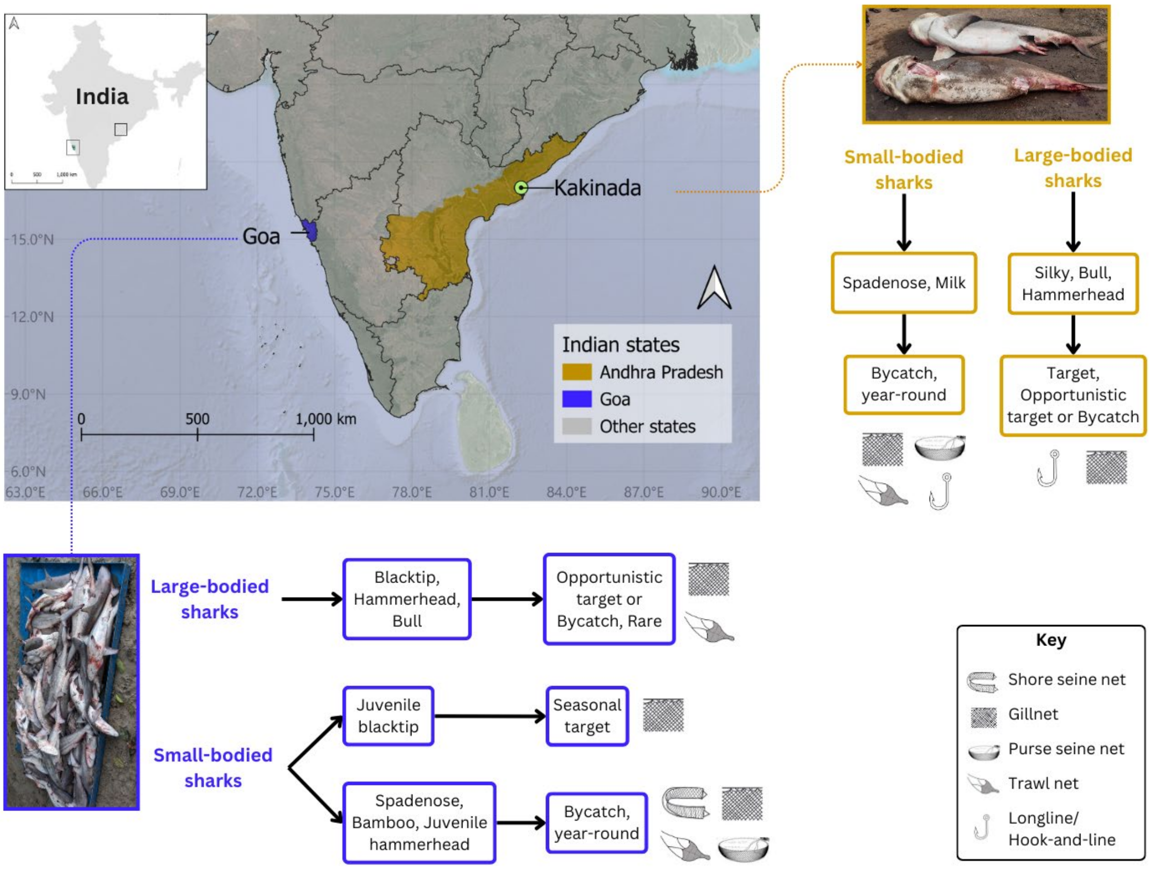


Figure 4.1: The study sites of Goa and Kakinada (in the state of Andhra Pradesh) in India (top left). The main groups and species of sharks caught, mode and gear of capture in each site are also shown. The shark species in the figure refer to: Spadenose: *Scoliodon laticaudus*, Bamboo: *Chiloscyllium spp.*, Hammerhead: *Sphyrna lewini,* Blacktip: *Carcharhinus limbatus,* Bull: *Carcharhinus leucas,* Silky: *Carcharhinus falciformis,* Milk: *Rhizoprionodon acutus.*

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 (Vivekanandan, 2001). 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 (Menon et al., 2018). 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 4.2). 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 4.2).

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 (Yin, 2009).

Table 4.2 Top: Demographic and fisheries statistics for the two study sites, obtained from Menon et al. (2018), CMFRI-DoF (2020), CMFRI (2023) and Goa Department of Fisheries (2023). **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 crafts	2,984	1,240
*Types of 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 (*gillnets & longlines*: 12, *gillnets only*: 2, *longlines only*: 8, *trawler*: 1) Traders: 12 (*Auctioneer*: 2, *Wholesaler*: 6, *Middleman*: 1, *Vendor*: 3) Gender: 32 male, 3 female
Mean 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

* 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 (CMFRI-FSI-DoF, 2020)
*** 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 (CMFRI, 2023).

4.4 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 4.2). 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 (Appendix C1 and C2). 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 (>1m in Total Length TL) and small-bodied sharks (<1m TL). In Goa, juvenile blacktip sharks (*Carcharhinus limbatus,* 60-80cm 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 (Appendix C1).

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 (Appendix C2). 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 Appendix C1). 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 4.1). 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 Kamins et al., 2011). 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 (Rudders & Ward, 2015). 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 4.1). 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.

4.5 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". Interview F-200222-04, 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 to 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*". Interviews KF-010923-01 and KF-160823-04, 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 (Menon et al., 2018) 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.

4.6 Actor analysis

Main actors and motivations

In both sites, our interviews suggested that the most important actors (in terms of numbers and influence) in the shark supply chain were fishers (small and large-scale); traders, such as wholesalers, middlemen and vendors; and consumers (Table 4.3). Fishers in Goa included gillnetters who seasonally target juvenile blacktip sharks, and other fishers who use a variety of gears that capture other shark species as bycatch throughout the year (Figure 4.1). 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 (Figure 4.1). 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 4.3). 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 4.3). 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 4.3). For most other actors across both sites, however, fishing formed their primary profession, and they lacked alternative sources of income.

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 4.3).

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 4.3).

Table 4.3: 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 from 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 from 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 from Goa "*Fishing is a very lucrative business, we can make high*	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

				profits" – a wholesaler from Kakinada	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 from 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 from 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. 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

4.7 Inter-actor analysis

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) 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 (Figure 4.2). 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 (Wamukota et al., 2014).

Small-scale fishers in the Canacona *taluka* in South Goa were 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 (Figure 4.2). The majority of locally caught sharks were sold and consumed within Goa, with both households and restaurants identified as end markets (Figure 4.2). 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 (Figure 4.2). Trade chains involved specific actors and channels through which the different products and shark species flowed (Figure 4.2). 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 (Phelps et al., 2016; Wamukota et al., 2014). 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 (Figure 4.2).

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, who hailed from neighbouring villages such as Pedapudi and Karapaka, 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 100km 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.

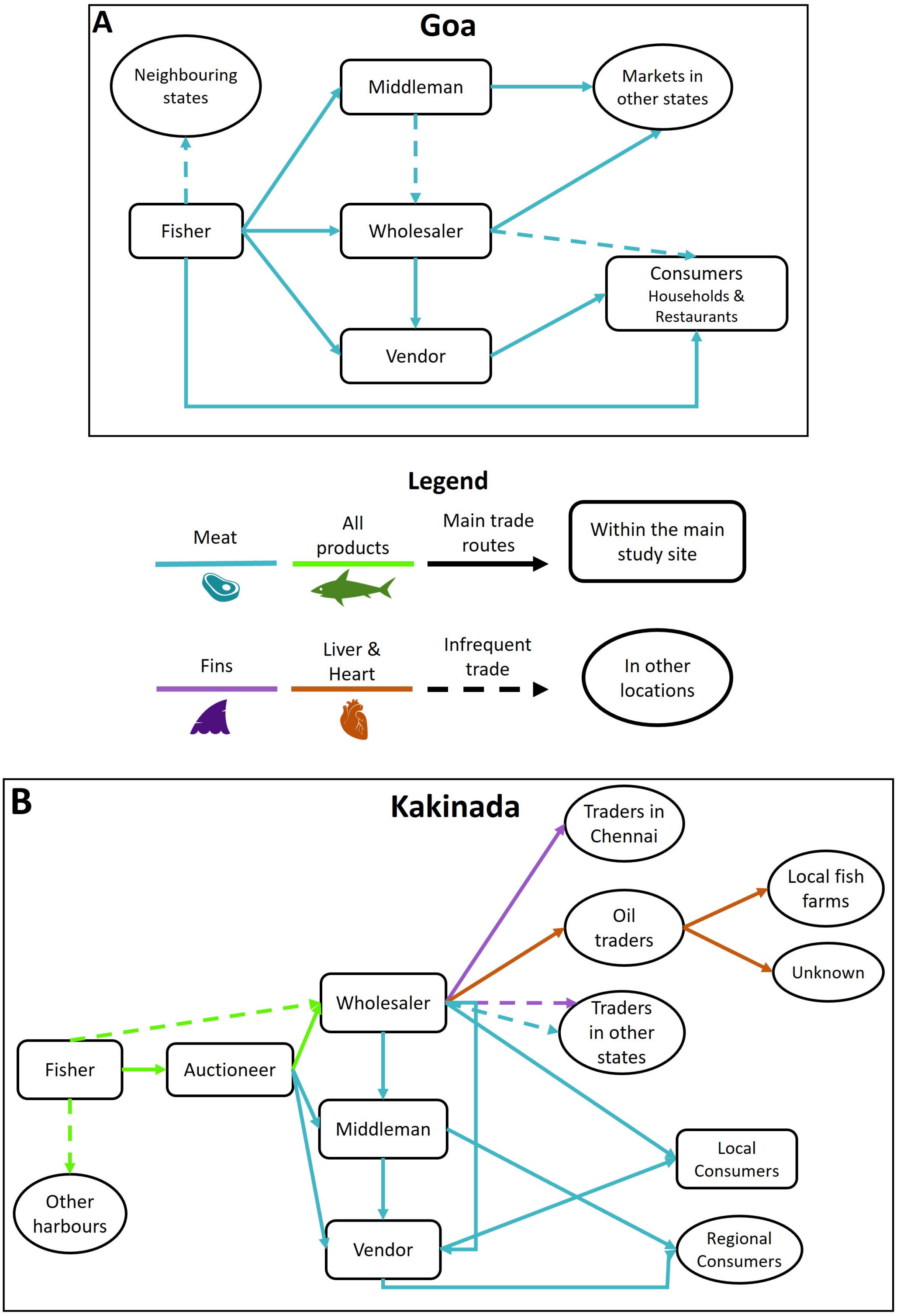


Figure 4.2: The basic structure of the supply chain for shark products in Goa (**A**) and Kakinada (**B**). Relevant trade routes for different products (meat, fins, heart, liver) are shown, representing all species traded (small and large-bodied sharks). Solid lines represent main trade routes (mentioned 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; sharks landed in other places that are imported into the markets are not represented here.

4.8 Market analysis

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 (Appendix C3). 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 (Figure 4.3).

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 (Figure 4.3). 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, 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.

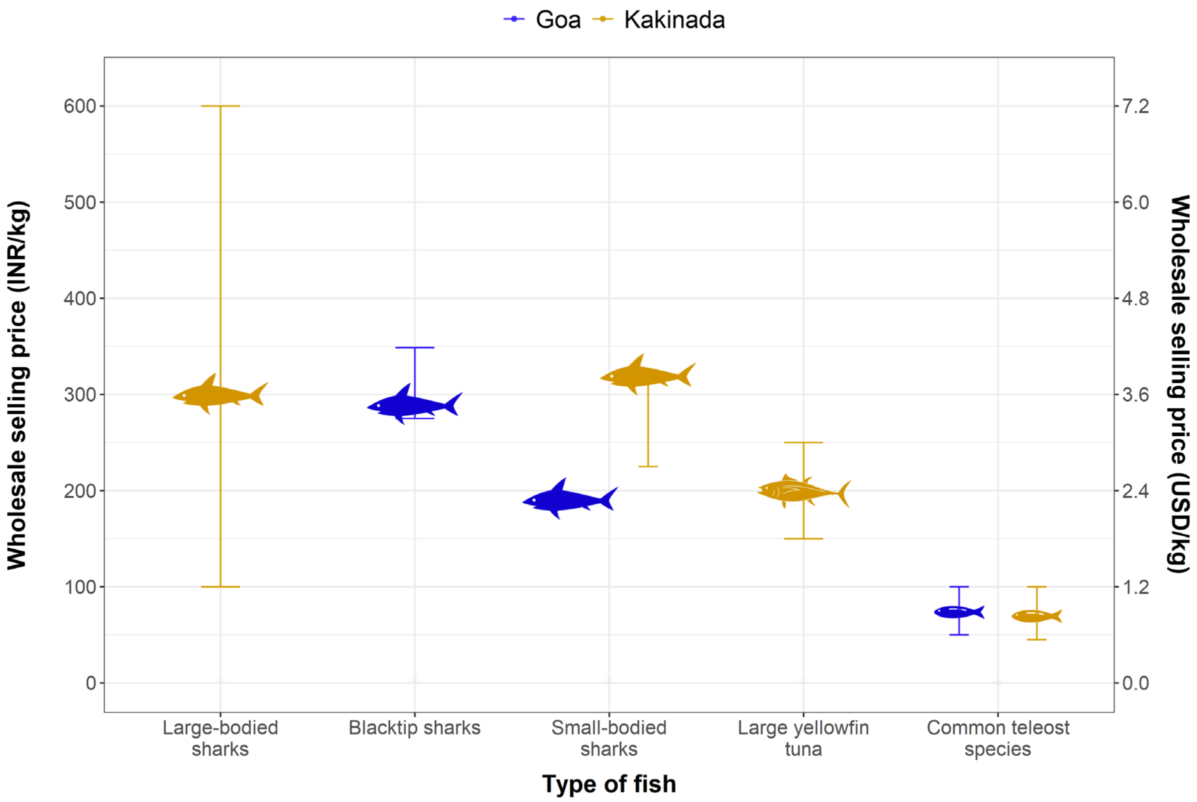


Figure 4.3: Average selling price for meat at the wholesale of different shark types (small-bodied, large-bodied and blacktips) as well as other fish species at each site (Goa = blue, Kakinada = yellow). Minimum and maximum prices are also shown where possible. Large yellowfin tuna refers to *Thunnus albacares* (>20kg) 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.

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 (Figure 4.4).

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 shark meat consumption was rising in both sites despite increasing prices, especially in Kakinada (Figure 4.4). 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).

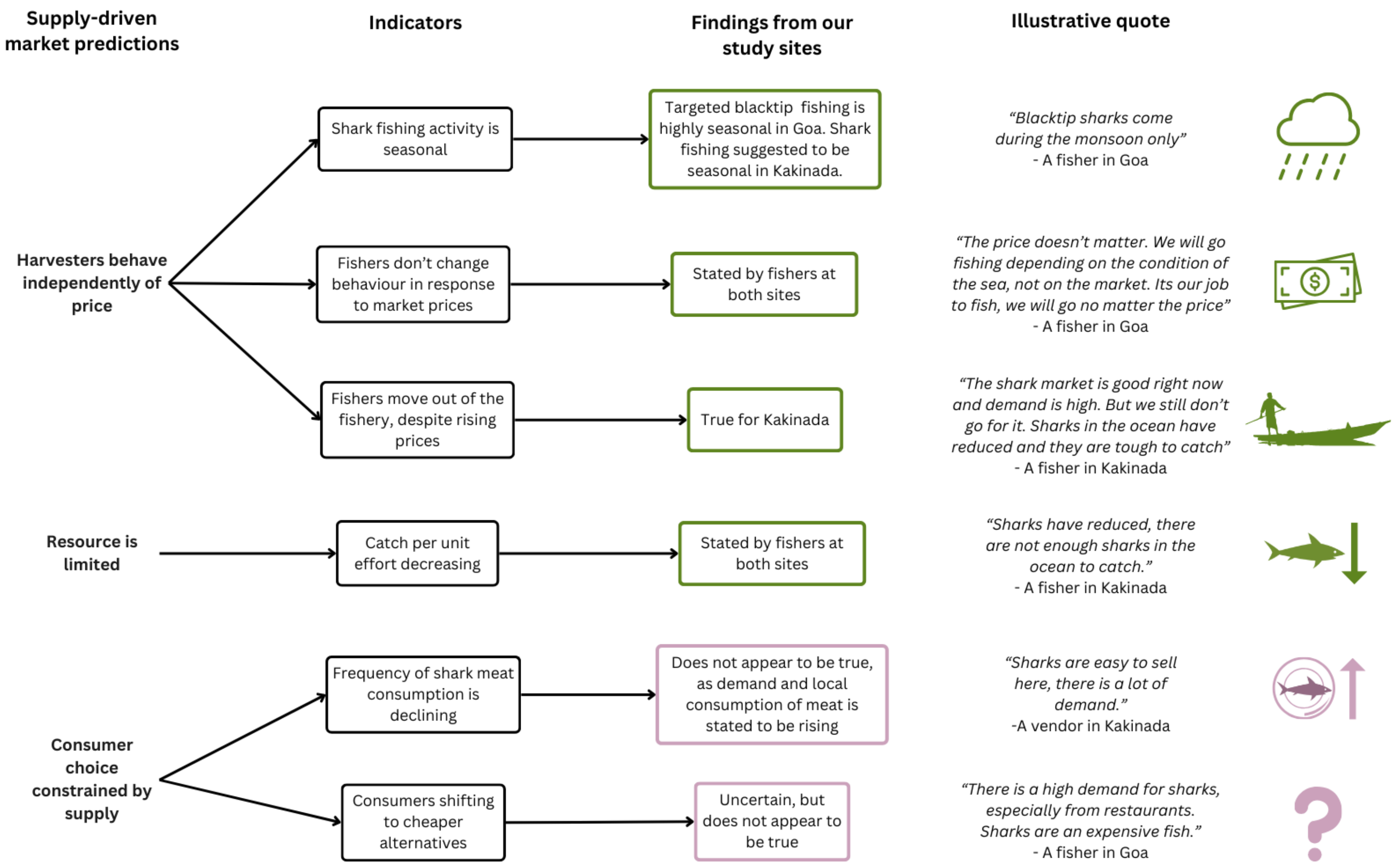


Figure 4.4: Predictors and indicators of a supply-driven market and findings from the present study, based on the framework developed by McNamara et al. (2016). Green boxes = evidence suggests a supply-driven market, pink boxes = evidence unclear or suggesting market is not supply-driven.

4.9 Interventions for shark sustainability

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*". Interview F-200222-01, Goa.

"*We used to get sharks 10 years ago, but not anymore. Sharks have gone extinct*". Interview KF-110823-04, 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 (Akhilesh et al., 2023). 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 (Rigby et al., 2021; SEDAR, 2020), harvest rates of juveniles in Goa appear to be relatively high. Exploratory population models suggest that these levels of fishing are likely unsustainable (Chapter 5). This is supported by previous research on India's west coast that found local blacktip shark populations to be likely overexploited or even collapsed (Mohamed & Shettigar, 2016).

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 4.4; Figure 4.5). 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 (Haque et al., 2023). 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.

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 (Bjørndal et al., 2015; Wamukota et al., 2014). 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 (CMFRI-FSI-DoF, 2020). 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 (Department of Fisheries Goa, 2023), 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 (Kaaya & Chapman, 2017; Mahmud et al., 2022). 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 (Haque et al., 2023). Fisher access can also be improved by strengthening local institutions, such as fisher cooperatives, which have been found to perform poorly for small-scale fishers within the state of Andhra Pradesh (Parappurathu et al., 2017; Rao & Jeyalakshmi, 2021).

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. Sall et al., 2021). 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 (Haque et al., 2023; Ostrom, 2009). 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 (Ribot, 1998). 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 economic means to do this (Ribot, 1998). As such, fishers can show varied responses to changing catch and market structures, which may need close monitoring (Cinner et al., 2011).

In Goa, fishers, particularly those targeting blacktip sharks, were identified as the actors with the most leverage (Table 4.4). 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 (Chapter 6). 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 (Lejano et al., 2007; Pomeroy, 1995). 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 (Gupta et al., 2020a).

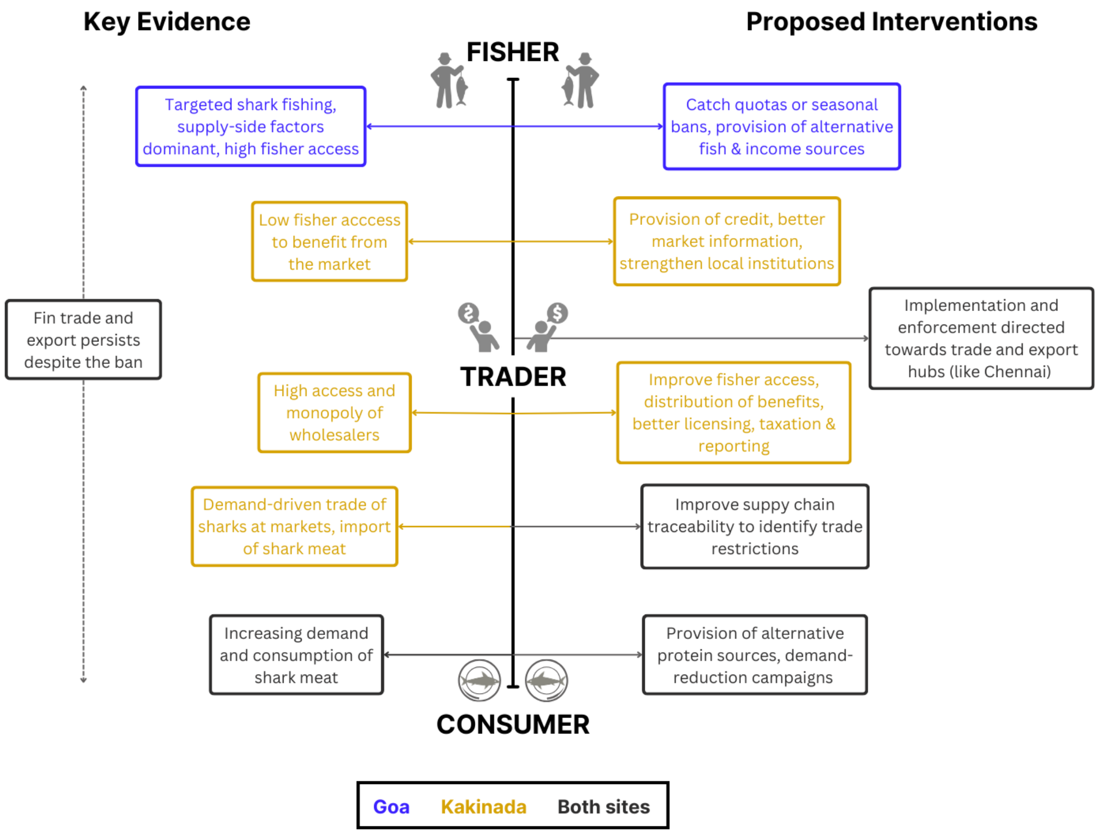


Figure 4.5: Interventions proposed for each driver or challenge linked to unsustainable shark trade, at different leverage points in the supply chain, based on evidence from our study. Interventions for Goa are presented in blue, for Kakinada in yellow and interventions applicable to both sites in dark grey.

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 (Bachmann et al., 2019), 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 (Kizhakudan et al., 2024). Strong policies to improve the equity of profit distribution along the supply chain can also help mitigate the monopoly power of wholesalers (Cooney et al., 2015; Oyanedel et al., 2021; Haque et al., 2023; Menon et al., 2018).

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 (WWF, 2021), with prominent shark meat consumption found in several countries such as Brazil, Sri Lanka and Indonesia (Booth et al., 2023a; Bornatowski et al., 2015; Collins et al., 2023). 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 (Karnad et al., 2019; Kizhakudan et al., 2024). 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 (Dent & Clarke, 2015; WWF, 2021). This suggests that majority of the shark meat landed in the country is consumed domestically (Kizhakudan et al., 2024). 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 (Kizhakudan et al., 2024). 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 (Rao & Jeyalakshmi, 2021), hence there may be a concern that shark meat is serving as a cheap and affordable source of protein (Dulvy et al., 2017; Jabado et al., 2018; Karnad et al., 2019). 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 (CMFRI, 2023). 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. (2024b) 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 (Karnad et al., 2024b; Veríssimo & Wan, 2019). Demand reduction interventions can be targeted at specific consumer groups to induce behaviour change, after first understanding consumer demographics, characteristics and motivations (Olmedo et al., 2021; Veríssimo et al., 2020). This may be most appropriate for tourist consumers. Given the potential 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 (Scholtens et al., 2020; Surathkal et al., 2023).

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 (Kizhakudan et al., 2024; Tyabji et al., 2022). 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 (WWF, 2021; Hasan et al., 2023, Akhilesh et al., 2023). With a growing number of shark species listed under Appendix II of CITES (CITES, 2024), there is a need to develop systems and policies for monitoring and regulation of exports of different shark products from India.

4.10 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 4.4; Milner-Gulland & Shea, 2017). 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 (Travers et al., 2019). Across both sites, limited knowledge on the quantities of sharks and their products flowing through the system is a major uncertainty (Kizhakudan et al., 2024). 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 (Arlidge et al., 2020). Demand and consumption patterns and motivations are further data gaps that need to be addressed in order to design behaviour change interventions for sustainability (Nuno et al., 2018). These points should be priorities for future work in this area, as they are dealing with important uncertainties and are feasible to address.

4.11 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 (Lindkvist et al., 2020). 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 (Booth et al., 2023b; Travers et al., 2019).

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 (Challender et al., 2015). 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 (Haque et al., 2023; McNamara et al., 2016; Challender et al., 2015; Macdonald et al., 2021; Phelps et al., 2014*)*. 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 (Dent & Clarke, 2015; Sall et al., 2021), 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 (Cowlishaw et al., 2005). 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 (Gelcich, 2014). We also illustrate the usefulness of the frameworks in this study (Oyanedel et al., 2021; McNamara et al., 2016), 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 (Tháy et al., 2019). There is a need to develop practical solutions that can contribute to the combined goals of sustainable development, biological conservation and social equity (Booth et al., 2019; Nash et al., 2020; Cooney et al., 2015). 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.

Table 4.4: 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.	**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.	**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.	**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	Market analysis	Improving traceability in the supply chain to understand	**High**: Quantities of shark products flowing through the	**High:** This will determine what trade restrictions are

	importing meat from other harbours, potentially driving fishing and retention of sharks in these other sites.		flow and end markets of shark products, to identify what management arrangements may be needed.	system and supply-demand dynamics at other harbours unknown.	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.	**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.

*References for the proposed interventions can be found in the main text (Section 4.9)

Chapter 5

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

A small-scale fishing craft setting off for shark fishing in Canacona, Goa

5.1 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, jeopardising the security of nearly 500 million people who depend, at least partially, on SSFs (FAO 2023; Exeter et al., 2021). 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 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 resource use is increasingly addressed through interdisciplinary techniques. For instance, interviews with villagers in Madagascar were reliable in estimating the quantities and effort of wildlife harvesting (Jones et al., 2008). Such quantitative data collection can be improved through structured expert elicitation: a set of techniques to collect quantitative data and aid in decision making (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 et al., 2018b). Expert elicitation has been used to supplement missing data and parametrise 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 et al., 2018a), 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 socio-cultural 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. Most SSFs, which contribute significantly to shark landings in many developing countries, 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 not only hosts one of the world's largest marine fisheries, with nearly 5 million fishers in the country, but also ranks amongst the top shark fishing nations (Department of Fisheries, 2022; Akhilesh et al., 2023). Sustainable fisheries management is challenged by the complexity and diversity of gear and vessel types operating along the coastline, with fish catch landed in over 3200 fishing villages and landing centres of various sizes (FAO, 2024; CMRFI-FSI-DoF, 2020). Limited resources and capacity to monitor these fisheries necessitates 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).

Here, we explored approaches to obtain the required information and assess the ecological sustainability of an undocumented shark fishery in India. Juvenile blacktip sharks (*Carcharhinus limbatus*) are seasonally targeted by small-scale fishers across the Canacona region in Goa, India. 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 parametrise 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.

5.2 Methods

5.2.1 Study species and site

Common blacktip sharks (*C. limbatus*) are a medium-sized coastal shark species found globally in tropical and sub-tropical waters. It is a relatively productive species, with females producing up to 11 pups every 2 years through viviparous reproduction (Rigby et al., 2021). However, global population reductions of 30–49% over the past three generations have led this species to be categorised as Vulnerable on The IUCN Red List of Threatened Species due to overexploitation (Rigby et al., 2021). Blacktip sharks are a commercially important species in India and commonly fished across the coastline. At the time of this study, there are no domestic regulations regarding either fishing or trade in this species, aside from a fins-attached policy that applies to all shark species (Akhilesh et al., 2023). Local populations, especially along India's west coast, are suspected to be overexploited or even collapsed (Mohamed & Shettigar, 2016).

Previous research (Chapter 4) found that small-scale fishers in Goa, especially in Canacona in South Goa, seasonally target juvenile blacktip sharks. Hence this study focused on 8 fishing villages in Canacona (Figure 5.1).

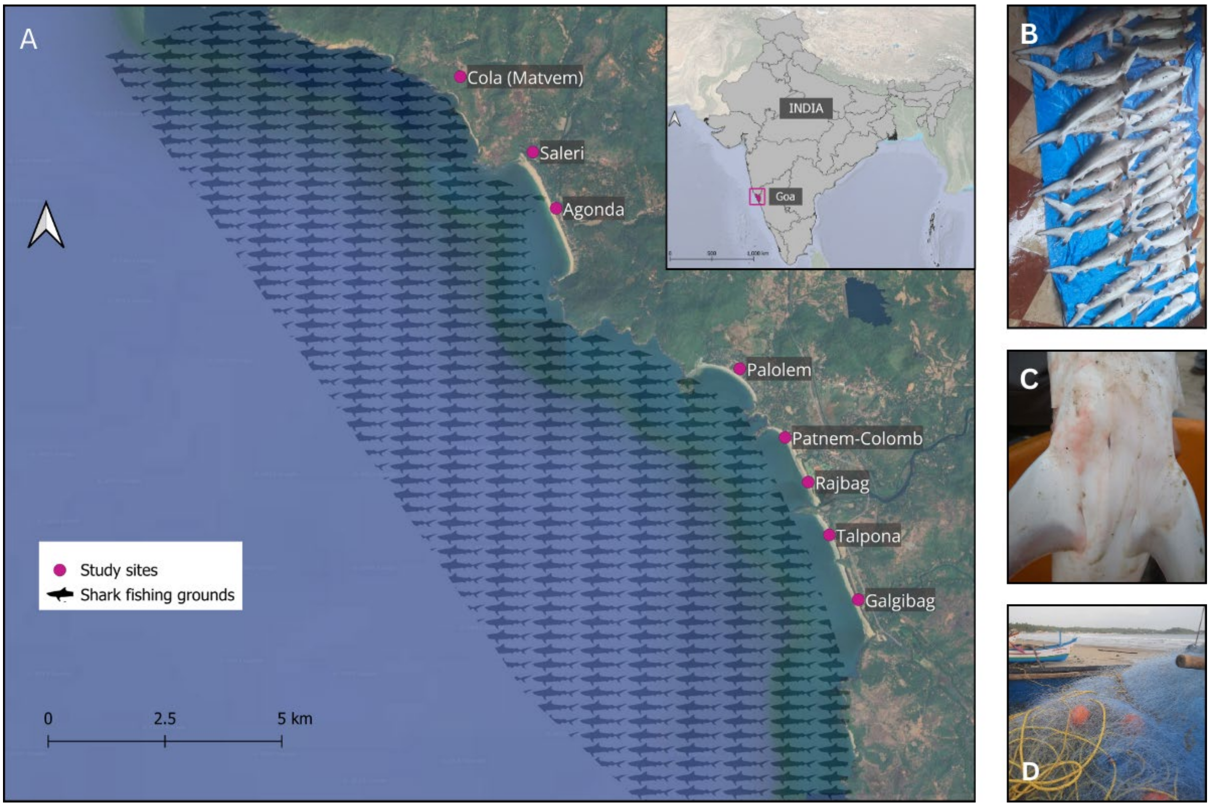


Figure 5.1: **A**: Study sites and extent of shark fishing grounds in Canacona, South Goa, on the west coast of India. **B**: Blacktip sharks caught by a gillnet. **C**: Open umbilical scar between the pectoral fins of a blacktip shark, suggesting a new-born individual (neonate). **D**: Gillnet used for shark fishing.

5.2.2 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 et al., 2018a) 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 provide a second and final 'Estimate'. Importantly, the aim of 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 didn't actively fish were still responsible for 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 (2022) and previous year (2021). This specific ordering has shown to elicit the most accurate results (Hemming 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 D1).

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 visualised 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 the 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.

5.2.3 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 5.1). 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 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.

5.2.4 Data analysis

Estimating total shark catch in Canacona

All data analyses were conducted on RStudio (Version 2023.12.1; R Core Team, 2023; RStudio Team, 2020). Our first step 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 calculated 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 D2). The upper and lower bound values were standardised to 80% confidence levels (based on the reported confidence levels from interviewees) for each round to provide credible intervals (Appendix D2). Standardised estimates from R2 were used as the final estimate of shark catch for each fisher; for fishers who were not available for R2, standardised 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 bootstrapped to get an estimate for the total number of sharks caught in Canacona assuming either 40 or 45 boats were operating.

Reliability of the adapted expert elicitation

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 landings surveys and reported by the owners in interviews, this shark catch was standardised as catch per trip in order to compare the two methods.

Assessing ecological sustainability

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, data deficiency of our study context meant that we modelled 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 2 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 5.1).
(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 8 other population sizes in between the lowest and highest N_s, for each K.
(3) We set 5 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, modelled 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 5.1), as reliable local data was not available. We used the stock size threshold (S) as a potential measure of sustainability (Cooper & Weir, 2006; Table 5.1). This threshold was calculated for each K value used in 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 D3.

Table 5.1: 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 grey 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: 16701 (for both K values) Highest: 25,000 or 100,000 (K/2) 8 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., 12500 or 50,000)	Cooper & Weir, 2006
Annual neonate catch (C)	5 catch scenarios: 2500, 5000, 10000, 15000, 20000	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

5.3 Results

5.3.1 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 5.2). 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 5 of these boats (3 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: 53.5cm) and adult spadenose sharks (*Scoliodon laticaudus*) captured in low numbers (Table 5.2). 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: 72.5cm), which is within the size at birth recorded for this species (Rigby et al., 2021).

Table 5.2: 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 25-63)
Years of fishing experience	22.4 (between 5-45)
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 feet in length with an outboard motor
Gear used	Shark-specific gillnet (locally called *Mori maag*)
Mesh size	4-6 inches
Net width	400m – 2000m
Fishing effort	Multiple hauls per trip, each haul having a soak time of up to 90 minutes.
Shark biological characteristics (landings surveys in 2023)	
Species	Blacktip (*Carcharhinus limbatus*), >90% Scalloped hammerhead (*Sphyrna lewini*) Spadenose (*Scoliodon laticaudus*)
Total number of blacktip shark landings 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 ± 0.5cm TL 2289 ± 57.6g weight

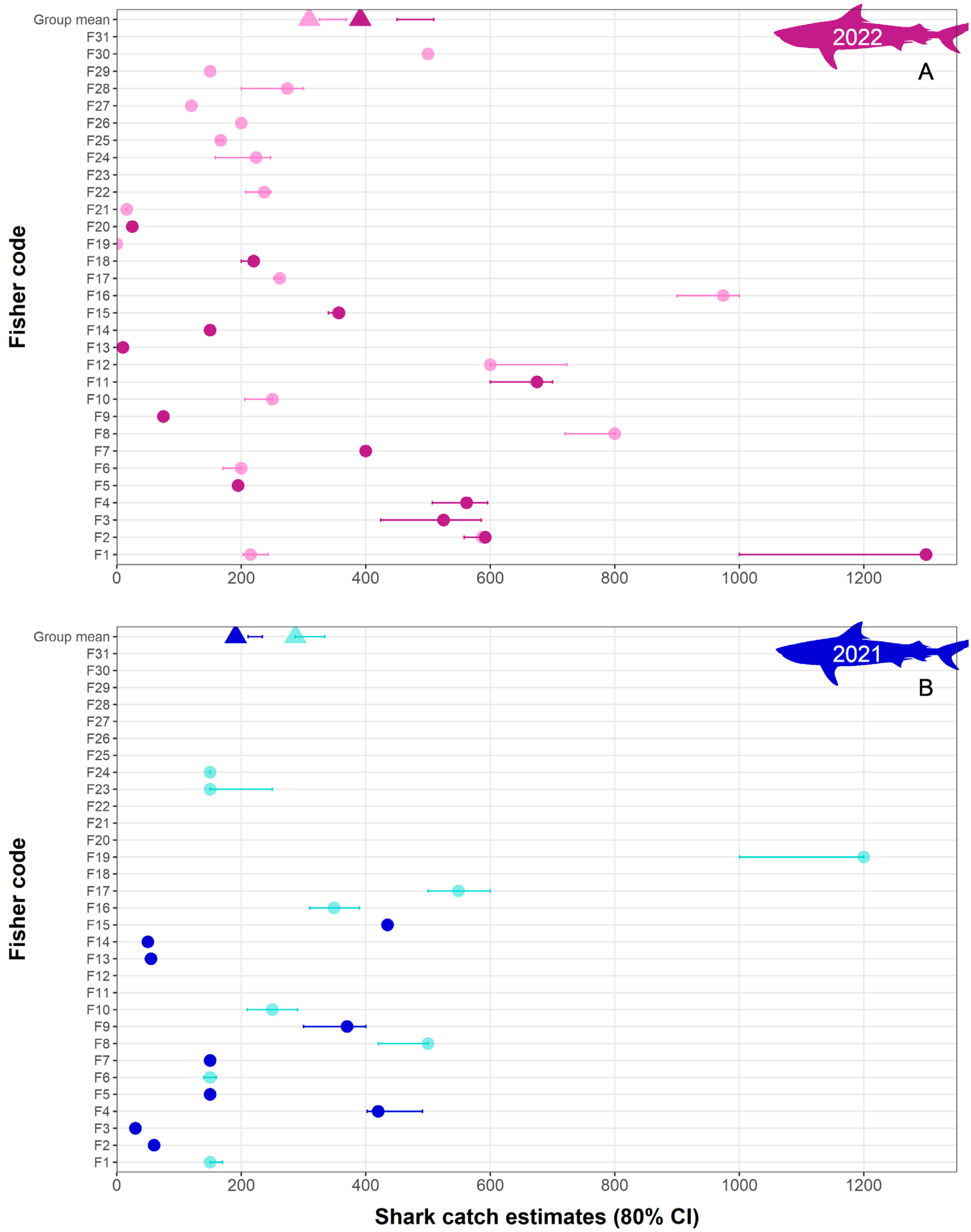
5.3.2 How many sharks are captured in small-scale fisheries in Canacona, South Goa?

Interviewed fishers were estimated to have caught a total of 10,060 blacktip sharks in 2022 (n=29 fishers) and 5,168 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 D4). These interviewees had little to no change in their responses for estimated catch, with one exception (Figure 5.2 A and B). Fisher 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: 9469-18272) if 40 boats were operating in 2022, or 15,616 sharks caught (95% CI: 10653-20556) if 45 boats were operating. In 2021, 9,351 sharks (6216-12427 CI) for 40 boats, or 10,520 sharks (6993-13980 CI) for 45 boats may have been caught (Figure 5.2C). Lower catch in 2021 as compared to 2022 was due to poor weather conditions that year, according to interviewees.

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

We compared shark catches (standardised 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 5.3). 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).



2022
A
2021
B
Group mean
F31
F30
F29
F28
F27
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F21
F20
F19
F18
F17
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F8
F7
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F5
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F3
F2
F1
Fisher code
0
200
400
600
800
1000
1200
Shark catch estimates (80% CI)

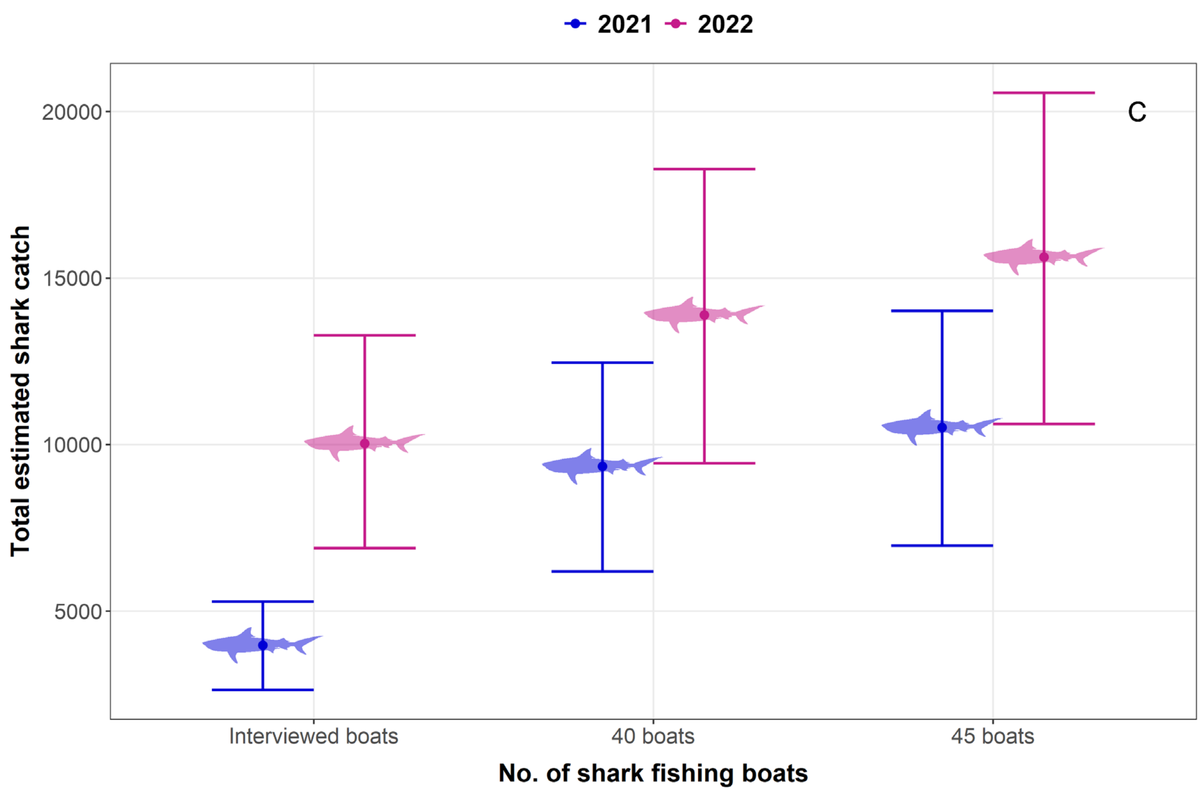

Figure 5.2: Estimates of sharks caught by interviewed fishers in 2022 (**A**) and 2021 (**B**), from R1 (light pink/light blue) and R2 (dark pink/dark blue), showing the upper bound, lower bound and best guess. Upper and lower bounds have been standardised to 80% confidence intervals. Triangles represent the aggregate values over all interviewees for each round. One fisher (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. **Figure 5.2 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.

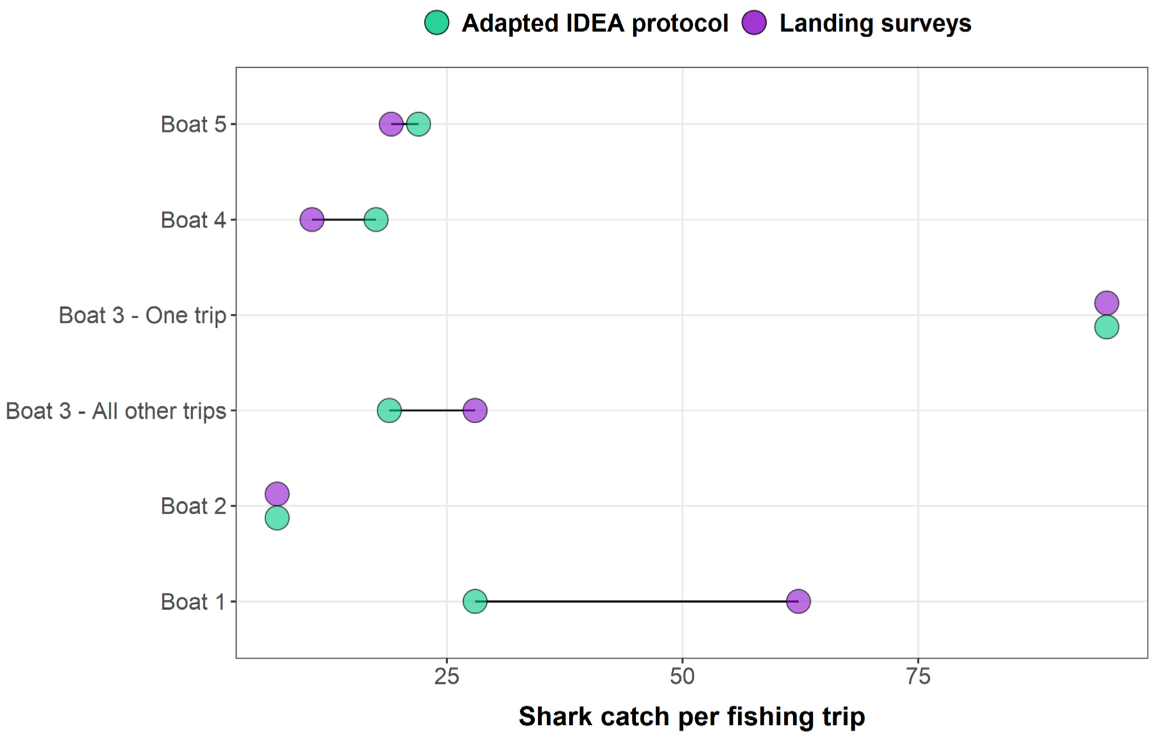

Figure 5.3: Comparison of catch data from interviews using the adapted IDEA protocol (green) and from landings surveys (purple) conducted for 5 fishing boats in 2023. Shark catch is standardised as catch per fishing trip (CPUE) across both methods.

5.3.4 Under what conditions can this fishery be sustainable?

The blacktip shark population was projected for 50 years under different conditions: 2 carrying capacities (K), with 10 starting populations (N_s) each, and facing 5 levels of fishing mortality (F). Fishing mortality was calculated from annual shark catch for Canacona (Table 5.1), which ranged from a minimum of 2500 neonates (the lowest possible total catch for the fishery as a whole, estimated from 2021, Figure 5.2C) to a maximum of 20,000 neonates (the highest possible total catch for the fishery as a whole, estimated from 2022, Figure 5.2C).

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 5.4).

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 levels of fishing for at least 50 years without falling below the threshold (Figure 5.4).

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 5.5).

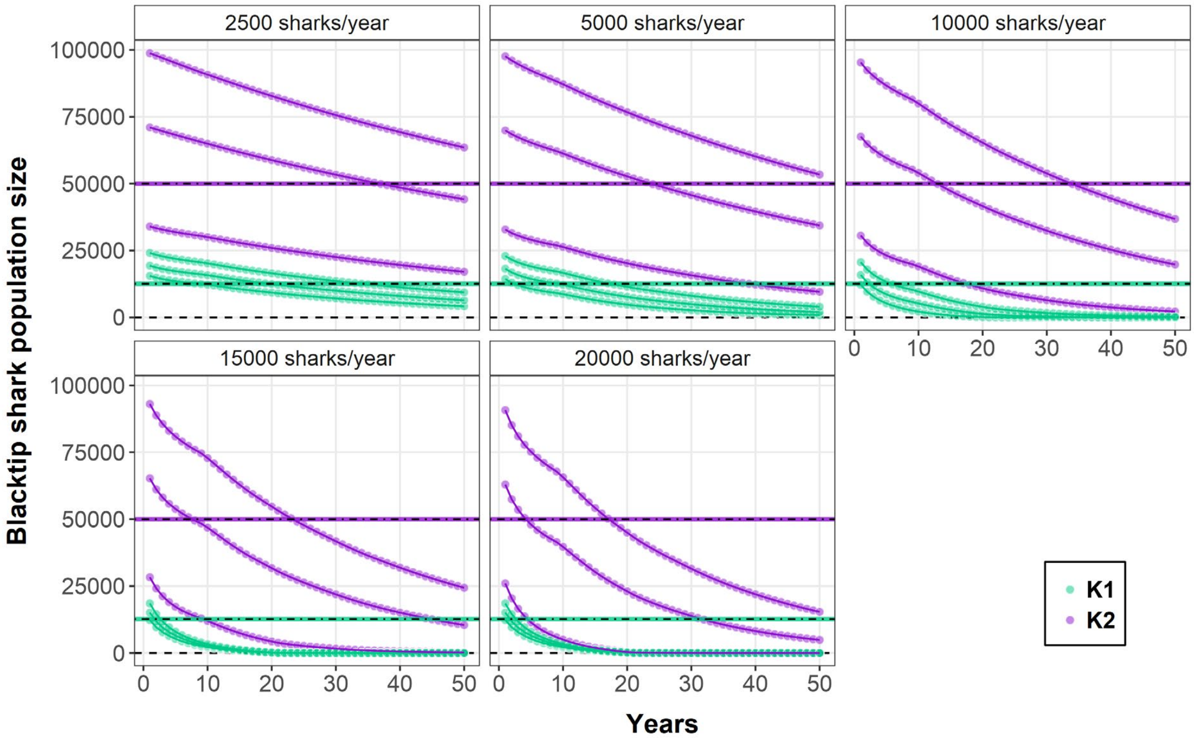

Figure 5.4: Trajectories of shark populations, for a few selected starting population sizes (N_s) and carrying capacity scenarios (K1=green, K2=purple), projected over 50 years under 5 different levels of fishing pressure (catches of 2500, 5000, 10000, 15000 and 20000). Sustainability thresholds (K/4) are represented as horizontal lines for each carrying capacity (K1=12,500, green; K2=50000, purple).

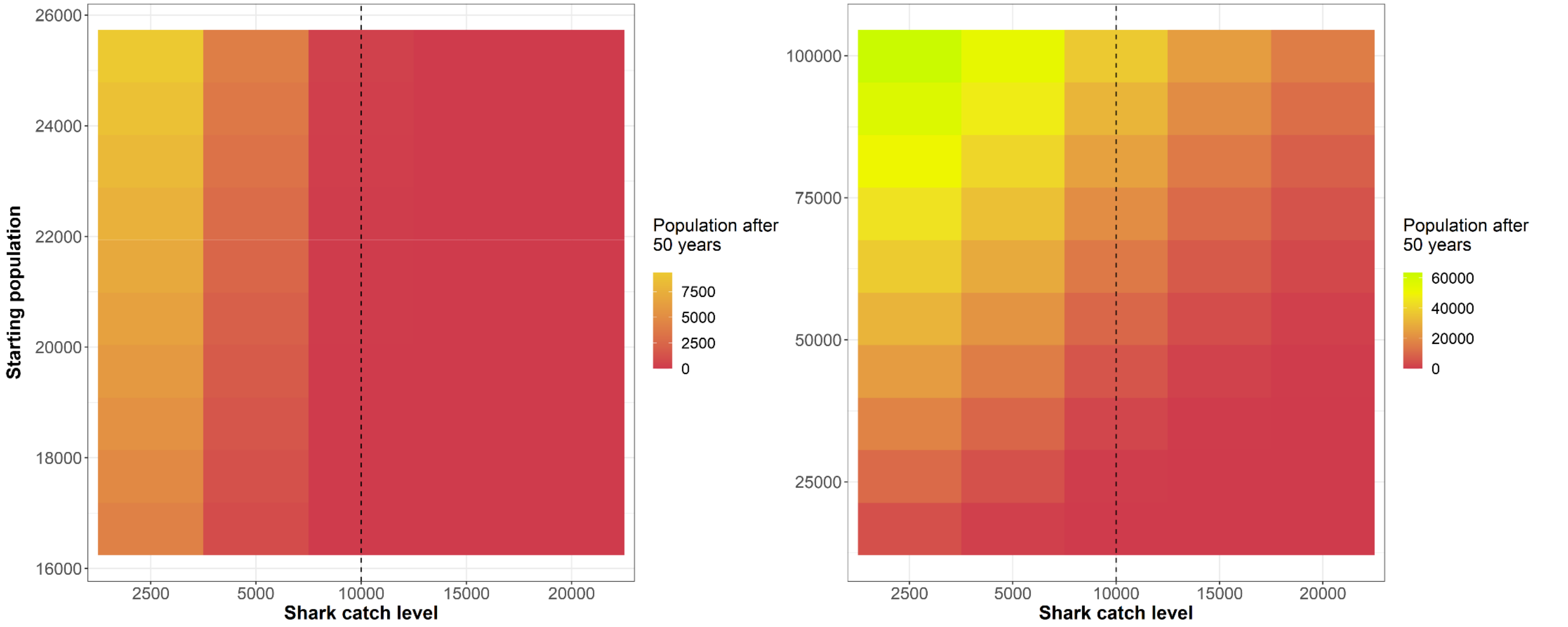

Figure 5.5: Shark populations projected for 50 years of fishing, under different conditions of carrying capacity (K1= left, K2 = right), starting population sizes (N_s, y-axis) and shark catch levels (x-axis). The colours represent the final population after 50 years for each combination of conditions, 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).

5.4 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 up to 20,000 neonate 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.

5.4.1 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 (FAO, 2024; CMRFI-FSI-DoF, 2020). 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 fishers, 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 (Brittain, 2019; Jones et al., 2008). As the movement to include local communities in conservation efforts grows, it is essential to expand our definition of 'experts' 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.

5.4.2 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 among locals and tourists (Karnad et al., 2024b; Chapter 4). The high value and potentially growing rarity of sharks may incentivise 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 quota and recreational size limits, amongst other measures, that 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 are significantly different. Our models suggest that shark fishing in Goa may be sustained if catch were 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 are 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" modelling 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 prioritised 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 (e.g. Gupta et al., 2022, Chapter 2). 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.

5.5 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.

Chapter 6

Exploring interventions for shark conservation in small-scale fisheries

Local men and women in Canacona, Goa, participating in an artisanal shore seine fishery

6.1 Introduction

Human behaviour is the key underlying driver of biodiversity loss, and hence represents a critical yet relatively understudied dimension of biodiversity conservation (Balmford et al., 2021; Nielsen et al., 2021; Veríssimo, 2013). Pressures on biodiversity such as climate change, land use change, pollution, and overexploitation are consequences of human behaviour and lifestyles globally (Schultz, 2011; IPBES 2019). These pressures manifest at different scales, from the global level to the local scale of a village, requiring a suite of interventions that target human populations at the appropriate scales. Conservationists are increasingly using behavioural sciences to understand why actors in populations behave as they do, and apply this evidence to inform the design and implementation of behaviour change interventions (Davis et al., 2020; Reddy et al., 2017). With millions of people across the world directly depending on the harvest and use of biodiversity (Cooney et al., 2015), it is also crucial that conservation interventions account for this dependence, particularly in vulnerable or low-income communities. Hence, interventions should be designed such that they effectively drive changes in human behaviour where possible, and produce positive outcomes for both people and biodiversity (Obura et al., 2023).

At least 60 million people globally are employed in small-scale fisheries (SSFs), accounting for 40% of capture fisheries and over 90% of fisheries employment (FAO, 2023). SSFs can be conceptualised as social-ecological systems (SESs), which are complex and adaptive systems defined by feedbacks and interactions between nature and people (Gurney & Darling, 2017; Ostrom, 2009). Millions of fishers rely on coastal common-pool resources, including marine biodiversity, which in turn are facing increasing threat and degradation due to overexploitation and other local and global pressures (Gurney et al., 2019). Some coastal taxa with slow life history traits and high vulnerability to anthropogenic threats, such as sharks and rays, are particularly threatened, with a high risk of extinction (Dulvy et al., 2021; Pacoureau et al., 2023). Sustainable management of SESs requires interventions that are targeted at the behavioural drivers and mechanisms underlying resource harvest (i.e. fishing).

Human behaviour is influenced by multiple intrinsic and extrinsic, and individual- and collective factors, such as values, beliefs, attitudes and social norms (Walsh Reddy et al., 2017; Cinner, 2018). Social norms are the rules or expectations within a group that influence behaviour, supporting desirable behaviours and forbidding undesirable ones (Oyanedel et al., 2020a). People, therefore, generally conform to social norms to avoid the disapproval of others;

hence, understanding the social norms of a group can be key to influencing behaviour (Bova et al., 2017). Social norms have been well studied in the context of small-scale fisheries, and applied for conservation. For example, McDonald et al. (2020) found that social norms helped shift behaviour towards more sustainable practices in SSFs in Brazil, Indonesia and the Philippines. Hence, norms can be leveraged to produce desired conservation or sustainability behaviours.

Behaviour change interventions targeting local communities are often centred around livelihood-focused interventions (Wright et al., 2016). These can be in the form of incentives to influence people's behaviour and livelihood strategies in line with conservation objectives. Financial incentives, such as payments for ecosystem services (PES), are conventionally used incentives in conservation. When poorly designed, financial incentives can be ineffective, or even lead to negative consequences for conservation (Cinner, 2018; Cinner et al., 2021; Walsh Reddy et al., 2017). However, financial incentives can also be important in contexts where there is high dependency on a resource, and the pro-conservation behaviour can have negative livelihood impacts; these measures have also been successful in some contexts, including small-scale shark fisheries (e.g. Booth et al., 2023b). Incentives can also be negative (i.e. disincentives), through measures such as bans or sanctions (Gneezy et al., 2011; Travers, 2014). Non-financial incentives such as social benefits have also been explored in conservation, although to a lesser degree (Booth et al., 2023b). Livelihood-focused interventions also include alternative or sustainable livelihood approaches, that seek to partially or completely substitute benefits obtained from the 'unsustainable activity', in ways that maintain or enhance a household's assets while not undermining the natural resource base (Wright et al., 2016).

Given the wide range of incentives and strategies to use in conservation, predictive techniques can be useful for understanding how people might behave in response to potential interventions before they are implemented (Travers et al., 2019). This approach can help better allocate costs and efforts for conservation interventions while avoiding unintended consequences. Scenario interviews are commonly used in behavioural sciences and predictive conservation; and involve constructing a set of plausible futures for conservation interventions and exploring how target populations might respond (Booth et al., 2023b). Scenarios can provide valuable quantitative and qualitative predictive insights, including estimated uptake and effect sizes for different interventions, and reasons for stated responses (Brittain et al., 2022; Travers et al., 2016). Such approaches can hence ensure that conservation interventions are framed, designed, implemented and evaluated to better account for future changes in human behaviour (Travers et al., 2019).

6.1.1 Case study: the shark fishery of Goa

Small-scale fishers in Canacona, Goa, on the west coast of India, seasonally target threatened blacktip sharks (*Carcharhinus limbatus*). This fishery forms an example of a complex SES where sustainable management must balance the economic and food security needs of fishers and their communities with conservation of shark populations (Temple et al., 2024). Previous research (Chapter 4) has found that this targeted fishery is not a traditional practice, but a relatively new fishery that emerged 10-15 years ago. Local fishers became aware of the seasonal presence of juvenile blacktip sharks nearshore. Improving socio-economic conditions allowed access to better fishing craft, and to a specialised bottom-set gillnet ('*Mori maag*') used to target these sharks.

Blacktip sharks are categorised as Vulnerable on The IUCN Red List of Threatened Species due to global overexploitation (Rigby et al., 2021). Evidence suggests that blacktip shark populations along India's west coast are likely to be overexploited or even collapsing (Mohamed & Shettigar, 2016). Exploratory population models in Goa suggest that this targeted fishery is likely unsustainable, and could continue only if the current harvest rate was reduced by at least half (Chapter 5). However, small-scale fishers appear to gain large economic and non-economic benefits from this fishery (Chapter 4), and fishing communities in Goa have previously expressed negative attitudes towards shark conservation (Gupta et al., 2023, Chapter 3). There is a need to develop practical solutions that address the underlying drivers of fisher behaviour, and lead to reductions in shark fishing mortality. This is crucial to maintain the health of local shark populations and the wellbeing of fishers who depend on them.

6.1.2 Research objectives

We explored incentives to change fisher behaviour for shark conservation, using the targeted shark fishery in Canacona as a case study. We aimed to (1) Understand the motivations for shark fishing and characterise factors that enabled or inhibited fisher behaviour (2) Design and explore incentive-based interventions to halt or sustainably manage shark fishing.

We used data and evidence from previous research on this shark fishery to develop several scenarios for plausible interventions to reduce or prevent shark fishing, while considering local socio-economic needs to ensure that fishing communities will be no worse off (Brittain et al., 2020; Booth et al., 2023b). We interviewed fishers who catch sharks to understand their hypothetical behavioural responses under each scenario, and the perceived impacts on their livelihoods. Our work informs conservation and sustainable management of sharks in India, and provides important empirical insights into community-based behaviour change interventions for threatened species conservation.

6.2 Methods

We first developed a Theory of Change (ToC) for shark conservation, using evidence and insights on the motivations and enablers of shark fishing from previous research (Chapters 4 and 5). Based on the ToC, we devised 6 scenarios of plausible interventions for shark conservation and sustainability in this fishery. We conducted interviews with boat owners who fished for sharks (hereafter, “shark fishers”) to validate the ToC and our understanding of fisher motivations and enablers. More importantly, the interviews provided insights into fisher responses to the interventions, guiding future management and conservation action.

6.2.1 Theory of Change and Scenarios for shark conservation

Juvenile common blacktip sharks (*C. limbatus*) are the main target species in this fishery, with multiple behavioural drivers for shark fishing (as seen from Chapters 4 and 5). These drivers include instrumental motivations (sharks are targeted for their high economic value, and they also serve as a food source), social motivations (people fish for sharks due to influence of others in the community), and intrinsic motivations (shark fishing due to enjoyment). Access to capital (for boat, gear, and operational costs) and access to knowledge (about the presence and movement of sharks and how to catch them) were identified as important enablers. Fieldwork for Chapter 5 also suggests that shark fishing is considered to be physically risky and dangerous, due to the rough weather, which serves as a limiting factor for engaging in this fishery.

These insights were used to develop the ToC to explore and identify strategies for shark conservation in Canacona. A ToC is a decision support tool that illustrates the causal links and sequences of events needed for an activity or intervention to lead to a desired outcome or impact (Biggs et al., 2017). Theories of change help outline the causal reasoning and scientific evidence underpinning an intervention for more effective outcomes (Baynham-Herd et al., 2018). Using the ToC (Figure 6.1), we devised 6 scenarios, describing potential interventions for shark conservation and/or sustainable fisheries management. The scenarios used different types of incentives (financial and social, positive and negative, S1-S4), as well as sustainable livelihood approaches that included a regulated, cooperative shark fishery (S5) and an alternative livelihood option (S6). Some of the potential interventions focused on a regulatory approach (i.e., using current or future policy instruments by the state), while others used social 'nudges' (i.e., small changes in the decision context that do not limit choices or change economic incentives; Reddy et al., 2017). Most of the scenarios were framed as being voluntary except for the financial disincentive (i.e. S3, the ban), which was mandatory and imposed by the government.

Descriptions of the scenarios can be found in Table 6.1. Scenarios were developed and refined with feedback and inputs from various local experts, including local scientists, conservationists and fisheries department officials. However, aside from pilot interviews, we did not consult the fishing community during this process. Due to the small population of shark fishers, incorporating their feedback in the scenario development would limit the sample size for this study, and risk bias.

The cooperative fishing scenario (S5) was developed and included in the study after pilot interviews. Cooperative and collective fisheries, where a group of fishers act collectively to manage some aspect of a fishery, can be highly complex systems, and different forms have been described in fishing communities globally (Cinner & Aswani, 2007; Johannes, 2002; Ostrom, 1990; Ovando et al., 2013). The cooperative fishing scenario in this study was not intended to be a perfectly designed and implementable intervention, but served as a way to explore what fishers may think about some form of regulated and sustainable shark fishing and community-based management.

The alternative livelihood option (S6) proposed was cage culture (i.e. mariculture), which was the farming of marine fish like sea bass (*Lates calcarifer*). This scenario was developed based on an existing policy: cage culture is currently under significant promotion by the Indian government, with subsidies and training offered to fishers to undertake this activity (Department of Fisheries, 2022). We hence explored this as an alternative livelihood to shark fishing, and we also aimed to understand local fisher perceptions on this government scheme.

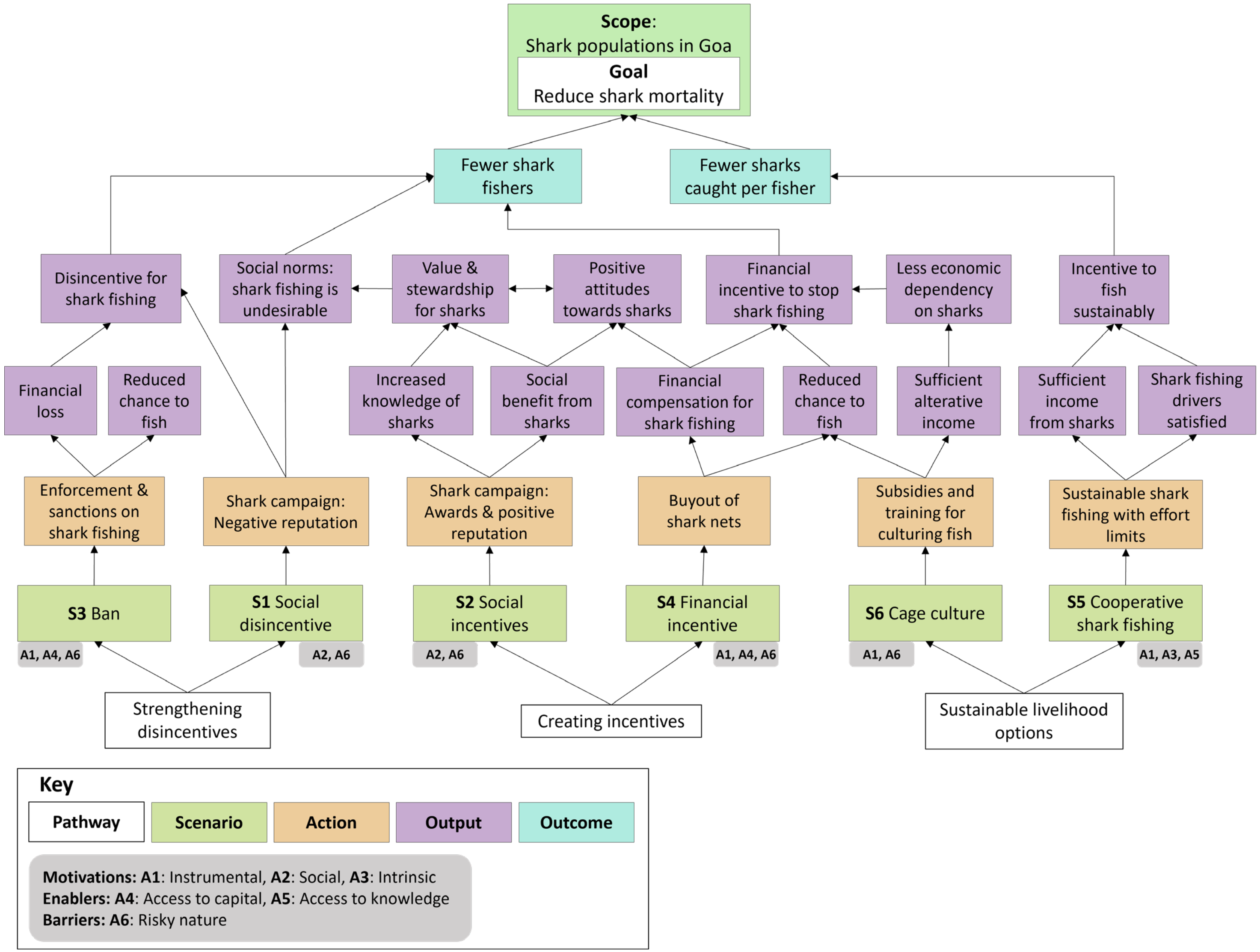

Figure 6.1: The initial Theory of Change (ToC) developed to change fisher behaviour and conserve sharks at the study sites. This guided the development of the conservation scenarios.

Table 6.1: The different scenarios for shark conservation used in the present study, including the baseline scenario (BAU). The underlying assumptions and conditions for each scenario are provided.

Scenario	Description[1]	Assumptions and Conditions[2]
Business-as-usual (BAU)	Everything continues the same as it is now, with no changes in regulations or incentives	Without any intervention, shark fishing will continue in Canacona and catch will increase. This will hold true as long as shark populations are stable. When the population starts to decline, catch will decline and fishers may exit this fishery.
S1: Social disincentive	Campaign to reduce shark fishing: Shark fishing in Goa receives negative media attention, and upsets tourists because sharks are threatened. This brings a negative reputation to the community. Other community members will also get upset and look down on you for shark fishing.	Sharks are not a key source of income. Social motivations of shark fishers are strong
S2: Social incentive	Campaign to reduce shark fishing: the government encourages fishers to voluntarily exit this fishery. If you do, you will receive an award (non-monetary) from the government and will be featured in the local media/news. You will achieve a positive reputation locally.	Sharks are not a key source of income Positive attitudes will be developed for sharks, which will lead to behaviour change (Ajzen, 1991) Social motivations of shark fishers are strong
S3: Financial disincentive (ban)	This targeted seasonal shark fishing will be completely banned by the government. The local fisheries department will monitor and enforce it. Any fisher caught shark fishing will be fined up to 5 times the value of the fish caught[3].	No corruption or collusion with enforcement officers. Sanctions are fair and proportionate. Sanctions will not cause negative attitudes towards sharks and result in increased targeting. Instrumental motivations of shark fishers are strong

S4: Financial incentive (PES)	A voluntary scheme to encourage fishers to give up shark fishing. You will be offered a one-time payment of Rs. 20,000 ($238.40 USD) to buyout your shark fishing net and exit the fishery.	There is funding for a PES scheme Fishers will not purchase/use another net and continue shark fishing Instrumental motivations of shark fishers are strong Capture of benefits by elites does not undermine success
S5 Cooperative fishing	A shark fishing cooperative is established in South Goa where fishers collectively manage the fishery. An effort limit (e.g., 5 days) is imposed, you can fish for sharks as much as you want within this. The cooperative will provide support with access to labour and information for shark fishing, and access to markets to provide a good rate for sharks.	Capture of benefits by elites does not undermine success Participating fishers follow the rules and fish within the effort limit
S6 Cage culture	A voluntary scheme by the government where fishers are offered subsidies and training for aquaculture for marine fish (i.e., mariculture, for species like sea bass) in return for exiting the shark fishery. The activity takes up to 6 months, and profits from it can be between Rs. 5-10,00,000. ($5950-11900 USD)	Fishers will be interested in participating in cage culture. Fishers will not continue shark fishing, alongside cage culture

1 Apart from the details mentioned for each specific scenario, the remaining conditions for the shark fishery stay the same. For example, the market for sharks will not change unless otherwise specified.

2 An assumption across all scenarios is that shark fishing is only conducted by fishers from Canacona. There is no harvest of the same shark population by fishers in other locations, and non-local boats are not entering Canacona waters to catch sharks.

3 This is in line with the current marine fisheries regulations and penalties for illegal behaviour.

On the whole, we hypothesised that under present circumstances (BAU scenario), the highest number of fishers would be unlikely to change their behaviour and will continue to fish for sharks. We also hypothesised that the number of fishers catching sharks will increase every year (based on findings from Chapter 5). Regarding the interventions, we expected that the financial incentive (PES) will result in the highest behaviour change among fishers, while the financial disincentive (ban) will be the least effective. The latter hypothesis was made as people generally respond poorly to negative incentives; furthermore, previous research from the west coast of India found that fishers were unwilling to comply with measures like spatiotemporal closures for elasmobranch conservation (Gupta et al., 2020a), suggesting that a shark fishing ban in Goa would likewise be ineffective.

6.2.2 Data collection

Data collection for this study focused on 8 fishing villages in Canacona, South Goa, similar to Chapter 5 (Figure 5.1). Shark fishing here appears to be undertaken by a total of 40-45 fishing boats (Chapter 5), with the majority of fishers who catch sharks belonging to the Pagi community (a traditional fishing caste in this region). While targeted shark fishing is practiced in most villages in Canacona, the village of Palolem appears to be the key docking location. Fishers from other villages dock their boats in Palolem for shark fishing, as it has the best access to fishing grounds during the shark fishing season.

Data were collected over a 3-month period in 2023, during and after the shark fishing season. We conducted semi-structured scenario interviews with shark fishers: Several had been previously interviewed (Chapter 5), and additional shark fishers were identified over the course of fieldwork. We aimed to build relationships and trust with these shark fishers over the course of the shark fishing season, through catch surveys, informal interviews and other participant observation activities (described ahead). Then, at the end of the season, shark fishers were approached and asked to participate in the scenario interview. A few declined due to lack of interest in the study (n=2) or lack of time (n=3), and some fishers who had been previously interviewed (for Chapter 5) could not be contacted (n=6). Seventeen shark fishers (n=17, representing 38-42% of shark fishers in Canacona) agreed to participate and provided informed oral consent.

For scenario interviews to be an effective method, scenarios should be relatively simple and easy to understand by study participants (Travers et al., 2016). Hence, explanation of each scenario was kept relatively minimal, to encourage questions and open-ended discussions from interviewees. We recorded interviewee's response to each scenario in terms of whether they would change their shark fishing behaviour, and their perceptions of what others in the community would do. The open-ended discussions provided insights on the interviewee's perceptions and opinions about the scenario, and the reasons or conditions under which they would or would not change their behaviour. The social scenarios (S1 and S2) were always presented before the financial scenarios (S3 and S4), followed by the alternatives scenarios (S5 and S6), although the order within each varied, to not bias the interviewees (Booth et al., 2023b). The questionnaire guide (Appendix E1) also contained questions to understand motivations and enablers of this fishery. These interviews followed procedures approved by the University of Oxford (Ethics Approval Reference: R79807/RE001).

Data were also collected and recorded through participant observation - participating in the life of the study community and making systematic observations - which was possible given the lead author's familiarity with the site (Newing, 2011; Bernard, 2017). The research team would visit the landing sites regularly (particularly in Palolem, where the majority of shark fishing took place), to speak with community members, and observe and participate in daily activities. Through this process, informal interviews were conducted with community members such as shark fishing crew members, fisherwomen, non-shark fishers, local leaders and tourism operators (at least 35 people). Some of these were locally recognised experts, with whom unstructured interviews are held regularly throughout fieldwork, and hence served as key informants (Newing, 2011). These interviews centred around understanding the process of shark fishing, the importance and use of sharks, and perceptions of these informal interviewees on some of the scenarios. We also discussed broader contextual factors, such as local social norms and institutions. Along with these interviews, daily observations were documented and compiled in field notes. These informal interviews and field notes were also analysed.

6.2.3 Data analysis

The data were coded and thematically analysed on NVIVO (Version 14; Lumivero, 2024). We started with the semi-structured scenario interviews with shark fishers. An initial codebook was developed based on the research objectives and ToC, containing top-level codes on shark fishing motivations, enablers and barriers, and response to the scenarios, each containing numerous levels of sub-codes. We then inductively coded new codes as they emerged from the data.

Responses to the scenarios were separately coded as personal and descriptive norms. Personal norms refer to an individual's own values regarding a behaviour and adherence to that behaviour, whereas descriptive norms are the individual's perception of how common that behaviour is within their group or community (Niemiec et al., 2020; Oyanedel et al., 2020b). In other words, personal norms provide insights into what the interviewee might themselves do in response to each scenario, while descriptive norms indicate what they perceive others in the community would do. These results are presented as the number of interviewees who *will* change their shark fishing behaviour and participate in or comply with the scenario, who *may* change their behaviour under certain conditions or circumstances, and who *will not* change their behaviour in response to the scenario (for both the personal and descriptive norms).

We coded the perceptions and opinions about each scenario, and the reasons or conditions provided by interviewees for their response to the scenario, i.e. changing or not changing behaviour. These reasons were categorised as the following: (1) Instrumental – related to financial benefits, including food, (2) Intrinsic – related to internal drivers such as inherent satisfaction or enjoyment, or sense of responsibility, (3) Social – related to social norms and influence of other community members, and perceptions of other fishers' behaviour (4) Institutional – related to state or local institutions and rules, such as a scenario being mandatory or not (5) Practical – related to logistical factors. These categories were developed based on existing literature (Booth et al., 2023a; Ramcilovic-Suominen & Epstein, 2012; Steg, 2016) as well as emergent themes.

We used similar categories as above to code motivations and drivers of shark fishing (Arias et al., 2020). Enablers for shark fishing were coded based on access theory, which refers to the ability of actors to operate in, and collect benefits from, a market, via mechanisms such as access to capital, access to knowledge, access to markets, and so on (Ribot & Peluso, 2003). Although we collected demographic data such as age, education level and others, we were unable to meaningfully analyse this in relation to the motivations and scenario responses due to our small sample size.

The informal interviews and field notes from participant observations were also coded using a similar codebook. These data are provided throughout the results where relevant, to support, complement, contradict or better explain the findings from the shark fishers.

6.3 Results

6.3.1 Motivations for shark fishing

Instrumental (n=9), social (n=4) and intrinsic (n=2) motivations for shark fishing all emerged from the data; however, instrumental motivations were predominant (Figure 6.2). High profits from sharks emerged as the most frequently reported (instrumental) driver for shark fishing (n=9, 53% of shark fishers). Fishers highlighted the high value of sharks compared to many other commercial fish, and stated that sharks had a high local demand. A few fishers (n=3) highlighted the time/output ratio of shark fishing, stating that sharks were 'fast money'. Only one fisher mentioned take-home consumption of sharks as a motivation for fishing, although field notes indicated that all shark fishers and crew members kept a few sharks after nearly every fishing trip as take-home consumption. This suggests that while shark consumption was prevalent, this by itself did not serve as an important driver of fishing behaviour.

Social motivations included fishing due to the influence of friends and family (n=4), while intrinsic motivations such as personal enjoyment and fishing due to boredom in the non-tourism season were also stated (n=2). We also coded practical reasons for shark fishing (n=4), such as that every fish had its season, and so sharks were fished as this was their season.

6.3.2 Enablers and barriers for shark fishing

The risky and dangerous nature of shark fishing, due to the rough weather during the shark fishing season, was the main barrier to shark fishing (n=11; Figure 6.2). Only fishers who were willing and capable of bearing these risks participated in the fishery. Informal interviews with a few former shark fishers indicated that this risk element was the main reason that they had exited the fishery and sold their shark nets.

Access to capital emerged as the most frequently reported enabler for shark fishing (n=14; Figure 6.2). The fishery was considered a financially risky venture, due to its unpredictable and unreliable nature. Hence, only fishers with access to sufficient capital could afford to invest in high-risk high-reward shark fishing. Furthermore, shark fishing required possession of a relatively large boat (30-38 feet), the specialised shark net, and high operational costs due to the fuel requirements, gear maintenance and so on, also requiring access to capital.

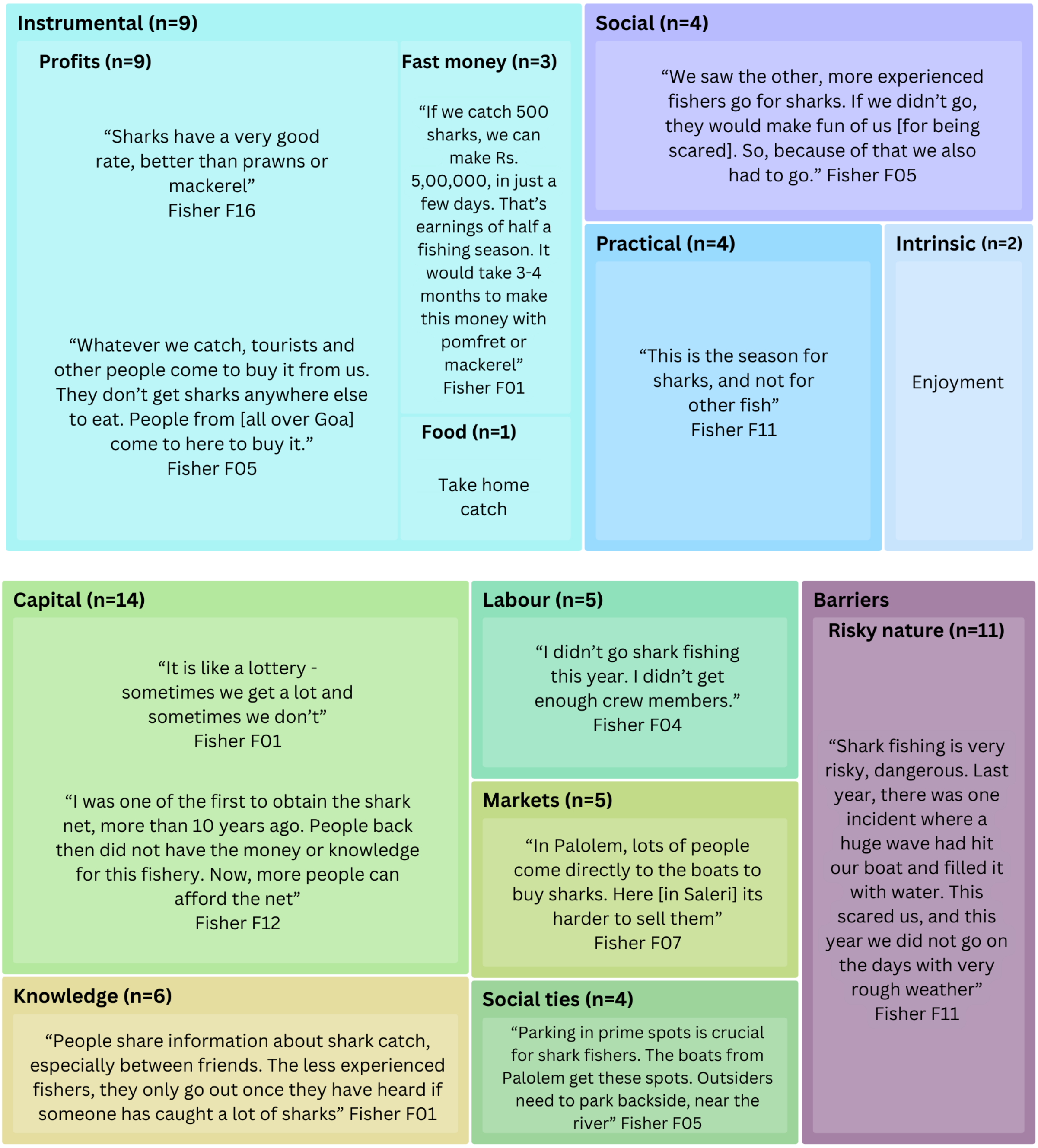

Figure 6.2: Motivations (**top**) and enablers and barriers (**bottom**) for shark fishing identified through interviews with shark fishers. Sample sizes of number of fishers who expressed or supported a particular factor are provided, along with an illustrative quote.

Access to knowledge, like where sharks were present or caught on a particular day, was also an important enabler (n=6). Such knowledge was often shared among shark fishers, and only fishers with access to this knowledge could successfully catch sharks, due to the unpredictable nature of this fishery. Social ties and networks played a role in this, as those with stronger ties with other shark fishers would receive the best or fastest information on which fishing grounds were most productive each day. Social identity and ties also enabled the fishery in other ways (n=4). Some fishers stated that they would venture out shark fishing with their friends or family, in groups of 2-3 boats and never alone, to mitigate the risky nature. Social identity also provided access to boat docking space in Palolem, an important criterion for this fishery. Key informants revealed that conflict between local fishers from Palolem and fishers from other villages had let to an informal agreement: Local fishers could dock their boats at prime spots on the beach, while non-local fishers had to dock down a small creek and could only access the sea during high tide. Non-local fishers were not allowed to fish at night (as it would 'scare away' the sharks for other fishers) and were not allowed to sell their catch locally. Hence, fishers from Palolem, through their social identify, had access to the best sites and conditions for shark fishing. Non-local fishers who had social ties with fishers from Palolem could sometimes benefit from this access.

Access to labour was another crucial factor mentioned by fishers (n=5), and strongly supported by informal interviews. Some fishers faced difficulty getting enough crew members to undertake shark fishing due to its risky nature, and hence did not fish that year (2023, n=3). Many interviewees hired non-local crew, particularly from the neighbouring region of Karwar, and did not go out fishing themselves (n=6). Interviews with crew members from Karwar indicate that they were instrumentally motivated as well. Crew members were paid through income from shark fishing, sometimes getting up to 60% of earnings from a trip depending on their agreement with the owner. Hence, crew members were incentivised to take risks and catch as many sharks as possible. Some crew members suggested that the Goan boat owners would be unlikely to go shark fishing without them.

Access to markets were also mentioned by a few fishers (n=5). Some stated that sale of sharks was easy and they received good rates, with minimal effort, whereas others mentioned lack of market access and challenges in selling shark catch. Lastly, although not mentioned in any interviews directly, participant observations suggested that most shark fishers were relatively wealthier or held a relatively higher socio-economic status in the community – which aligned with the access mechanisms that we coded.

These findings support our ToC, where access to capital and to knowledge were identified as important enablers, and the risky nature was the main barrier to this fishery. However, other important enablers, such as access to social identity and ties, labour and markets, emerged from the fieldwork.

6.3.3 Business-as-usual scenario (BAU)

"*Fishing is our main work, we'll go every year*" – Fisher F09

"*It is very risky. I got married 7 years ago, and my wife also insisted on not going while the sea is rough, so I reduced [shark fishing]. I didn't go this year, and I am planning to sell the net*" – Fisher F12

Most interviewees (n=13/17) would continue fishing for sharks next year, and over the next 5 years, under BAU conditions. Only 3 fishers stated that they would likely not fish the following year. Of these 3, one fisher (F12) had not fished for sharks in recent years and was planning to sell his net and exit the fishery, due to its risky and challenging nature as well as influence of his family. Another (F06) had not fished in the present year (2023) due to challenges in finding the right crew, and was considering exiting the fishing as well. The third fisher (F17), although he fished for sharks in 2023, had very low catch and faced challenges with crew access. He stated limited interest in and dependence on fishing, especially for sharks.

Confirming our hypothesis, many interviewees (n=7) perceived an increasing number of local fishers joining the shark fishery every year, and believed that the number would continue to rise in coming years.

6.3.4 Overview of responses to scenarios

Against our hypotheses, the ban scenario was estimated to lead to the largest reductions in shark fishing, with most fishers stating that they will (n=7/17) or may (n=3) change behaviour and perceiving that others would as well (n=12). The PES and cooperative scenarios received mixed responses, with 8 and 7 fishers indicating behaviour change for each of these scenarios, respectively. The social scenarios showed poor performance, with the majority of fishers unwilling to change behaviour (n=11 for the disincentive, n=12 for the incentive) and perceiving that others in the community would respond similarly. For the PES and social scenarios (S1, S2 and S4), fishers who stated that they would change behaviour included fishers F12 and F06 who were planning to exit the fishery anyway. The cage culture scenario received negative responses, with nearly all fishers indicating no change in behaviour (n=13) and only 1 fisher who said he may take up this scheme (Figure 6.3, Table 6.2).

Overall, personal and descriptive norms for each interviewee aligned except in two cases. Fisher F04 stated that while he may participate in the PES scenario if the payment amount was increased, he did not believe that others in the community would do so. For the cooperative fishing, Fisher F16 stated he may participate and change behaviour as it looked like a good measure, but expressed uncertainty about how this fishing would work and did not feel like others would participate.

The views of informal interviewees largely aligned with the shark fishers. Negative opinions were held by most people about cage culture, with one key informant stating: "*The government is moving from 'capture' to 'culture'. All subsidies that us small-scale fishers used to get are now being given to cage culture*". For the PES, while many suggested that receiving some financial compensation to restrict unsustainable fishing practices would be nice, they would be unlikely to actually stop fishing because of this. They would prefer to continue fishing as it was more reliable, as compared to relying on the compensation or other income sources. Unlike in the shark fisher interviews, the ban produced mixed views. Most crew members from Karwar were against this intervention, as it would cause anger among local fishers and non-compliance.

On the whole, several fishers (n=6) perceived that no regulations or interventions on their shark fishing were required, as there were 'enough sharks in the oceans' (n=4), or that other fishing crafts like trawlers and purse seines captured many more sharks than them and should be regulated instead (n=4). Fisher F03 explained: "*Trawlers catch so many sharks, 5000-6000, so many tonnes! This 300-600 sharks [that we catch] is nothing, this won't decrease the number of sharks in the ocean"*. These fishers appeared to be unwilling to change their behaviour in response to most scenarios.

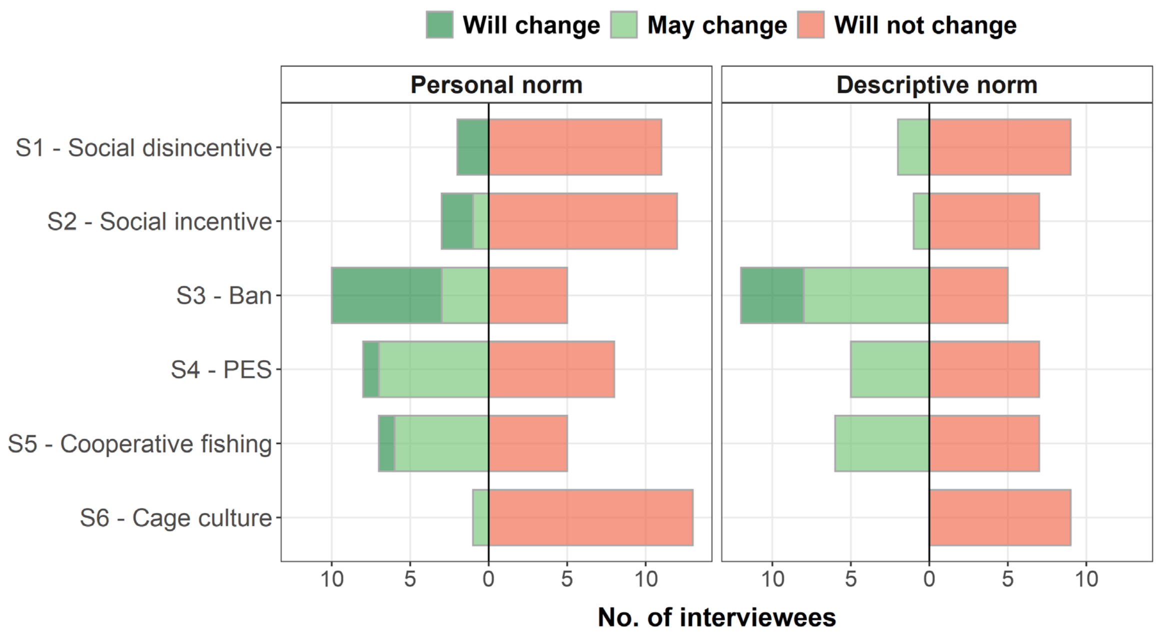

Figure 6.3: Responses to the scenarios, in terms of number of fishers who would (dark green) or may (light green) change behaviour, or would not change behaviour (red), to each scenario. The responses are divided into personal norms (what the interviewee would do themselves) and descriptive norms (what they think others in the community would do).

6.3.5 Reasons for responses

Instrumental reasons

Instrumental reasons appeared to be the most prominent factors for changing (or not changing) behaviour, mentioned by nearly all interviewees across all scenarios (n=16/17, Figure 6.4). The livelihood dependence on sharks was challenging to discern. When responding to the ban scenario, several fishers stated limited dependence on sharks for their living (n=7) and were hence willing to comply. According to these fishers, halting shark fishing would not cause a major loss for themselves and other shark fishers as they had other forms of income (from other fish as well as tourism). However, some (n=5) emphasised the importance of sharks to their income and livelihoods and would be negatively impacted by changing behaviour for any scenario. A few fishers (n=4) stated that while these measures would not impact on *their own* earnings, they would impact *other fishers* who depended on sharks. Furthermore, some fishers suggested that income from sharks was used to invest into gear and boats for the subsequent fishing season, or even to pay off loans, hence they were unwilling to change behaviour. Fisher F01 explained: "*With this [mackerel, pomfret, other fish], we fishers can manage – our stomach can be filled. And our workers, their household expenses can be met. But after these expenses, there's nothing left. That's why we like the shark fishing. In 10 days, we can easily get upto Rs.*

60,000 of savings after expenses are removed. This much savings we can't get from other fishing…. we can buy new nets for the next season".

For the PES scenario specifically, the buyout of the net was highlighted as a main barrier to behaviour change (n=8). The nets cost up to Rs 1,50,000 ($1718 USD), and if not used for shark fishing, could be modified and used for other species such as crabs. Hence fishers would be unwilling to give their net up in this scenario, and also felt that the payment amount offered was too low. However, some of these fishers (n=4) would be willing to take up this intervention under the conditions that the payment amount was significantly increased, some payment was given to crew members as well, and they could keep the net. Only one interviewed shark fisher (F06, who was planning to exit the fishery) found the amount satisfactory and would potentially return the net as well. For the cooperative scenario, instrumental reasons for behaviour change included getting a good and reliable rate for shark sale (n=5). Positive impacts for shark populations, and hence for the fishers themselves, was also stated as a reason for behaviour change, particularly in response to the ban (n=2).

Institutional

Institutional factors emerged as an important theme in mediating fishers' response to the scenarios (Figure 6.4, Table 6.2). This was largely related to the regulatory nature of a scenario, with many fishers stating compliance and behaviour change if an intervention was mandatory and imposed by the government or local fisheries department (n=14/17), or even enforced or promoted by the *Pagi Samaj*, the local fishing institution (n=3). Hence, institutional factors were key reasons for reported compliance with the ban scenario. Some fishers further explained that they would comply with the ban if enforcement was strict and regular (n=5). However, other interviewees perceived that the state government was corrupt or ineffective and would not be able to enforce measures like the ban, making them unwilling to change behaviour (n=3). Fishers also brought up existing wildlife laws, such as the protection of dolphins, turtles or other shark species that prohibited them from being fished, making these fishers reluctant to give up shark fishing as well (n=6).

Practical

Practical reasons were cited by all participants for not changing behaviour (n=17), but were primarily mentioned for cage culture (n=13, Figure 6.4). For this scenario, interviewees perceived practical barriers such as the time-consuming and longer-term nature of this activity (n=6), requiring too much effort (n=4), the habitats in the study sites were unsuitable for an activity like cage culture due to the presence of rivers (n=5), and interference of the cages in fishing activities (n=4).

Practical reasons also emerged as a barrier for the cooperative fishing, which largely centred on uncertainty around how this cooperative would work (n=5), including unpredictability of shark fishing and lack of similar mechanisms in the region at present. For the PES, fishers raised concerns that such an intervention could be misused by non-shark fishers attempting to avail themselves of this scheme, and hence this measure would not work (n=4). For the other scenarios, practical barriers to behaviour change were largely around the perception that this scenario would not work in the local context: For example, some fishers believed the social disincentive scenario was unlikely to occur as shark fishing could make a fisher more popular and well-known, and that as locals enjoy consuming sharks, it was unlikely that they would condemn shark fishing (n=2).

A few practical factors were stated in favour of the scenarios and reasons for behaviour change (n=7 across all scenarios, Table 6.2). This included the risky and dangerous nature of the fishery, which motivated some fishers to give up shark fishing in response to the ban (n=3) and the PES (n=1). For the cooperative fishing, some interviewees mentioned the lack of access to markets and hence would be willing to change their behaviour in response to this scenario as it would make trade easier (n=2).

Social

Perceptions that other fishers would continue shark fishing even if the interviewee stopped were highlighted as a barrier to behaviour change by many interviewees for nearly all scenarios (n=7/17, Figure 6.4). Such a situation was considered to be unfair by these interviewees. However, this same factor also served as a reason for compliance with the ban scenario, as several fishers (n=5) stated that such a measure would be equally imposed on everyone, and was hence 'fair'.

Some interviewees felt that the scenarios may incite anger in other fishers, who would prevent them from changing behaviour (n=4, Table 6.2). Influence of family and household was also stated, where one fisher (F04) suggested that if he halted shark fishing in response to the social incentive, his family and household would not allow it, seeing others continuing to make money from shark fishing. However, another stated that influence of his wife and family were reasons that he had not gone shark fishing in recent years, due to the risky nature, and was planning to exit the fishery (F12).

6.3.6 Other interventions suggested

"*LED fishing is illegal. That should be stopped and banned. Then the fish will grow on its own. That should be stopped*" – Fisher F14

A few fishers suggested other interventions or measures that could be implemented to conserve sharks, or to increase compliance with the proposed scenarios. This included a complete and effective ban on LED fishing (an illegal fishing technique where mechanized vessels use strong LEDs, i.e. light-emitting diodes, to attract and capture large volumes of fish) and other destructive fishing practices in order to let sharks and other fish populations grow (n=5). Fishers also suggested releasing gravid sharks and pups live (n=1), captive breeding of sharks to increase their populations (n=1) and banning small mesh-sized nets (n=1). One fisher (F01) suggested that if subsidies for small-scale fishers were reinstated, they would be happy to comply with shark conservation measures. In contrast, another (F12) stated that the government should stop providing subsidies and enforce complete seasonal fishing bans across all gear types in order to let fish populations recover.

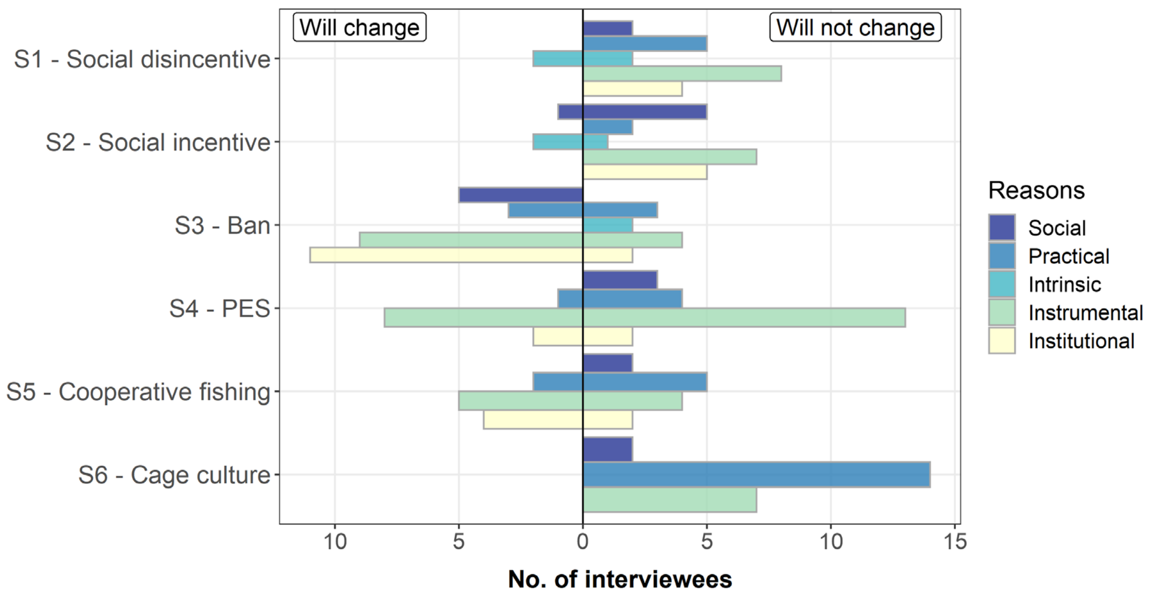

Figure 6.4: Reasons or conditions for changing or not changing behaviour for each scenario, categorised as instrumental, intrinsic, institutional, practical and social reasons (also see Table 6.2).

Table 6.2: Response of interviewed shark fishers (personal norms, n=17) to each scenario. Reasons or conditions for changing or not changing behaviour, categorised as instrumental, intrinsic, institutional, practical and social, are given for each scenario along with examples of each reason and illustrative quotes.

Scenarios	Will/May change behaviour			Will not change behaviour		
	N*	Reasons or conditions for change	Illustrative quote	N	Reasons for not changing	Illustrative quote
S1 Social disincentive	2/0	**Intrinsic** (personal values, planning to exit the fishery, n=2)	"If this happens, I will feel a bit bad, a bit emotional. Men like me, they might think about it, and think "*okay let it be*". Since everyone is feeling bad about it, they will stop fishing." **F01**	11	**Instrumental** (e.g., high value of sharks, n=8) **Institutional** (Other species were banned, n=4) **Practical** (e.g., This scenario will not occur, n=5) **Social** (e.g., other fishers would keep fishing, n=2) **Intrinsic** (personal values, n=2)	"We are all fishermen, if we start doing this [not catching species because of people's perceptions] with all fish like sharks, kingfish and so on, our business will go down." **F05**
S2 Social Incentive	2/1	**Intrinsic** (planning to exit the fishery, n=2) **Social** (will participate only if all other fishers participate, n=1)	"Back in 1998, I had initiated something like this for turtles. I caught a turtle which would have fetched Rs. 800 but I let it go. I received recognition for this. I continued to help the forest officers in protecting the turtle nests. I did it because I cared. Even for sharks, only people with big hearts and true love for ocean and fish will do this." **F12**	12	**Instrumental** (e.g., high value of sharks, impact on livelihoods, n=7) **Institutional** (e.g., voluntary measures would not work, n=5) **Practical** (This scenario will not occur, n=2) **Social** (e.g., other fishers would keep fishing, n=5) **Intrinsic** (personal values, n=1)	"I might agree and stop fishing for sharks but my family and people at home will send me to catch them because they will see others making money from it." **F04**

S3 Financial disincentive (ban)	2/1	**Institutional** (e.g., mandatory measure, enforcement is strict, n=11) **Instrumental** (e.g., not dependent on sharks, n=7) **Social** (fair and equal on everyone, n=5) **Practical** (e.g., shark fishing is risky, n=3)	"Shark fishing with this net started only 10-12 years ago. So people are not so dependent on it, and they will be fine…. If the government bans it, and catches people, cancels their license, then it will work and people will comply. They may curse the government for a few days, but then they'll be fine. It won't really be a big loss for anyone." **F10** "If there is a ban from the government, it is applicable for everyone, for all it is the same. If ban is imposed for all then it is okay." **F08**	5	**Instrumental** (e.g., impact on livelihoods, n=4) **Practical** (such a measure will not occur, n=2) **Intrinsic** (personal values, n=2)	"A ban would have a major impact on people who completely depend on shark fishing for their income and would be unfair for them. I have other nets, I catch other fish, so catching sharks is not my only way of earning." **F02** "It can't be banned. We get crew from outside to come here and fish, what will happen to them? No, it can't be banned, we won't allow it. No one will comply!" **F07**
S4 Financial incentive (PES)	1/7	**Instrumental** (e.g., if they don't have to return the nets, if the payment amount was higher, n=8) **Institutional** (if it was mandatory, n=2) **Practical** (shark fishing is risky, n=1)	"The amount is fine – Rs. 20000. Because we're getting money for just sitting at home and not doing anything, which is okay!" **F06**	8	**Instrumental** (e.g., payment amount too low, will not return the net, n=11) **Practical** (e.g., non-shark fishers will misuse this, n=4) **Social** (e.g., other fishers would keep fishing, n=3) **Institutional** (e.g., voluntary measures would not work, n=2)	"It costs up to Rs. 1,00,000 to make a shark net. Rs. 20,000 as compensation is nothing!" **F03**
S5 Cooperative fishing	1/6	**Instrumental** (e.g., getting a good rate for sharks, n=5) **Institutional** (e.g., will work if mandatory and	"This one is good, it could work. We can still catch sharks, and their populations will be protected… It will be better than a full ban" **F10**	5	**Practical** (e.g., uncertainty about how this will work, n=5) **Instrumental** (e.g., will reduce their earnings, n=4)	"Something like this has not been done here before, how would it work? And why would someone who can make *crores* [millions] out of shark

		established by the government, n=4) **Practical** (selling sharks will be easier, n=2)	“If they buy the fish from us and give us good prices, then this can work. It’s hard to sell fish here [in Saleri], there are very few buyers.” **F15**		**Social** (e.g., other fishers would keep fishing, n=2)	fishing agree to participate?” **F13** “This won’t work. No one will listen to anyone. When someone gets good catch and I tell them don’t fish for more than five days, they will give me 2 slaps and go fishing. No one will listen.” **F04**
S6 Cage culture	0/1	-	“I have heard about this – it’s been successful in some places in Goa. It was a good scheme, but it takes a long time” **F15**	13	**Practical** (e.g., time-consuming, too much work, n=13) **Instrumental** (e.g., not profitable, risky, not everyday money, fish tastes bad, n=11) **Social** (e.g., conflict with local fishers, n=2)	“It is not a profitable source of income as we can’t install the cage in our village due to rough sea. It also involves a high cost and can have a poor outcome. It’s done in some parts of North Goa. But I am not interested in it and would continue fishing for sharks” **F02**

*The sample size is presented as: will change behaviour/may change behaviour. That is, N of ‘2/4’ indicates that two interviewees stated that they *will* change their behaviour, while 4 stated that they *may* change.

6.4 Discussion

Our study investigated the drivers of a targeted, seasonal SSF for threatened sharks in Canacona, Goa, and explored interventions for conservation or sustainable fishing of these species through scenario interviews. We found that shark fishing was driven mainly by instrumental motivations, and enabled primarily by access to capital, labour and social identity. A ban emerged as the most effective intervention for delivering conservation outcomes, with the highest levels of reported behaviour change amongst fishers, while social nudges and cage culture interventions are likely to be relatively ineffective. Instrumental and institutional factors meditated response of fishers to the scenarios. Based on these findings, we discuss plausible next steps for shark sustainability in Goa.

6.4.1 Motivations for shark fishing

Instrumental motivations, centred around the high value of and demand for sharks, emerged as the primary driver for shark fishing in Canacona. This demand is fuelled not only by traditional consumption of shark meat but also by the growing market for shark dishes in restaurants catering to international tourists in Goa (Karnad et al., 2024b; Chapter 4). Among the species, blacktip sharks are particularly sought after, commanding higher prices and greater demand compared to others, such as hammerheads (*Sphyrna spp.*, Chapter 4).

Assessing the significance of sharks to fishers' livelihoods and income proved complex. Although interviews initially featured statements such as "*this is our livelihood*" and "*this is how we fill our stomachs*," many fishers later revealed a limited reliance on shark fishing. Given that this is a relatively new and highly seasonal fishery, and considering that all interviewees conduct other forms of fishing, with many also engaged in tourism-related businesses, it seems that most fishers' livelihoods could be sustained without shark fishing.

However, as interviewees noted, shark fishing remains one of the few opportunities for fishers to earn substantial profits in a short period, providing them with savings that help advance their livelihood strategies. Dorward et al. (2009) suggest that people not only aim to maintain their current well-being ("Hanging in") but also seek to improve it by expanding their existing activities ("Stepping up") and/or moving into new activities ("Stepping out"). This perspective resonates with our findings regarding shark fishers in Goa, many of whom appear to use the additional income from shark fishing to expand their fishing activities, invest in new gear, pay off loans (i.e., Stepping up), or even invest in tourism and other ventures (Stepping out). Such strategies are often employed by individuals seeking to move away from poverty (Dorward et al., 2009). Therefore, the importance of shark fishing to these fishers' total economic wellbeing should not be underestimated.

Several studies have identified non-instrumental drivers behind the fishing and trade of sharks and related species, including social norms, cultural influences, and even fear of sharks (Booth et al., 2019; Glaus et al., 2018; Skubel et al., 2019). In this study, we observed similar motivations, where social norms, community influence and intrinsic enjoyment play a role in encouraging shark fishing. Participant observation also revealed community-level motivations: on days with a good shark catch, fishers often share their catch with other community members, creating a sense of excitement and enjoyment in the village. This communal participation and motivation for shark fishing were not anticipated in our Theory of Change and suggest that scenarios like the social disincentive would be unlikely to play out in reality. These non-instrumental motivations need to be better understood and integrated into the design of interventions. Nonetheless, it remains evident that instrumental reasons—primarily financial incentives—are the dominant drivers of this shark fishery, as reflected in the responses to our scenario interviews.

6.4.2 Response to scenarios

Contrary to our expectations, the financial disincentive scenario (the ban) elicited the highest levels of reported behaviour change amongst interviewed fishers. The regulatory scenarios outperformed nudges, and disincentives (at least the ban) performed better than positive incentives. These unexpected findings can be understood by drawing on various theories and literature, and contextualising our results within our original Theory of Change.

Given that the shark fishery appears to be primarily instrumentally driven, the higher behaviour change reported in response to regulatory scenarios likely stems from their inclusion of financial or in-kind incentives or disincentives, unlike the nudges that focused on social (dis)incentives. Institutional factors also played an important role in explaining the preference for regulatory scenarios, as interviews revealed that voluntary measures were seen as unlikely to be effective, and the mandatory nature of the ban was a key factor in securing compliance. This could be explained by cognitive biases, which are factors that influence the conscious and unconscious decisions people make (Cinner, 2018). For instance, status quo bias suggests that if people are asked to opt in to a conservation program voluntarily, as with most scenarios, they are unlikely to do so, even if they recognize its value (Byerly et al., 2018; Cinner, 2018).

The low behaviour change reported for voluntary measures was also linked to social factors. Fishers were often unwilling to alter their behaviour because they believed others in the community would continue shark fishing. Being mandatory, the ban was perceived as 'fair' since it applied equally to everyone. This highlights the critical role of social norms, where individuals are reluctant to adopt a behaviour if it goes against the norm. This can also be seen in the correlation between people's personal and descriptive norms, suggesting that if a particular behaviour becomes normative, people are likely to adopt it, even when it may be against their best interests (Nyborg et al., 2016). Although some of our scenarios aimed to make shark fishing undesirable and against the norm (as depicted in Figure 6.1), it seems unlikely that they would achieve this outcome, except for the ban. Therefore, alternative strategies that can effectively leverage social norms should be explored.

Although interviewees' personal and descriptive norms were generally correlated, we also found that descriptive norms were more negative than personal norms on the whole (Figure 6.4). Two interviewees reported behaviour change as their personal norms for specific scenarios, but perceived that others in the community would not change behaviour; furthermore, some interviewees did not provide responses for personal norms but suggested non-compliance in their descriptive norms. This trend has been described as 'pluralistic ignorance' in social norms literature, where individuals misperceive the behaviour of others (Miller & McFarland, 1987). Pluralistic ignorance has been documented in the context of fisheries and illegal behaviour, where fishers' incorrect perceptions of the non-compliance of their peers can lead them to become non-compliant themselves (Bergseth & Roscher, 2018; Bova et al., 2017; Hatcher et al., 2000). In our study, fishers believed their peers were less likely to change behaviour as compared to themselves, which hindered their own response and behaviour change even for scenarios they perceived were beneficial.

Conversely, the more negative descriptive norms could also be explained through social desirability bias, where participants tend to provide responses they believe are 'correct' or may please the researcher (Fisher, 1993; Nuno & St. John, 2015). Given our study methods and potentially sensitive topics, we acknowledge the possibility of this bias in our study. However, responses about descriptive norms may be less prone to social desirability bias, serving as a form of indirect questioning. Hence, responses concerning descriptive norms may be a more accurate reflection of the interviewees' opinions and potential behaviours. While the descriptive norms data were relatively negative for most scenarios (indicating low participation), the ban once again had the highest likelihood of behaviour change.

Cognitive biases can also explain the higher reported behaviour change with the ban as compared to the PES. People have a strong tendency to avoid making difficult decisions and are prone to accepting the default option, even when it is not in their best interest (Cinner, 2018). When faced with making decisions, people prefer simpler, more intuitive choices, as humans have limited cognitive resources for processing information (Reddy et al., 2017; Tversky & Kahneman, 1974). Although the ban could result in financial losses, it was relatively simple, familiar, intuitive and mandatory – removing the burden of complex decision-making. Furthermore, some economic literature suggests that people can simultaneously benefit from access to a service or activity, while also benefiting from its elimination, if only this could be done (Sunstein, 2023). For example, Bursztyn et al. (2023) found that people demanded compensation if asked to deactivate their social media accounts but would also be willing to pay to have all of the world, including themselves, deactivate from the same platforms. Similarly, while fishers benefit from the shark fishery and demanded substantial payments to voluntarily give it up (as seen in the PES scenario), they were more accepting of a ban that would 'eliminate' the fishery altogether, if it applied equally to everyone. This suggests that the mandatory nature of the ban made it more tolerable because it removed individual decision-making and ensured collective compliance.

Of the sustainable livelihood scenarios that our study considered, the cooperative fishing showed mixed responses with practical reasons forming the main barrier for interviewed fishers. This scenario may have the potential for further development, to design a more feasible shark fishing cooperative using existing local institutions. We introduced it following feedback during the pilot phases, but design of cooperatives such as this requires substantial engagement from the potential members. However, our results indicate that fishers may be unlikely to participate in a complex cooperative fishing structure, in line with the cognitive biases discussed earlier. This suggests that within the context of our case study, devising some form of regulated and sustainable shark fishing could be challenging or unfeasible. A complete exit of the fishery through whatever combination of (dis)incentives may be the only option.

Furthermore, it is evident that cage culture as an alternative income source is not viable or preferable in this region, primarily due to perceptions of time and effort cost. Cage culturing (in both marine and freshwater systems) is currently under development and promotion by the Central Indian government (through the *PMMSY* scheme; Department of Fisheries, 2022; ICSF, 2020) to improve food production and local livelihoods. In Goa, this activity is being touted as successful and popular, even among traditional fishing communities - which is not supported by our findings. This scheme has received criticism particularly from traditional fishing communities and groups in the country (e.g. The Mooknayak, 2024). Alternative livelihood options must align with the needs and aspirations of the people concerned and fulfil the same range of functions as the original activity (Wright et al., 2016). Hence, state-driven efforts to provide alternative and supplementary livelihoods to fishers need to take this into consideration; a more diverse and desirable range of strategies could ideally be co-developed with fishing communities.

6.4.3 Other leverage points in the system

While our primary focus was on the 6 conservation scenarios, our study provided a more comprehensive understanding of the broader social-ecological system. We identified additional levers within this system that could be utilized to either increase behaviour change within the proposed scenarios, or to provide other incentives to reduce shark fishing. A major leverage point that emerged through our study was the prevalence of LED and other destructive fishing methods. Despite being banned in several states including Goa, LED fishing persists illegally (ICSF, 2019; Times of India, 2024). These fisheries, operated by fishers from other parts of Goa and India, were perceived as major threats to fish populations, and consequently local livelihoods in Canacona. Interviewees suggested that it would be ineffective and unjust to impose regulations on small-scale fishers while such destructive practices are rampant. LED fishing and related practices represent a complex socio-political challenge in this region. Although beyond the scope of the present study, addressing this issue could have direct benefits for marine ecosystems, as well as improve livelihood outcomes for SSFs and encourage them to adopt more sustainable practices and pro-conservation behaviour.

Access to labour emerged as a crucial enabler for this fishery, especially the reliance on crew members from the neighbouring region of Karwar. Limiting access to this labour pool could thus be an effective strategy. Our research indicates that fishers from Karwar have high dependence on fishing for their livelihood with limited alternative income options, unlike their Goan counterparts. Providing incentives such as alternative income sources (through fishing or non-fishing activities) during the shark fishing season could reduce the participation of Karwar fishers in this fishery, particularly given its risky nature.

The inherently risky and dangerous nature of shark fishing was identified as the main barrier and deterrent for many fishers in Canacona. However, for those who do engage in shark fishing, the risks seem to be offset by the high potential rewards, which is also incentivising new fishers to join the fishery every year. Such risk-taking behaviours in fisheries are often linked to poor fisheries management and market failures, which can create a misalignment of economic incentives, exacerbating the risks associated with commercial fishing (Pfeiffer & Gratz, 2016). Although previous research has suggested that this shark fishery is more supply-driven than demand-driven (Chapter 4), engaging with the market and consumers to reduce demand and prices for shark products could help diminish the extrinsic financial incentives for fishers to take on such risks, thereby supporting the exit from this fishery (Holden et al., 2019). Additionally, the hazardous nature of shark fishing and concerns for fisher safety could be strategically emphasized when designing, communicating, and disseminating interventions aimed at this fishery.

Risk was also involved in women's relationship with shark fishing, as several interviewed fisherwomen expressed concern over the men in their household participating in this fishery. Influence of family and women was stated to be the main reason a fisher (F12) exited the shark fishery. Our informal interviews suggested that, beyond their significant contributions to post-harvest activities such as fish trade, women played a role in decision-making regarding the participation in or compliance with external schemes or interventions, and can hence serve as a crucial lever. Despite playing vital roles in fisheries, trade and resource management, women have been historically overlooked by research and management efforts globally (Mangubhai & Lawless, 2021). Local women are often neglected in the design and implementation of conservation or sustainability interventions (Goldman et al., 2021; James et al., 2023). This gender inequality is not only unethical, particularly as women are disproportionately impacted by environmental degradation, but it also diminishes the efficacy of such measures (James et al., 2023). Improvements in local natural resource governance and in conservation outcomes have been documented when women participated in the management of the resources (Agarwal, 2009; Leisher et al., 2016). While our study included women in the community more informally, we did not explicitly investigate the role of women in shark fishing, and fishing more broadly. Addressing this gap is a top priority for future research and conservation.

Our study uncovered several misconceptions or misperceptions held by shark fishers about this fishery. Many fishers believed that shark populations were stable, despite evidence to the contrary from both other fishers and existing literature (Mohamed & Shettigar, 2016; Chapter 5). Some fishers perceived that others in the community were heavily dependent on sharks for their livelihoods, even when they themselves were not, although our findings provide little evidence to support this belief. We also identified instances of pluralistic ignorance, where fishers perceived that non-compliance was more common among their peers than it actually was. Research indicates that simply providing information and increasing knowledge among a target group does not necessarily lead to behaviour change (Reddy et al., 2017; Heberlein, 2012). However, addressing these misperceptions and providing accurate information - such as the threatened status of sharks - can help shift attitudes, which can ultimately support behaviour change (Ajzen, 1991). Communicating accurate social norms and correcting pluralistic ignorance can encourage more sustainable, normative behaviours (Cinner et al., 2018; Bova et al., 2017).

6.4.4 Ways forward

Although evidence from a sample of shark fishers indicated that a ban may be the most effective conservation measure, the design and implementation of such an intervention needs careful consideration. While blanket bans are common in species conservation, they often lead to marginalisation of local communities, low compliance and ultimately, poor biodiversity outcomes (Castellanos-Galindo & Booth, 2021; Collins et al., 2020; Cooney & Jepson, 2006). There are also some important caveats to our findings. Scenario interviews may not always accurately predict people's actual behaviour (Travers et al., 2019), and while our sample represents nearly half of the shark fisher population in Canacona, it may not be sufficient to create equitable solutions for all fishers. Additionally, while a ban may be perceived as fair because it applies to everyone equally, its consequences could disproportionately affect certain individuals and groups.

Nonetheless, our research does suggest that sustainably-managed shark fishing may be unfeasible at this site, and a complete exit from this fishery may be the way forward. Examples from other regions show that combining top-down state policies with community-based initiatives can be effective in some circumstances, such as in the conservation of Amur falcons in Northeast India (Kudalkar & Verissimo, 2024) and local fisheries management in Southeast India (Bavinck, 2003). As noted by Berkes (2004, p. 626), community-based conservation should ideally have "as much local solution as possible and only so much government regulation as necessary." In Canacona, an intervention could take the form of community-based agreements to exit this fishery, through local institutions such as the *Pagi Samaj*, which could be supported through regulation and enforcement from the state. The relatively nascent nature of the fishery and the low apparent livelihood dependence on sharks suggest that this approach may be feasible if appropriately implemented. Such interventions should aim to deliver individual and community-level benefits to encourage compliance and offset any negative livelihood impacts (Booth et al., 2023b).

Leveraging enablers and barriers, such as access to crew and the risky nature, can also promote behaviour change. Participatory approaches could further help legitimise these interventions, as rules and enforcement can generally be effective when they are perceived as socially legitimate (Oyanedel et al., 2020b). These steps are important given the negative attitudes held by fishing communities in Goa towards shark conservation (Gupta et al., 2023; Chapter 3). We also note that consultation with shark fishers and the broader community in the design of these scenarios, which was not done in our study, may have led to more effective and appropriate interventions being developed (Brittain, 2021). Ultimately, there is a need for further researcher and deeper engagement with the fishing community to explore feasible conservation models before any policy or action is implemented.

Findings from our study went against our initial hypotheses; it is unusual to find local communities showing higher reported compliance, and even preference, for a ban and financial disincentive over incentives. Our results underscore the complexity of human behaviour, and the potential pitfalls of conservation interventions implemented based on untested behavioural assumptions. We highlight the value and usefulness of predictive approaches like scenario interviews that enabled us to uncover these unexpected findings in a cost-effective manner. These findings not only suggest a viable pathway for shark conservation in Goa but also demonstrate the broader applicability of our methods. By exploring and testing behaviour change interventions directly with local communities, our work offers a valuable model for species conservation efforts. This approach can be widely applied to other conservation challenges, ensuring that interventions are both effective and aligned with local needs and realities.

Chapter 7

Discussion

A fisher voluntarily releasing a widenose guitarfish back into the water in Goa

7.1 Key research findings

My thesis made advances towards a better understanding of how the sustainability of elasmobranch fisheries can be improved in coastal, Global South fisheries. My first research question aimed to identify the gaps and limitations in existing knowledge. My scoping review (Chapter 2) found that most research on sharks and rays in India has limited relevance to their conservation. I identified regions and species that have been overlooked, and critical research themes such as the socio-economic and human dimensions that need to be prioritised. My remaining chapters attempted to address some of these gaps, focusing on some overlooked species (like rhino rays) and regions (Goa and Kakinada), and particularly on understanding the human dimensions of elasmobranchs in India.

My second research question explored what drives and motivates people to catch and trade elasmobranchs, especially within the context of multi-species coastal fisheries like those in India. I further aimed to characterise the underlying mechanisms that enabled or facilitated people's behaviour. This question was addressed across Chapters 3, 4, and 6. I explored people's fishing and trading motivations across the spectrum of elasmobranch catch, from low-value, incidentally caught rhino rays, to opportunistically caught sharks in Kakinada, to targeted juvenile blacktip sharks in South Goa. Instrumental benefits (i.e. for economic gain) were the primary motivations for most shark fisheries across the study sites. Use for food and subsistence also emerged as a driver, along with cultural and traditional reasons to fish or trade sharks, as seen in Kakinada. Although rhino rays were caught entirely as bycatch in Goa, I recorded a range of relational values underpinning people's interactions with these species. Using the theory of access, I identified several access mechanisms used by fishers and traders to benefit from elasmobranchs. This included access to capital, social identity, knowledge and information. Hence, my research highlighted the diverse range of motivations, values and access mechanisms underpinning elasmobranch fishing and trade in India, across different species and contexts.

Given my broader goal that focused on sustainability, my next research question attempted to understand the sustainability of elasmobranch fishing at my case study site in Goa (Chapter 5). I combined data from multiple sources, including expert elicitation interviews with shark fishers, to conduct a preliminary assessment of shark fishing sustainability. Using a 'what-if' exploratory population model, I investigated conditions under which this targeted seasonal harvest of juvenile blacktip sharks may be ecologically sustainable. This analysis revealed that harvest needs to be reduced to at least half the present rate, and the current shark population should be high, for this fishery to be sustainable – highlighting the urgent need for management intervention at this site. This study also demonstrated promising methods to understand sustainability in extremely data-limited contexts.

My final research question focused on behaviour change interventions for elasmobranch conservation and sustainability. I identified leverage points for interventions within the social-ecological system, across the supply chain (Chapter 4) as well as within the broader fishing community (Chapter 6). I explored conservation strategies for different elasmobranchs across the spectrum of catch, from low-value incidental catch (rhino rays, Chapter 3) to high-value targeted sharks (blacktip sharks, Chapter 6). Voluntary live release measures appeared to be the most promising strategy for rhino rays in Goa. In contrast, a mandatory exit from the shark fishery, co-developed with the local community, may be the only option for blacktip sharks.

Hence, through these case studies, my thesis research provided important insights on the conservation and sustainable management of elasmobranchs in coastal fisheries, drawing insights from specific sites, but also providing lessons and methods that are more broadly applicable.

7.2 Cross-cutting themes

Several common thematic patterns emerged throughout the data chapters of my thesis, which have relevance across and beyond my study sites and species. Here I discuss some of these themes and their broader implications for conservation science and practice.

7.2.1 Multidimensional importance of elasmobranchs

It is increasingly being recognised that people use or interact with biodiversity for a diversity of reasons, beyond economic gain (Chan et al., 2016; Perino et al., 2022; Thomas-Walters et al., 2021). My thesis explored a range of cognitive dimensions underpinning people's use of elasmobranchs, such as motivations driving fishing and trade (Chapters 4, 6), relational values (Chapter 3), attitudes (Chapter 3) and social norms (Chapter 6). My chapters show how these dimensions, especially motivations and values, can influence the effectiveness of conservation interventions, which I will synthesise and discuss in this section.

My work revealed a low economic importance of rhino rays in places like Goa (Chapter 3) – where they were entirely bycaught, and infrequently sold, consumed or even discarded when small. However, I also documented numerous relational values expressed for these species, including non-fishing experiences and interactions. This combination of motivations and values may have produced the pro-conservation attitudes that my study documented. Harnessing these existing pro-conservation values and attitudes could produce voluntary behaviour change. For example, fishers would be willing to participate in rhino ray conservation, particularly live release. In contrast, for sharks in Canacona, Goa, the higher economic value, frequent consumption, and non-instrumental (i.e. cultural enjoyment) motivations related to shark fishing, and negative shark conservation attitudes, suggested that voluntary initiatives would not work (Chapters 3 and 6). Interviewed fishers perceived that a mandatory shark ban could be the most effective strategy. Hence, suitable strategies in each of these contexts are strongly linked to the motivations and values underpinning people's relationship with the species (Carmenta et al., 2023b; Perino et al., 2022). For example, people's motivations and values regarding biodiversity can 'crowd in' or crowd out' the desired conservation behaviour, and hence determine the effectiveness of voluntary or mandatory interventions – as seen in my research (Cinner et al., 2021; Zhang & Khachatryan, 2023).

Within social-ecological systems, people tend to develop multifaceted relationships with the environment, which can strongly influence their views as to how natural resources should be used and managed (Jones et al., 2019). These cognitive dimensions (i.e., the many ways in which people think about their environments, and the ways their thinking is influenced by those environments) deserve more attention in efforts to study sustainability and biodiversity conservation (Jones et al., 2019). As my research shows, these dimensions can play a role in determining what to conserve and where, what are acceptable ways of using and managing biodiversity, how to frame and negotiate trade-offs (Daw et al., 2015), and ultimately how to shape effective and socially meaningful biodiversity conservation interventions (Klebl et al., 2024). Multiple studies and real-world examples show how harnessing existing value systems and attitudes about nature or the environment can be successful in bringing about behaviour change (Heberlein, 2012; Pascual et al., 2023; Sponarski et al., 2014).

Diverse cognitions also emerged in the different perceptions of elasmobranchs between fishing community members and scientists. As western-trained conservation scientists, my research team and I would perceive elasmobranchs differently from other marine fish and see them as species that are charismatic, threatened, and in need of conservation. However, throughout my research chapters and fieldwork, it became apparent that to most fishers, elasmobranchs were not specifically unique within the multiple fish species that they caught on a daily basis. While interviewees did express particular motivations or values underpinning their harvest and trade of elasmobranchs, these species were still viewed as *'just another fish*'. Hence, significant differences can exist in the value systems of researchers and the communities they work with, yet conservation is often framed by externally defined values rather than those of the community (Newing et al., 2024; Pascual et al., 2023). This emphasises the importance of incorporating plurality of values, positionality and reflexivity into conservation science (Kaechele et al., 2024; Pienkowski et al., 2023). Acknowledging my positionality at the start of my DPhil helped reconcile some of these inherent biases.

Elasmobranchs represent a good example of how wildlife can mean and contribute multiple things to different people (Skubel et al., 2019). The diverse cognitive dimensions of wildlife are gaining attention and momentum in the field – for example, the IPBES conceptual framework aspires to account for the diversity of human values about nature in order to support policy formulation and implementation (Díaz et al., 2015). However, practical uptake and integration of these concepts within conservation remain a challenge (Pascual et al., 2023). This requires interdisciplinary thinking across fields such as psychology, economics and others, as well as more participatory approaches, which I discuss in section 7.3.

7.2.2 The role of structural interventions for sustainability

For sustainable management of sharks and rays, different combinations of interventions and policies have been conventionally applied on fisheries and trade. For instance, Shiffman & Hammerschlag (2016) categorise shark conservation policies into two types: target-based policies, which focus on sustainable exploitation of some species (e.g., catch quotas, gear restrictions), and limit-based policies, which include conservation measures that ban certain types of exploitation entirely (e.g., fin trade bans, MPAs). These interventions use various incentives and disincentives to work directly with relevant actors to influence their behaviour in respect to catch and/or trade of elasmobranchs. However, my thesis highlights the importance of 'structural interventions' that indirectly influence behaviour by changing the context or social environment within which the behaviour is occurring (Baynham-Herd et al., 2018; Heberlein, 2012).

The decisions made by individual actors tend to be constrained by the structural or socio-economic context within which they exist (Duffy et al., 2016). According to the Theory of Planned Behaviour, perceived behavioural control (i.e. people's perception of the ease or difficulty of performing a behaviour; Ajzen, 1991) is a critical factor in fostering long-term behaviour change. This indicates that interventions that directly target individual actions are insufficient unless they also address the systemic drivers and constraints shaping those actions (Nielsen et al., 2021).

The need for such structural interventions is evident in my thesis. While my work focused on fishers and traders, and behaviour change interventions with them, I also considered the social-ecological system within which they operate. For example, by mapping access and benefit sharing, I identified the need to improve market access for fishers in Kakinada by provision of information, improved distribution of benefits, and other mechanisms (Chapter 4). This could strengthen the socio-economic conditions of these fishers, hence addressing some of the drivers of overexploitation to promote shark conservation.

In Goa, the prevalence of destructive and/or illegal fishing practices, particularly LED fishing emerged as a major systemic driver of (unsustainable) fishing behaviour among SSFs. LED fishing was undertaken by mechanised crafts with both Goan and non-Goan owners. This fishing was not practiced by the small-scale fishing communities I worked with, and it appeared to drive these SSFs to increase fishing efforts and adopt unsustainable practices themselves, like targeting sharks, not only due to their profitability but as a way to counter perceived losses caused by LED fishing. LED fishing and related practices are linked to issues around political power and corruption, forming complex socio-political challenge along parts of the west coast of India (including Goa, Herald Goa, 2024) where they have created conflicts with the livelihoods and equity of local fishing communities. Although addressing such fisheries was beyond the scope of my thesis, it is evident that tackling these problems can create important contextual changes that directly benefit both biodiversity and people, as well as potentially encouraging local fishers to adopt more sustainable practices over the long-term.

Hence, achieving broader sustainability goals requires looking beyond the target actors and behaviours - such as fishing, trade and consumption - and considering the larger context that shapes those behaviours. Intervening in the structural and systemic drivers, where appropriate, can help deliver socio-economic sustainability outcomes alongside ecological sustainability. Conceptualisation of elasmobranch fisheries as social-ecological systems with complex human dimensions is relatively rare, and structural and contextual actions have only been suggested by a few recent studies (e.g. Booth, 2021). Within the wider literature, however, structural interventions have shown success in behaviour change across the fields of conservation, environment and health, especially when combined with community-based efforts and achievement of socio-economic goals (e.g. poverty alleviation) (Blankenship et al., 2006;

Challender et al., 2015; Heberlein, 2012; Undurraga & Pokorny, 2024). A systems thinking approach, which is a way of thinking and understanding that considers the elements, interconnections, and function or goal of things (Mahajan et al., 2019), can play an important role here. Systems thinking can integrate the different components of an SES and understand their relationships, in order to identify the root cause of biodiversity challenges. Hence, systems thinking can support the design and implementation of crucial structural interventions required for behaviour change.

7.2.3 Issues of scale

The challenge of scale is well discussed in conservation, and one that I struggled with at the start of my DPhil. I contemplated the usefulness of conducting a broader study along the Indian coastline to increase the potential impact and applicability of my work, against the need for nuanced research at the local scale of fishing communities. My thesis ultimately looks across different spatial scales as well as scales of fisheries (large and small-scale), with a stronger focus on the local scale. I explored the national context of elasmobranch research (Chapter 2), looked at the regional/local scale of Goa (Chapters 3 and 4) and Kakinada (Chapter 4) across different types of fisheries, and finally at the local scale, focusing on SSFs in Canacona, Goa (Chapters 5 and 6). The local-scale studies provided an intricate understanding of elasmobranch fisheries that helped address my research questions at the next scale up. However, this research approach comes with limitations and trade-offs, which I discuss in this section.

Local-scale research and action, such as in my thesis, are invaluable within conservation for multiple reasons. There is a high diversity and variability within local communities and socio-economic contexts, even within the same country and region, as well as in species ecology and biology – particularly within an evolutionarily diverse group like elasmobranchs (Dulvy et al., 2021). Numerous studies suggest that one-size-fits-all approaches are ineffective in conservation, and the need for context-specific interventions has been well established (McClenachan et al., 2016; Ostrom, 2007; Salerno et al., 2021). My DPhil involved deep-dives at the local scale, where repeated engagement with the same communities helped build trust and gain valuable insights and data to devise contextually appropriate interventions. This would not have been possible with a shallower, large-scale study. Lessons emerging from this work can be transferred and adapted to other case studies exhibiting similar contexts. For example, Ostrom's (1990) work on the governance of commons built a comprehensive global framework from local case studies, suggesting that such granular research can have wider implications.

However, conducting highly nuanced and localised studies everywhere and devising a range of locally appropriate solutions for each place is simply not feasible. This is particularly the case in countries like India with its large size, high population of fishers (nearly 5 million; Department of Fisheries, 2022), socio-economic complexity and limitations of resource and capacity. Furthermore, structural interventions that aim to change the contextual factors driving the problem, as discussed above, likely need to be applied at a larger scale. Individual conservation projects, particularly ones conducted at specific local or regional scales, have limited ability to produce the scale of structural change needed for effective conservation impact (Duffy et al., 2016).

Such challenges of scale can be seen within my research. For instance, regarding the targeted seasonal shark fishery in Canacona (Chapters 5 and 6), my models found that it was likely to be unsustainable, and the scenario interviews explored solutions towards sustainable fishing and conservation. While this localised evidence is important, this blacktip shark population is likely to be facing further mortality through incidental or opportunistic capture in neighbouring regions, which my research does not account for. In general, the smaller scale of my research may mean its potential for direct impact is limited, especially in the context of global targets such as the Sustainable Development Goals (SDGs) and the Global Biodiversity Framework (GBF), and bending the curve of biodiversity loss (Leclère et al., 2020; Pienkowski et al., 2024)

Ultimately, conservation science needs to consider the scale of the problem when studying and developing interventions. Effective action has to be applied at the spatiotemporal scale(s) at which the problem is generated, even if the immediate problem is perceived at a different scale (Du Toit, 2010). My research identified the predominance of local-scale supply-side drivers of shark fishing in Goa (and Kakinada, Chapter 4), hence justifying the scale of my subsequent research chapters. However, it is important that social-ecological systems are analysed at multiple scales – local, regional and multi-regional – especially in the context of fisheries with long, complex and often global supply chains (Mahajan et al., 2019; Oyanedel et al., 2021). Hence, as seen in Chapter 4, broader drivers of shark fishing such as the demand for fins and meat require larger-scale research and interventions at national or global levels. Furthermore, the scale of conservation action or policy needs to align not only with the scale of the drivers of the problem, but also with species ecology and the scale of the relevant institutions (Gangal et al., 2023).

The problem of scale remains an intractable one within conservation. Although this was not a main objective of my thesis, my work does highlight the importance of local-scale science and practice. Particularly for elasmobranchs and small-scale fisheries, research should be rooted at the level of the community (i.e. at the local scale). Frameworks and approaches are emerging that integrate local scale action with global drivers and goals. For instance, Obura et al. (2021) outline a shared earth framework that proposes ground-up action at the local level that works with diverse knowledge sources, local institutions and principles of equity to address multiple targets of the GBF concurrently. Carmenta et al. (2023a) propose the Connected Conservation model that combines actions to tackle distant wealth-related drivers of biodiversity loss with enhancing local level conservation to empower biodiversity stewards. Such approaches offer pathways to more effective, scalable conservation efforts grounded at the local scale.

7.2.4 Data limited contexts and making decisions under uncertainty

A recurring theme throughout my DPhil was conducting conservation science under conditions of data scarcity. Gaps in knowledge of threatened species pose one of the toughest challenges for global conservation efforts (Amano & Sutherland, 2013); interdisciplinary understanding of the human dimensions of biodiversity remains even more scarce (Detoeuf et al., *in review*). Data limitations are particularly prevalent in the Global South, due to limitations in resources and capacity, social and economic priorities of governments, and conflict between development and conservation objectives (Amano & Sutherland, 2013; Obura et al., 2021; Rodriguez et al., 2022; Sheil, 2002). In this section, I critically discuss approaches to collecting data and informing conservation decision-making under such contexts of scarcity and uncertainty, drawing from my thesis research.

My scoping literature review (Chapter 2) helped identify priorities for elasmobranch conservation research in India – some of which my other chapters attempted to address, largely through knowledge generated from local people. This included specific methods such as Local Ecological Knowledge (LEK, Chapter 3) and expert elicitation (Chapter 5). For rhino rays, a species group poorly studied in India, LEK was invaluable in building a foundation of knowledge that has informed further research and conservation in Goa. Furthermore, LEK was pivotal in notifying Galgibag beach, one of my study sites in Goa, as an Important Shark and Ray Area (ISRA; IUCN SSC, 2023). The ISRA assessment is a global effort to identify ecologically important areas for elasmobranchs (Kyne et al., 2023). My proposal for Galgibag beach as an ISRA due to the high presence of juvenile guitarfish, was based entirely on LEK, along with some preliminary ecological surveys. This proposal was accepted, illustrating the growing recognition and acceptance of these diverse forms of knowledge.

Diverse knowledge sources are particularly useful under uncertainty. Uncertainties are inevitable in ecology and conservation science, particularly within social-ecological systems (Milner-Gulland & Shea, 2017; Nuno et al., 2014). Uncertainty has been an underlying theme throughout my thesis, and I explicitly identify, categorise and prioritise uncertainties in elasmobranch supply chains across Goa and Kakinada (Chapter 4). Likewise in Chapter 5, exploratory population models for blacktip sharks helped guide management while acknowledging uncertainties. These approaches were useful in understanding the caveats and assumptions underpinning my findings and their interpretation, across these chapters. Furthermore, explicitly looking at uncertainties helped suggest and inform preliminary recommendations for decision-makers, while identifying priority areas for further research.

Therefore, the methods used in my thesis served as rapid, cost-effective, and inclusive approaches to filling data gaps. However, they are not without their limitations. Beyond the biases acknowledged in my data chapters, there are intrinsic challenges in generating knowledge (particularly quantitative data) from people and integrating this with conventional science. For instance, questions framed from a western science perspective are not easily understood by local communities due to the different ways of thinking. This was particularly the case with expert elicitation interviews (Chapter 5) where it was sometimes challenging to elicit catch estimates in the structured manner of upper bound, lower bound and best estimate. Other studies using this method with local communities have faced similar challenges (Arlidge et al., 2020; Brittain, 2019). In the data analysis process, LEK does not always fit into scientific frameworks, as I saw in Chapter 3 when comparing LEK with published scientific literature. These challenges make it clear that methods such as expert elicitation and even LEK interviews need careful adaptation to the local context and community (Brittain, 2019).

Another concern is the loss or erosion of relevant LEK from many communities globally (Aswani et al., 2018). Efforts and frameworks to better understand, conserve and integrate LEK and other knowledge systems into the scientific and management mainstream are growing (e.g. Calderwood et al., 2023; Cowie et al., 2020; Karnad, 2022; Tengö et al., 2017; Yanou et al., 2023). Lessons from my DPhil suggest the importance of diverse value systems and ways of thinking when working with LEK, and the need to bridge this knowledge with the scientific mainstream in a mutually respectful and collaborative manner (Newing et al., 2024; Díaz et al., 2015; Tengö et al., 2017).

My research underscores the need to rethink our conservation science efforts, particularly in the Global South, where the limited resources and capacity must be efficiently allocated towards applied research that can inform policy and on-ground action (Game et al., 2013; Cook et al., 2009). My thesis provides empirical evidence and examples of approaches to use in such contexts, and indicates the need to adapt conventional methods or develop new strategies that are more suitable. More broadly, there is a need to critically examine trade-offs between needing to collect more robust data and the urgent need for management intervention, in data-limited contexts (Johannes, 1998; McCook et al., 2009; Vaidyanathan et al., 2024). Making poor decisions due to insufficient data can harm both biodiversity and people, yet waiting for more data is impractical in the face of the mounting biodiversity crisis (e.g. Vincent et al., 2022). Alongside the use of alternative methods and people-generated knowledge to address data gaps, I also emphasise the need for improved decision-making with the data that are available. Robust decision science tools can be used to inform preliminary conservation and management strategies, as this thesis demonstrates, which can be strengthened through adaptive management as more data is collected (Johnson, 2011; Keith et al., 2011). Ultimately, these processes are context dependent, and local socio-economic considerations must be at the forefront of decision-making.

7.3 Ethics and implications for local communities

Biodiversity conservation is inherently about people. A guiding principle throughout my thesis was to align elasmobranch conservation outcomes with socio-economic outcomes, or at the very least, ensure that conservation does no harm to local livelihoods and well-being. Here, I discuss the implications of my research (both positive and negative) for the communities I worked with and reflect on the extent to which I was able to follow these principles.

The majority of my research focused on the case study of Goa, and I worked with the same fishing communities in Canacona, South Goa for my last two chapters (5 and 6). While sustained engagement with local communities is vital for conservation research, it may also have unintended negative effects, such as research fatigue (psychological and emotional exhaustion due to engaging with research that causes reluctance or refusal to engage further, Casal–Ribeiro et al., 2024). I interviewed the same small population of shark fishers across two chapters, using methods like expert elicitation and scenarios that can place a significant cognitive and time burden on people. I acknowledge the potential of research fatigue appearing in some of my participants during or after my study. I did my best to reduce this burden on people, by building relationships with different members of the community, respecting their time, participating in their daily activities, contributing to the local economy and following strict ethical practices. Development of trust can be seen in the honesty of some of my interview responses, for example where a fisher changed his answer through the expert elicitation interviews (Chapter 5). I hope that my fieldwork has left a positive legacy, improving community perceptions towards researchers and conservationists and encouraging open dialogue with future research and policymaking (Brittain et al., 2020).

When it comes to my research findings, aligning elasmobranch conservation with socio-economic goals remains challenging, particularly for blacktip sharks in Goa. Evidence suggests that a regulatory intervention (i.e. shark fishing ban) would be most effective (Chapter 6), yet this risks harming fisher livelihoods (at least in the short-term), and conflicts with the principles of doing no harm (Brittain et al., 2020). While I recommend community-based approaches in the development and implementation of such a ban (or 'exit' from the fishery), along with social and financial instruments to offset the negative consequences, these measures may ultimately not deliver meaningful socio-economic benefits to people. This case study illustrates the challenges in reconciling development with conservation in the Global South (Bawa et al., 2021; Loos, 2021). It is crucial that any action taken for shark fishing at this site is done after more research, community engagement and careful consideration of all these implications.

In Kakinada, on the other hand, my research did identify structural interventions such as improving market access and distribution of benefits to fishers, to enhance their livelihoods and facilitate pro-conservation behaviour. These measures will provide benefits for both fishing communities and shark populations, forming a more optimistic example of aligning conservation and socio-economic outcomes. However, these recommendations may negatively affect trader groups such as wholesalers, emphasising the complexity and heterogeneity of social-ecological systems and should be accounted for. For rhino rays in Goa, my recommendation of live release programmes likely has minimal negative economic impact on communities but may entail effort and opportunity costs for people. These costs could be balanced, at the very least, with social benefits from conservation, fostering values and attitudes that make participation in live release programmes intrinsically rewarding (e.g. as seen with live release of guitarfish in Brazil, Wosnick et al., 2020).

When considering the participatory nature of my work, although my research relied on social science methods which inherently involve some form of participation (Newing et al., 2024), local community involvement was limited to data collection. Much of my research process was top-down, with research questions driven by external interests rather than the communities and their priorities. According to Newing et al. (2024), good practice in participatory research does not necessarily require participation at every stage of each research project. This is unfeasible in many contexts, and also places a significant burden on local communities. Researchers must respect the rights of communities and engage early with them to determine what level of participation is realistic and appropriate at each step. When it comes to conservation of threatened species like elasmobranchs, study objectives often stem from researchers and do not necessarily align with local interests or priorities. However, this type of work, including my own DPhil, could be made more participatory, ethical and inclusive through actions like incorporating traditional worldviews in the study design, inclusion of local concerns, and feeding back of data and results (Chua et al., 2022; Newing et al., 2024; Tengö et al., 2017).

Another consideration is in the use of LEK and other forms of knowledge generated from local communities. Using LEK is often seen as a way to involve communities, but it can still be extractive or exploitative if not managed properly (Brittain, 2019). Local communities, particularly Indigenous groups, often hold collective intellectual property rights over their knowledge systems (Swiderska, 2006). It is important to recognise and respect this ownership of local knowledge and ensuring that benefits derived from research are shared equitably according to agreements negotiated in advance with the knowledge-holders. While my thesis highlights the importance of more LEK and diverse knowledge sources in conservation science and practice, I also emphasise the need to generate and apply this knowledge through ethical practices.

Conservation scientists have moral, pragmatic and legal obligations to avoid harm to their research participants, and local communities more broadly (Brittain et al., 2020). Furthermore, there is an increasing recognition for the need to work with broader socio-economic goals such as poverty alleviation alongside species conservation (Walpole & Wilder, 2008; Woodhouse et al., 2022). Throughout my fieldwork I was exposed to a range of issues faced by communities, such as illegal LED fishing, poverty and health concerns, as people viewed me as a platform to take these problems forward. As my thesis discusses, addressing these challenges over the long-term could represent important structural interventions for supporting both conservation and equity. Beyond this, conservation scientists and practitioners can play a unique role in bringing attention to these socio-economic issues where possible, while managing expectation with local communities (Chua et al., 2022). Through more participatory approaches, meaningful engagement and open dialogue with community members at the start of the research process, the dominant priorities of people and common interests can be identified. Ultimately, improving and providing socio-economic benefits to locals will likely have positive outcomes for biodiversity (Oldekop et al., 2016).

7.4 Next steps for elasmobranchs in India

Based on my thesis research, I propose a series of next steps for elasmobranchs in India, from research needs, conservation actions and interventions, and policy changes. My scoping review provided a prioritisation of research and conservation efforts, including risk and sustainability assessments for elasmobranchs, identification of critical habitats (such as nursery grounds), and most importantly, the socio-economic dimensions of elasmobranchs. The importance of structural interventions for elasmobranch conservation also emerged through my research, which needs further study in the context of Indian fisheries. For example, research on the drivers and human dimensions of destructive practices like LED fishing can inform science-based strategies for their mitigation (Mangar, 2022). As my work has exhibited, diverse knowledge sources such as LEK can be extremely valuable as cost-effective, rapid and inclusive methods to address the most critical data gaps at multiple scales across the country. Along with addressing these gaps, I also suggest the need for more of such reviews and prioritisation exercises for marine conservation in India, to streamline future efforts.

In terms of conservation actions, immediate efforts can focus on rhino rays, given their highly threatened status, low economic value in places like Goa, and the relative feasibility of the proposed interventions (i.e. live release). Building on my DPhil research, I initiated a follow-up project on rhino rays in Goa. Using LEK as a foundation (Chapter 3), we designed and conducted cost-effective ecological surveys to estimate abundances of juvenile widenose guitarfish (*Glaucostegus obtusus*) and identify important nursery habitats in South Goa. Moreover, we initiated the groundwork for live release programmes in the region through targeted outreach activities. We produced a short film in the local language (Konkani) targeting the fishing community in Goa, which aimed to increase awareness of the threatened and protected status of the widenose guitarfish, enhance positive attitudes towards rhino rays, and promote live release.

The film, rooted in our research and local social norms, was well-received by the fishing community. One fisher stated "*We see this fish regularly, but didn't know that it was endangered. We'll make sure to release it now, and also tell our friends about this*". Although formal monitoring and evaluation of the impact of this outreach was beyond the scope of this project, we received anecdotal reports and photographic evidence of local fishers voluntarily releasing guitarfish (Gupta, 2024) - a positive indicator for the potential of live release measures for guitarfish. Our project hence laid the groundwork for community engagement and live release interventions, and I aim to continue developing this. This work serves as a model for threatened elasmobranch conservation with local communities and can be applied to other similar contexts within India and across Global South fisheries more broadly.

Conservation of high-value elasmobranchs (like blacktip sharks in Goa) forms a more intractable challenge, as seen in my research. Previous studies in this region have found that socio-economic feasibility and stakeholder perceptions, rather than technical effectiveness, may be the deciding factors for management (Gupta et al., 2020a). Therefore, for places like Goa, there is a need to explore how a complete exit from the shark fishery can be feasibly achieved, through a combination of community-based agreements and government intervention. Working with communities for rhino ray conservation can develop local partnerships and trust, and foster pro-conservation attitudes, that can serve as an entry point to shark conservation (Gupta et al., 2020a; Redpath et al., 2013). Further research is needed to develop and trial a scalable conservation model for sharks in such contexts. While it is important that such initiatives are grounded at the fishing community, my research also indicates the role of state regulations and policies in supporting conservation (Chapter 6).

My research points to the need for a paradigm shift in marine conservation policy in India. Evidence from my chapters suggest the importance of interventions such as live-release programmes, improvement of fisher access and benefit sharing, community-based monitoring and conservation, and demand reduction of elasmobranch meat. However, marine conservation policies in the country currently do not have any provisions for such approaches. Policy related to conservation of elasmobranchs and other marine species take similar approaches as terrestrial wildlife by listing species under the Wildlife Protection Act (WLPA) and are not grounded within fisheries or its management. The WLPA by itself cannot be an effective strategy for elasmobranchs, with evidence of protected species continuing to be harvested and traded, incidentally or intentionally (Akhilesh et al., 2023). For taxa like elasmobranchs, where overfishing forms the biggest threat and the socio-economic context is complex, improved fisheries and trade management are urgently needed. However, it was only in 2017 that the National Marine Fisheries Policy explicitly acknowledged the need to conserve and protect vulnerable habitats and species for the first time (Gangal et al., 2023) – this strongly indicates how far behind fisheries policy in the country is.

Such challenges and conflicts between marine fisheries and conservation policies are pervasive in many countries, and the need for fisheries management and policy reform has been long advocated for (Salomon et al., 2011; Sridhar & Namboothri, 2012). Strengthening and empowering fisheries policy in India, and using a more holistic and interdisciplinary approach to fisheries management that includes species conservation as well as stronger local access and use rights, can facilitate a more sustainable and equitable fishery (Lobo, 2012; Salim & Anuja, 2022). Some of these steps have been integrated into India's new Blue Economy Policy for better marine spatial planning in Indian waters (Government of India, 2021). An adaptive and iterative approach can be taken, where policy and management can be improved with time as better data and knowledge are generated, and engagement and participation of local communities progresses (Gupta et al., 2020a; Salim & Anuja, 2022; Vaidyanathan et al., 2024).

With the Global Biodiversity Framework's target of protection of 30% of all marine areas (Target 3), there is an increasing pressure on states to protect their oceans – which may lead to ineffective 'paper parks', and negative impacts on local communities (CBD, 2022). It is crucial that marine conservation policy and fisheries management in countries like India are reformed in order to support more effective and ethical implementation of such global targets, including Target 5 (Sustainable Harvest and Trade of Wild Species) and Target 10 (Enhance Biodiversity and Sustainability in Fisheries).

7.5 Conclusion

For healthy shark and ray populations and thriving marine ecosystems, there is a need to reconcile biodiversity conservation with the basic needs and wellbeing of people, especially in countries of the Global South with complex socio-economic contexts where dependence on natural resources is high and data are lacking. My DPhil research investigated this challenge in coastal fisheries in India, suggesting pathways for sustainability through the use of diverse knowledge sources and the design of ethical and effective interventions with local community participation, amongst other actions. Such local-scale research is important both to provide ways forward for the specific context, and to provide methods, frameworks, and lessons to support more effective conservation action at regional, national and global scales.

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Palolem beach, one of my study sites in Goa, at sunset

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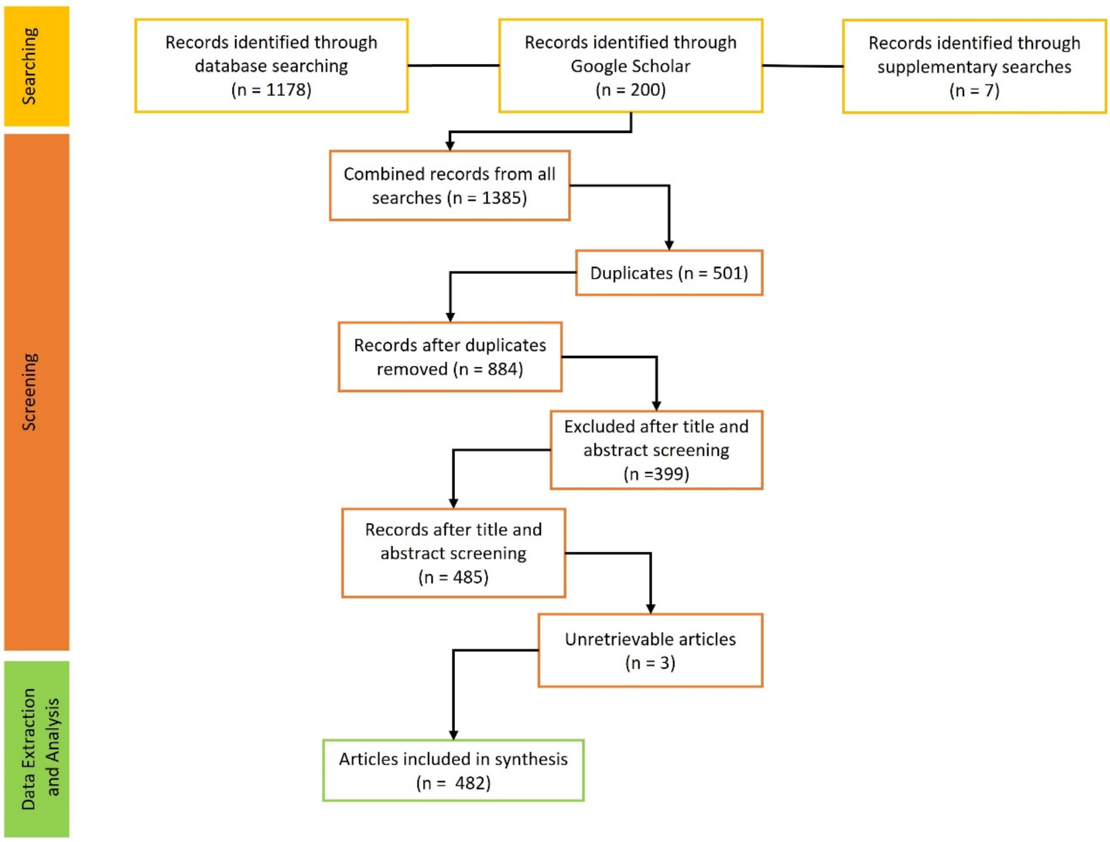
Appendix

List of Appendices

Appendix A1: Flowchart of literature search and screening process, adapted from Haddaway et al. (2017).



Appendix A2: Protocol and definitions for literature search, screening, data extraction and coding of chondrichthyan literature in India

First Reviewer: Trisha Gupta

Supervisors: Dr. EJ Milner-Gulland and Dr. Divya Karnad

Team of Reviewers: Trisha Gupta, Shruthi Kottillil, Sudha Kottillil

1. Search Strategy

Language: searches will be conducted in English

Strategy: a search of the following terms will be carried out in the databases listed below to capture both peer-reviewed publications and grey literature on the subject. Searches will be restricted to search terms appearing in the abstract, title or keywords only, in order to only include literature primarily focused on chondrichthyans.

Search terms:

(india OR gujarat OR maharashtra OR goa OR karnataka OR kerala OR tamil OR andhra OR orissa OR odisha OR "west bengal" OR lakshadweep OR andaman*)

AND

(*shark* OR stingray* OR whipray* OR elasmobranch* OR chondrichth* OR guitarfish* OR wedgefish* OR dogfish* OR skate* OR batoid* OR “sting ray*” OR wobbegong* OR hammerhead* OR bonnethead* OR carcharhin* OR dasyati* OR mobul* OR manta OR isurus OR alopi* OR sphyrn* OR sawfish* OR gymnur* OR chimaer*)

Databases:

Global databases: Google Scholar, Web of Science, Scopus, ProQuest

Indian databases: Central Marine Fisheries Research Institute (CMFRI), Central Institute for Fisheries Technology (CIFT), National Institute of Oceanography (NIO), Centre for Marine Living Resources & Ecology (CMLRE), Zoological Society of India (ZSI) and Shodhganga

2. Screening Strategy

Findings from the first ten pages of results in Google Scholar and all findings from the databases will be screened for inclusion in the review. The title and abstract of each publication will be read, and those meeting the criteria for exclusion will be recorded and removed from the review. Duplicates, which refers specifically to the same publication, will also be recorded and excluded. All other publications will be included for the study, reviewed and coded.

Exclusion criteria:

The following publications will be excluded from the review:

- Paleontological publications and fossil records
- Parasitology publications
- Studies conducted outside India
- Studies not related to chondrichthyans
- IUCN red list pages
- Media articles

3. Data extraction

All findings included will be reviewed in full-text and analysed qualitatively. Information extracted will include metadata such as study locations, affiliations of authors and publication type, as well as research theme and potential relevance to policy. The following codes will be used to guide the data extraction:

Code	**Definition/Description**
Background data: metadata of the publication	
1. Reviewer	Name of the reviewer
2. Paper ID	Unique ID of the publication.
3. Paper Title	Title of the publication
4. Author type:	The category(ies) of the lead author based on their affiliation(s).
a. Governmental research organisation	Government-affiliation research bodies, organisations and institutes, including CMFRI, ZSI, etc.
b. NGO	Non-governmental organisations
c. Indian university	Institutes and universities in India, not affiliated with the government
d. Foreign university	Institutes and universities outside India
e. Other	Not belonging to any of the previous categories. Eg. Independent researchers

f. Unknown	Affiliations are not provided or specified, or unknown if the full paper is not available
5. *Year of publication*	Year of publication of the paper
Research characteristics: site, species, theme and type of publication	
6. *Study State:*	Indian state(s) where the study was conducted. List as many as required.
a. All mainland coastal states	The publication explicitly has primary or secondary data from all across mainland India, excluding Andaman and Nicobar, and Lakshadweep Islands.
b. All coastal states & islands	The publication explicitly has primary or secondary data from all across mainland India as well as the islands
c. None	The study is not based in any particular geographic location.
d. Gujarat/ Maharashtra/ Goa/ Karnataka/ Kerala/ Tamil Nadu/ Andhra Pradesh/ Odisha/ West Bengal/ Andaman & Nicobar Islands/ Lakshadweep Islands	The publication has primary or secondary data from either of these states or union territories
e. Other	The study was conducted at a non-coastal state, or in another country outside India
f. Unknown	The study location is not specified
7. *Study site*	List the specific town(s) or site(s) where the study took place, if applicable
8. *Study group:*	Taxonomic group of chondrichthyans under study
a. Shark	The publication has data on, or focuses only on sharks. Rays may be mentioned in the introduction or discussion, but are not the focus of study
b. Ray	The publication has data on, or focuses only on batoids (rays, skates, guitarfish). Sharks may be mentioned in the introduction or discussion, but are not the focus of study

c. Chimaera	The publication has data on, or focuses only on chimaeras
d. All	The publication has data on, or focuses on sharks and rays
e. Not specified	The study group is not explicitly mentioned
9. Publication type:	Whether the publication is a peer reviewed article or grey literature
a. Peer reviewed	Indexed on Web of Science or Scopus. Also includes publications in known, peer-reviewed journals
b. Grey literature	Not indexed on Web of Science or Scopus, but on other databases. Includes all reports, theses, conference proceedings, newsletters, bulletins, etc.
10. Data type:	Whether the publication has primary or secondary data
a. Primary data	Original data directly generated by the publication, through surveys, interviews, experiments, observations etc. Publications that generate primary data but also use secondary data will be categorised here.
b. Secondary data	The publication uses and analyses existing primary data.
11. Research Theme:	The main topic or theme of research for each publication. Up to 3 themes can be coded for each publication. Write the most dominant theme (if present) under Research Theme 1
a. Biology	Focused on biological data and characteristics, including size, sex, maturity, reproduction, growth, etc. Also includes biochemistry.
b. Ecology	Focused on ecological data and characteristics, including diet, habitat, spatial ecology, seasonality, behaviour. Also includes distribution, phylogeography.
c. Records	A specific landing or record of chondrichthyans, focused on a single event or observation. Includes new records of a species in a region, specimens with morphological abnormalities, etc. New Records may include

	morphometrics and morphological data, which will not separately be coded as Biology publications.
d. Taxonomy/Phylogeny	Focused on taxonomy, phylogeny, new species descriptions, barcoding. Taxonomic studies will include morphometrics and morphological data, which will not separately be coded as Biology publications.
e. Fisheries	Focused on characteristics of chondrichthyan fisheries, such as landings, catch composition, catch rates, gear, fishing behaviour, etc.
f. Socio-economic	Focused on the social and/or economic aspects of chondrichthyans, such as trade chain, economic value, utilisation, social value, cultural value and perceptions.
g. Management/ Policy	Focused on reviewing, discussing, or assessing management or conservation measures, and/or evaluating, discussing and recommending policy. Includes launching, describing and/or evaluating a conservation campaign.
h. Checklists & Field guides*	Publication is one of the following: – National or regional species checklists – Field and identification guides
i. Ecotoxicology/ Disease*	Publication is one of the following: – Focused on the effect/presence of chemicals, heavy metals, plastics, pollutants etc. on chondrichthyans – Focused on diseases, parasites etc. in chondrichthyans
j. Biochemistry*	Focused on biochemical properties of chondrichthyan products, such as the chemical properties of liver oil, medicinal properties of cartilage, etc.
k. Non- chondrichthyan focus*	Focus is not on chondrichthyans (i.e. other marine species, general fisheries studies, etc.)

* *Publications of these themes were grouped as 'Other' for the analysis*

12. Type of fishery	For Fisheries-themed publications, list the type of fisheries under study. List as many as required
a. Trawler, gillnet, dol net, purse seine, longline, shore seine, other artisanal	The publication surveys or collects data from one of these fisheries
b. Other fishery	The publication surveys or collects data from a type of fishery not mentioned in the list
c. Not specified	It is a Fisheries-themed publication, but the fishery type is not specified
d. Not applicable	It is not a Fisheries-themed paper, and the fishing type is not relevant
13. Is species-level data available?	Whether the publication has primary or secondary data at the level of chondrichthyan species, or grouped at a higher taxonomic level.
a. Yes	The publication has data (biological, catch data, etc.) at the species level. Publications with some part of the data at species level and other data at a broader level will also be included here.
b. No	The publication does not have any species level data, but at the level of family or other taxonomic levels
Application of research: potential relevance of the research and data towards management and policy	
14. Policy recommendations	Whether the publication provides explicit recommendations for chondrichthyan management or policy
a. Yes	Publication fills at least one of the following criteria: – Theme of the publication is Management/Policy – Provides explicit and clear recommendations and suggestions for management, conservation and/or policy based on its data – Evaluates and assesses existing management measures and policies (e.g. looks at awareness, compliance, effectiveness, etc.)

b. No	Publication does not fulfil any of the above criteria
15. Relevant data for single species management	
a. Yes	– Stock assessments – Fisheries data: Catch rates, landings, gear (at population level, not of one/few individuals) – Biological data: Population dynamics, growth rate, demographics, mortality rates, size, sex, reproduction, fecundity (at population level, not of one/few individuals)
b. No	Publications that don't fulfil the above criteria
16. Relevant data for Ecosystem Approach to Fisheries Management (EAFM)	
a. Yes	– Biological data: Population dynamics, growth rate, mortality rates, size, sex, reproduction, fecundity (at population level, not of one/few individuals) – Ecological data: diet, habitat, spatial ecology, – Ecosystem data: community ecology, diversity, etc. – Environmental data: including pollution, heavy metals, etc. – New species discovered/described – Fisheries data: Catch rates, landings (at population level, not of one/few individuals) – Socio-economic data on stakeholder groups (fishers, traders, etc.) – Trade and export – Governance and policy data/discussions
b. No	– Reports and secondary data publications that don't fit the above criteria. – Single observations or events – Morphological abnormalities – First record of a species in a particular site – Phylogeny, phylogeography – Taxonomy – DNA sequencing and barcoding – Checklists – Species ID guides

	– Chondrichthyan products and utilisation (including properties and biochemistry of the products)
Other	
17. Remarks	Any comments, uncertainties, justifications for certain coding, etc.

Appendix A3: List of reviewed literature

This can be found as supplementary material on the journal website as Supplementary data: Multimedia component 3. Please see here:
https://www.sciencedirect.com/science/article/pii/S0964569121004877

Appendix B1: The study sites

District	Fishing villages sampled	Fishing harbours sampled
North Goa	Arambol Baga Dona Paula Kekdole Morjim Vagator	Malim/Betim Jetty
South Goa	Agonda Baina Benaulim Betul Cansaulim Galgibag Palolem Patnem Utorda Varca	Betul Jetty Talpona Jetty Vasco Jetty

Appendix B2: Semi-structured interview questionnaire guide for fishers

Informed oral consent was first obtained from respondents as per the ethics guidelines of Ashoka University's Institutional Review Board. The consent script is as follows:

Hello, I am XX, a researcher from Ashoka University and University of Oxford. I am conducting research to understand the occurrence, habitats and fisheries of guitarfish and wedgefish in the Goa coastline. As a part of this research, I would like to understand what fishers know about these species. I hope that you will participate in my research and speak to me about your knowledge of guitarfish in this region. This can take 20-30 minutes of your time. Are you interested in taking part in the project? *[Await confirmation]*

I will be asking you questions related to the habitat use and behaviour of these fish, their fisheries and how you use them. You do not have to answer any questions that you do not want to, and can leave the interview at any point. This research may be published in peer-reviewed scientific journals, and may also be summarised and published through other media such as blogs and popular articles. I will not be collecting your name or any personal details. Any publication from this study will present the results at an aggregate level only, and the information you provide will not be traced back to you.

Are you willing to take part in the interview? Can I have your permission to quote you directly in research publications, but not against your name? *[Await confirmation]*

Date: **Location:** **Interview Code:**

Rhino ray ecology

1. Have you seen this fish? (*show picture of rhino rays*). If yes, what are the local Konkani names?
2. Have you ever seen any rhino rays in the water? Which ones?
3. Where all have you seen them? (*names of the beaches/villages/rivers/fishing grounds etc.*)
4. Can you tell me more about the rhino ray sightings in the water:
    a. What depth of water do you usually see them?
    b. What distance from shore do you usually see them?
    c. What months of the year have you seen them?
    d. Which months do you see them *the most*?
    e. Is there any month/time of the year when you don't see rhino rays at all?
    f. What time of the day/night do you see them?
    g. What all sizes of rhino rays have you seen?
    h. Are there any sites where you see only small rhino rays? If yes, where?
    i. How many do you usually see at a time (together)?

5. What type of habitat have you seen rhino rays in? (eg. rocky areas, sandy bottoms, river mouths, etc.?) (*open ended question*)

6. Do you know what time of the year rhino rays breed and have their young?
    a. If yes, do you know what sites/locations they come to give birth?
7. Have you seen these rhino rays in the water since you started fishing?
    a. If no, when (what year/age) did you first start seeing them?
8. Has the number of rhino rays in the water changed since you first started seeing them?
   ☐Increased ☐Decreased ☐Stayed the same ☐Don't know
9. Aside from fishing, what are the main activities that occur in this beach/site (*tourism, mining, any industrial development, port, harbour construction etc*.)?
    a. Do you think these activities have any impact on marine life like rhino rays? How so? (*open ended question*)

Background information:

10. How old are you?
11. Where are you originally from (*name of village*)?
12. How many years have you been fishing?
    a. How many years in/around this beach?
13. Is fishing your main occupation? ☐**YES** ☐**NO**
    a. If no, what are your other occupations?
    b. Which is the main source of income?

Boat and gear information:

14. What type of fishing do you do? (*Prompt for type and size of boat, type of fishing gear, depth of operation*)
15. What are the main species you target?
16. What is your position in the boat (owner, driver, crew etc.)?
17. How many boats do you work on/own?
18. What months of the year do you fish?
19. How many days/hours is one fishing trip?
20. How many fishing trips/days per month?

Fishing and socio-economic value of rhino rays:

21. Do you ever target rhino rays in your fishing activities? ☐**YES** ☐**NO**

22. If yes, can you tell me more about:
    a. What rhino ray species do you target?
    b. What sizes do you target?
    c. How many (approximately) do you catch per month?
    d. What gear do you use to target them?
       (*Get details about net type, material, mesh size, boat type, etc.*)

e. Where do you target them (location/fishing grounds)?
f. What month(s) do you target them?
g. What time of the day do you target them?

23. What do you do with the rhino rays that you target and catch (*select all that apply*):
 Sell in the market Take home for consumption Discard (dead)
 Release (Alive) Other (*Specify*)__________
24. Do you accidently get rhino rays (as bycatch) in your fishing activities?
 YES **NO**
25. If yes, can you tell me more about:
   a. What rhino ray species do you catch as bycatch?
   b. What sizes do you get?
   c. How many (approximately) do you catch per month?
   d. What gear do you usually get them as bycatch in? (*Get details about net type, material, mesh size, boat type, etc.*)
   e. Where do you usually get them as bycatch (location/fishing grounds)?
   f. What month(s) do you get them the most?
26. What do you do with the rhino rays that you capture as bycatch, and why? (*select all that apply*)
 Sell in the market Take home for consumption Discard (dead)
 Release (Alive) Other (*Specify*)__________
27. For the rhino rays sold in the market (both targeted and bycatch):
   a. What sizes do you sell in the market?
   b. What price (on average) do you sell it for?
   c. Do you separately sell the fins and other parts?
   d. Do you know what happens to the rhino rays after you sell it (*eg. used for local consumption, sold outside of Goa, etc*)?
28. For the home consumption (both targeted and bycatch):
   a. What sizes do you take home for consumption?
   b. How often do you consume rhino rays at home? (*how many times a week/month*)
   c. Why do you eat rhino rays (*taste/tradition/cost/availability/medicinal value, etc*.)?
29. If discarded or released, why do you do so?

Appendix B3: Key Informant Interview Questionnaire Guide

(Informed oral consent was first obtained from respondents as per the ethics guidelines of Ashoka University's Institutional Review Board. The consent script is as follows:

Hello, I am Trisha Gupta, a PhD student from the University of Oxford. I am conducting research to understand the occurrence, habitats and fisheries of guitarfish and wedgefish in the Goa coastline. As a part of this research, I would like to understand what fishers know about these species, and what you think about them. As you are a fisher society president/community leader/experienced fisher, I hope that you will participate in my research and speak to me about your knowledge of guitarfish in this region. This can take 30-60 minutes of your time. Are you interested in taking part in the project? *[Await confirmation]*

I will be asking you few questions related to the habitat use and behaviour of these fish, their fisheries and how you use them. I also want to understand how guitarfish populations have changed over recent years, and what people in this region think about these species. You do not have to answer any questions that you do not want to, and can leave the interview at any point. This research may be published in peer-reviewed scientific journals, and may also be summarised and published through other media such as blogs and popular articles. I will not be collecting your name or any personal details. Any publication from this study will present the results at an aggregate level only, and the information you provide will not be traced back to you.

Are you willing to take part in the interview? Can I have your permission to audio record you [*if needed*]? Can I have your permission to quote you directly in research publications, but not against your name? *[Await confirmation]*

Date: **Location:** **Interview Code:**

Background

1. Where are you originally from (*name of village*)?
2. How many years have you been fishing or involved with fisheries?

Rhino ray ecology and fisheries:

3. What are these fish called in the local language (*show pictures of rhino rays*)?
4. How many types of rhino rays have you seen in Goa? What are the local names of each?
5. In general how often do rhino rays get caught? What times of year and places, and what sizes? What time of day do you see/catch them the most?
6. Do fishers in this village ever actively target and catch rhino rays? Are there any special nets specifically to catch them?
    a. Were rhino rays targeted by fishers earlier – in your father or grandfather's time?

7. What happens to rhino rays once they are captured? What are the different uses? (*Prompt for their economic value, use for subsistence, any cultural values*)
    a. Have the uses of rhino rays by fishers living in this village changed in the last 10 years? How and why? And by you?
8. Have the number of rhino rays caught by fishers living in this village changed in the last 10 years? If yes, how and why?
    a. Some other fishers in Goa have said they believed that rhino ray populations have increased in the last decade. What do you think could be the reasons for them thinking this?

Protected species:

9. Are there any protected marine species in Goa, that you're not allowed to catch?
10. What happens when a protected species is captured and landed? Are there any sanctions/penalties?
11. Do you receive any compensation to release a protected species?
12. What is your opinion on these sanctions for protected species? Do you think they are fair?

Protection of sharks and rhino rays

13. Similar to the above-mentioned protected species, what if sharks were banned and you couldn't catch them anymore? That has happened in some countries, to protect shark populations. If this happened in Goa, what would you think about it?
    a. What impact would it have on local livelihoods?
    b. What impact would it have on food availability?
    c. What impact would it have on your own livelihood and food?
    d. What impact would it have on sharks?
14. Similarly, what if rhino rays were banned and you couldn't catch them anymore?
    a. What impact would it have on local livelihoods?
    b. What impact would it have on food availability?
    c. What impact would it have on your own livelihood and food?
    d. What impact would it have on rhino rays?
15. If you weren't allowed to catch rhino rays anymore, would people here follow it? Would you? Why/why not?
    a. How can we incentivize fishers in this village to follow these measures and reduce their rhino ray catch? (*Probe for fines/compensations*)
16. If you had to comply with the ban, how would you do it? (*prompt for avoiding capture, releasing them if captured, etc.)*
17. Do you have any other thoughts or concerns about rhino rays or sharks and their fisheries?

Appendix B4: Local names of rhino rays from different parts of Goa

Name	No. of responses	Locations	District
Ellaro/Ellado	9	Galgibag, Palolem, Rajbag, Agonda, Benaulim, Colva, Cansaulim	South Goa
Waghare (Wedgefish)	1	Talpona	South Goa
Wagh mori (Bowmouth guitarfish)	1	Agonda	South Goa
Waghuli (same name is used for stingrays)	1	Cutbona	South Goa
Hadke/Phadke	4	Baina, Dona Paula, Marivel	North and South Goa
Baaban	1	Baga	North Goa
Imsee	1	Malim Jetty	North Goa
Kharra/Khorro	5	Morjim, Arambol	North Goa

Appendix C1: Methodology

Pilot interviews were first conducted with fishers and traders at both study sites in order to trial the questionnaire guides and collect preliminary data to improve the study. Pilot surveys revealed that shark supply chains tend to vary based on the size of the shark, with large-bodied (>1m in Total Length TL) and small-bodied sharks (<1m TL) caught by different types of gear, sold sometimes to different types of traders at varied prices and uses. Additionally, juvenile blacktip sharks (Carcharhinus limbatus, 60-80cm TL) appeared to be specifically targeted and traded in Goa, hence these sharks also formed a separate category for data collection. Actors (particularly traders) were not always able to distinguish between blacktip sharks and look-alike species. However, the blacktip shark fishery was highly seasonal, and during the season relatively large volumes of this species would be fished and traded as compared to the lookalike species (Chapter 5). Using this seasonal nature, as well as market and landing surveys conducted by the research team, we were able to verify and ensure that the information provided by respondents about blacktip sharks referred to this targeted fishery only, and not any other shark species. Aside from grouping of the shark species, pilot interviews did not lead to any other modifications of the questionnaires and approaches, and we commenced with the final interviews.

In both sites, interview respondents were recruited through a mix of convenience (interviewing whoever we could find that fits our criteria of respondents for this study) and chain referral sampling (where interviewed respondents were asked to suggest potential places to visit and people to approach, without providing specific details like names and contact information; Newing et al., 2011). Potential respondents were approached at markets, landing centres or at their homes. The researcher(s) introduced themselves, explained the research objectives and asked if the actor was willing to participate in the research. Informed oral consent was obtained, rather than written consent, due to variability in literacy rates. This study received ethics approval from University of Oxford's ethics committee (Reference: R79807/RE001).

The entry point for a supply chain study can vary based on the research questions and logistic feasibility (Kaplinsky & Morris, 2001). In Goa, we started with wholesalers at the wholesale market in Margao, as they are likely to be the smallest group of actors, with knowledge of the entire supply chain. Snowball sampling was used to identify and approach further actors along the shark supply chain, upstream (i.e. fishers) and downstream (i.e. vendors). Interviews in Goa were conducted over February-March 2022 by TG and HG in Hindi or Konkani, and spanned the fishing centres across the state, including local fishing villages, harbours, local retail markets and larger markets. In Kakinada, data collection occurred over August and September 2023 by TA in Telugu. Interviews focused on the Kumbabhishekam landing centre – being the main centre for shark trade, we did not have to use an iterative approach to identify key actors.

Fishers and traders were identified and approached at the harbour during or after the fish auctions and interviewed (Appendix C2).

Interviews were audio recorded with permission wherever possible. When this was not possible, which was particularly the case in Goa, detailed notes (including direct quotes from respondents) were written down during the interview. Data from both sites were translated and transcribed to English. Quantitative data (including nominal data) were extracted and analysed on RStudio (Version 2023.12.1; R Core Team, 2023; RStudio Team, 2020) to produce summary statistics. Qualitative data were analysed on NVIVO (Version 14; Lumivero, 2023). We created a codebook of a priori themes and sub-themes based on our research questions and analytical frameworks. New codes were also developed inductively through the analysis process based on emerging ideas. Coding was conducted by TG, with TA re-coding a few interviews to check for coder bias.

Appendix C2: Questionnaire guides

These questionnaires served as a guide to interview actors across Goa and Kakinada about shark fishing and trade. Questions were tailored to each respondent, and not all questions we asked in every interview. Preliminary questions were first asked with each potential respondent to ensure that they caught or traded sharks, and the interview then proceeded after obtaining informed oral consent.

Questionnaire guide for fishers

Interview code: **Location:** **Date:**

Background*:*

1. Age
2. Years of fishing experience
3. Where are you originally from (*name of village*)?
4. What all types of boat and gear do you operate? (*trawler, gillnet, purse seine, longline, etc*)
5. Position on boat (*captain, crew, owner*):
6. Do you have any other occupation, aside from fishing?
    a. If yes, which is your main occupation?

Shark catch and motivations:

7. What all sharks do you catch, and what sizes? (*show pictures*) What are they called in the local language?
8. What all craft and gear (type of boats, nets etc.) do you use?

Boat type and size	Type of gear (net, hook, etc.)
Mesh size	No of hooks/lines
Net length	Bait

    a. In which gear do you catch these sharks the most?
    b. Is there a special/specific gear that is used just for sharks?
9. Do you ever go out fishing specially to catch these sharks?
    a. If no, are they most bycatch – caught accidentally in your gear?
    b. Do you see sharks when you're out fishing, and then opportunistically catch them?

If the sharks are targeted in any way:

10. Did you always catch these sharks, since you started fishing, or did you recently start catching them?
    a. If recently started, why did you start? (*Prompt for profits, easy to catch, traditional, etc.)*
    b. If always caught, did your father also target and catch them? And grandfather?
11. Is there a season for these sharks, when you catch them the most?
    a. If yes, how much did you catch in the 'season' in 2022?
    b. Is this the usual catch that you get in the season for these sharks?
    c. If not, how much do you usually get?
    d. Why did you get less/more this year?
12. If there is no season, how much did you catch overall in 2022?
13. In the last 10 years (*Or since you first started fishing, if its less than 10 years*) has there been any change in **your** catch quantities of these sharks?
    a. If yes, how and why?
    b. In general for fishers in this site, has shark catch changed over the last 10 years?
    c. Any change in the number of fishers in this site targeting and catching sharks? Why?

Selling locations:

14. Are these sharks sold whole, or do you cut and sell each part separately?
    a. If cut and sold, what are the different parts?
    b. What is each part used for?
15. Who all do you sell these sharks to? (*list all the types of actors & locations, and of each body part*)
    a. Which actor/location do you sell to the most?
    b. Do you directly sell to these people/places yourself, or do you sell it to a middleman?
16. Do the selling actors vary throughout the year? Eg in the 'season', do you sell sharks to the same actors, or different?
17. Do you also take the sharks you catch home for consumption? How often?
18. In the last 10 years has there been any change in the actors or locations you sell these sharks to? And the way you sell them? Why?

***Prices*:**

19. What is the selling price currently – for each part of the shark?
20. Does this price vary throughout the year? If yes, what factors does it depend on (*size, quantity, etc.)?*
21. In general, do you see the market prices for different fish, and go out to catch fish that have high rates?

22. For sharks, do you check market rates and then go fishing for it?
    a. If selling prices for sharks decreased, what would you do? Would you fish for more/less sharks? Or no change?
    b. If selling prices for sharks increased, what would you do? Would you fish for more/less sharks? Or no change?
23. Do you get advances from traders or customers for sharks?
    a. If yes, how often?
    b. What happens if you don't catch sharks then?
24. What is the minimum price that you would sell sharks for?
25. Do you know where the sharks go, after you sell it?
    a. What are the selling prices at the next step?
26. In the last 10 years, any changes in the prices of these sharks?
    a. Has this change affected your fishing behaviour for these sharks?
    b. Has there been any change in demand for this species?

Access dimensions

27. Who sets the prices for these sharks? How much control do you have in setting prices?
28. How do you decide where to sell the shark products?
29. Do you have a fixed relationship with any trader, where you sell all catch to them?
30. In general, do you take any loans or advances from anyone for fishing?
    a. If yes, how do you pay it back?
31. Can a new person (an outsider) come and fish here? What are the barriers for new fishers to come here?
32. Are there any fishers who have more control & power in the fishing business? (*eg. have more boats, political connections, presidents of societies, etc*)?
33. How dependent are you on these sharks as a source of income/or as food?

Fisheries and conservation issues

34. (*If they said that shark catch has decreased*) What do you think can be done to avoid the declines in the future? What can be done to increase their populations?
35. Are there any other major issues and problems with fisheries?
36. Can we talk to some other fishers about these sharks? And some traders? How do we contact them?

Questionnaire guide for traders

Interview code: **Location:** **Date:**

Background:

1. Role in the shark supply chain (*middleman, wholesale, vendor, auctioneer, etc.*)
2. Gender
3. Age
4. Years of experience
5. Where are you originally from (*name of village*)?
6. Scale of operation –
    a. What areas do you cover for trading?
    b. Do you work independently or as part of a company/collective?
    c. How many people in the company?

Shark trade:

7. What all sharks do you catch, and what sizes? (*show pictures*) What are they called in the local language?
8. Which of these species do you trade the most?
9. Do you buy/sell them whole, or cut/dried or processed in any way?
    a. If yes, what type of cutting/processing? Who does it?
    b. What are the different shark parts/products you trade?
10. Where do you buy the sharks from? (*list all types of actors & locations, for each body part if relevant)*
    a. Who do you buy from the most?
    b. Do you know where it comes from originally (where its caught/what type of gear)?
11. Where do you sell the sharks to? (*list all types of actors & locations, for each body part if relevant)*
    a. Who/where do you sell to the most? Why?
12. Do you know where the sharks go after you sell them – who are the final consumers?
13. Do you buy/sell fish directly, or through some agent or middleman?

Quantities:

14. How often do you buy/sell sharks? (*Daily, weekly, etc.*)?
15. Is there a particular season for sharks?
    a. In this season, what quantities do you usually buy and sell?
16. Quantities of sharks traded this week?
    a. Is this the typical amount?
    b. If no, why was it less/more?
17. On average, what quantities of sharks did you trade per day/week last year (2022)?
18. In the last 10 years (*Or since you first started trading, if its less than 10 years*) has there been any change in **your** trade quantities of these sharks?
    a. If yes, how and why?

b. In general at this site, has shark catch and trade changed over the last 10 years?
c. Has there been any change in the number of traders in this site buying/selling sharks? Why?

Demand

19. Is there demand for sharks in this site? From who?
20. Is it easy to sell sharks – do you have buyers lined up from the start?
    a. How many days do you keep sharks with you until they are sold?
21. Do buyers call you and place orders for sharks beforehand?
22. Do you have any fixed or regular buyers for sharks?
23. When sharks are less in this site, do you/other traders specially bring in sharks from outside to sell here?
24. When there is a demand and/or sharks are less, do you ask your fishers/suppliers for more sharks?
25. Do buyers/traders pay you advances for sharks?
    a. If yes, how often?
    b. What do you do when you don't have sharks?
26. Do you pay any fishers loans/advances for sharks?
    a. If yes, how often? Why?
    b. What do you do when they don't catch sharks?

Prices:

27. What are the buying prices currently for each shark species/product?
28. What are the selling prices currently for each shark species/product?
29. Does price vary over the year? If yes, what factors do the price depend on (*size, quantity, etc.)?*
30. Do the prices of sharks affect your decision to buy/sell them? How?
    c. If the market prices for sharks decreased, what would you do? Would you buy/sell more/less sharks? Or no change?
    d. If the market prices for sharks increased, what would you do? Would you buy/sell more/less sharks? Or no change?
31. What is the minimum price that you would sell a shark for?
32. What is the max price that you would buy a shark for?
33. What are the selling prices at the next step?
34. In the last 10 years has there been any change in the prices of these sharks?
    a. If yes, how and why?
    b. Has this change affected your buying/selling behaviour for these sharks?
    c. Has there been any change in demand for this species?

Access dimensions

35. Why are you in this profession?
36. Who sets the prices for these sharks?
    a. Buying price
    b. Selling price
    c. How much control do you have in setting prices?
37. How do you decide where to sell these sharks, and its different products?
38. Do you have a fixed relationship with any fisher, where they sell all fish to you?
39. Do you have a fixed relationship with any trader/middleman/vendor, where you buy/sell fish to them?
40. In general, do you take or give loans/advances to anyone? Do other traders?
41. Can a new person (an outsider) come and sell fish here?
    a. What are the barriers for a new person to come here – what would they need?
42. Are there any traders here who have more control and power in the fishing business? (*eg. Big companies, political connections, presidents of societies, etc*)?
43. How dependent are you on these sharks as a source of income/or as food?
44. Is there any dealer/agents society or association here?

Fisheries and conservation issues

45. (*If they said that shark trade has decreased over the past decade*) What do you think can be done to avoid the declines in the future? What can be done to increase their populations?
46. Are there any other major issues and problems with fisheries?
    a. What do you think can be done about this?
47. Can we talk to some other traders about these sharks? How do we contact them?

Confidential interviewer comments

1. How knowledgeable and experienced did the fisher seem? (identified species, had lots of info about fishing, etc.)

☐Very knowledgeable ☐Reasonably knowledgeable☐Not very knowledgeable

2. How open and honest did the fisher seem about answering questions?

☐Very open/honest ☐Somewhat open/honest ☐Not honest

3. How interested and engaged did the fisher seem with interview?

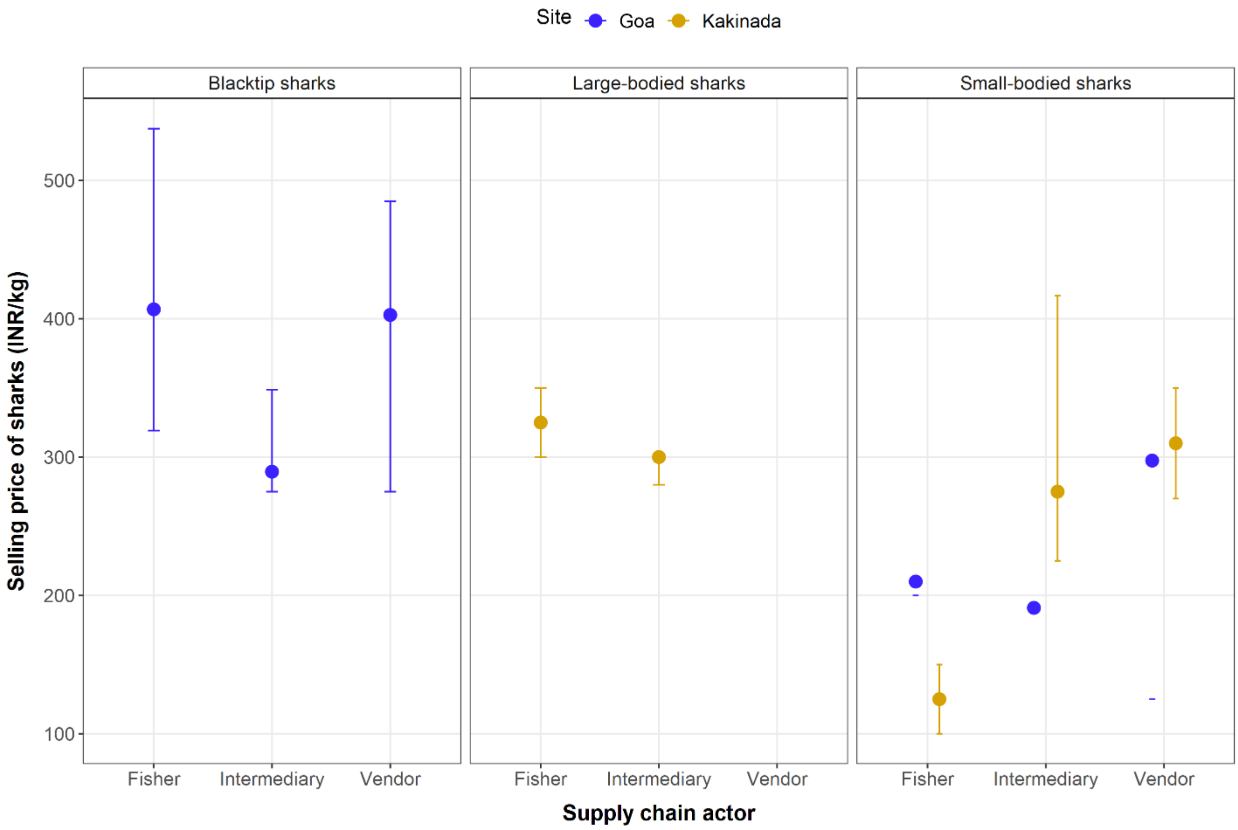
☐Very interested ☐Moderately interested ☐Bothered/ Not interested

4. How certain did the fisher seem about answers to numerical questions?

☐Very sure ☐Reasonably sure ☐Unsure

5. Please indicate why (if any) questions were not asked:
6. Any remarks/comments about the interview?

Appendix C3: Average and range of price for meat of different shark types at different stages of the supply chain at each site



Average and range of price for meat of different shark types (small-bodied, large-bodied and blacktips) at different stages of the supply chain at each site (blue for Goa, yellow for Kakinada). Intermediary here refers to traders who don't sell to consumers - wholesalers, middlemen, auctioneers etc. Prices were obtained by taking the mean of prices reported by each actor type across interviews. Error bars here represent standard error.

Appendix D1: Semi-structured interview questionnaire

Shark fishers were approached at the beach, in community areas, or at their homes, and were asked a few preliminary questions to confirm that they practiced the seasonal, targeted shark fishing. Following this, we explained the study objectives, provided a brief overview of the interview process, and obtaining informed oral consent before proceeding with the interview.

Interview code: **Location:** **Date:**

***Background**:*

1. Age:
2. Years of experience:
3. Place of origin (*village name*):
4. Type of crafts used (*canoe*, *trawler, purse seine, hook, etc.*):
5. Position on boat (*captain, crew, owner*):
6. Alternative livelihoods, if applicable (*tourism, etc*.):
    a. Which livelihood was the main source of income?

Shark catch:

7. This is about the targeted fishing for 'big sharks' that you practice (*show picture*). Can you tell me the following details about your shark fishing:
    a. Fishing months:
    b. Net used:
    c. Mesh size of net:
    d. Length of net:
    e. Fishing start time:
    f. Distance from shore:
    g. Net soak time:
    h. Fishing location:
    i. Fishing depth:
    j. Boat size, motor details:
    k. No. of crew members:
    l. When did you start fishing for sharks this year (what date):
    m. No. of fishing trips this year:

Explanation: My research is interested in understanding the exact number of sharks caught in this village, because we currently don't have any data for this. Only by understanding the number of sharks caught, can we understand the status of shark populations and how to manage them sustainably for the benefit of both sharks and fishers. So can you think about the [*insert* *number of fishing trips]* fishing trips that you have done for sharks this year, in the shark fishing season. Think about **all** the sharks that you caught this year, imagine them in front of you.

8. Can you say, approximately, how many sharks you caught in total this year over the [*insert number of fishing trips]* trips that you undertook, by proving a range? For example, 100 to 200 sharks, or 450 to 500 sharks?
    a. Okay, so you may have caught between x-y [*insert lower and upper bound*] sharks this year. Are you certain that you did not catch more than y [*insert upper bound*] sharks in total this year? Or could you have caught more than y [*insert upper bound*] sharks? If yes, please provide a number.
    b. Are you certain that you caught at least x [*insert lower bound*] sharks in total this year? Or could you have caught fewer than x [*insert lower bound*] sharks? If yes, please provide a number.
    c. If you had to guess exactly how many sharks you caught in this range of x-y, what is the number?
    d. How sure or certain are you that this number is correct – that the exact, total number of sharks you caught this year falls within this range of x-y?
9. Do you know how many boats went fishing for sharks this year, from here [*village name*]?
10. Now think about the shark season last year, in **2021**. Similarly, try to remember and imagine all the sharks that you caught over the season.
    a. How many fishing trips for sharks did you do last year?
11. Can you say, approximately, how many sharks you caught in total last year over the [*insert number of fishing trips]* trips that you undertook, by proving a range? For example, 100 to 200 sharks, or 450 to 500 sharks?
    a. Okay, so you may have caught between x-y [*insert lower and upper bound*] sharks last year. Are you certain that you did not catch more than y [*insert upper bound*] sharks in total last year? Or could you have caught more than y [*insert upper bound*] sharks? If yes, please provide a number.
    b. Are you certain that you caught at least x [*insert lower bound*] sharks in total last year? Or could you have caught fewer than x [*insert lower bound*] sharks? If yes, please provide a number.
    c. If you had to guess exactly how many sharks you caught in this range of x-y, what is the number?
    d. How sure or certain are you that this number is correct – that the exact, total number of sharks you caught last year falls within this range of x-y?
12. Do you know how many vessels went fishing for sharks last year, in 2021, from here [*village name*]?

Shark trade

13. Where did you sell the sharks to this year? List all the places/people.
    a. Who/where did you sell to the most? Why?
    b. Do you also take the sharks you catch home for consumption? If yes, how many sharks do you take home?
14. What is the total income you got from sharks this year, after selling them?
15. Think about the entire year – when you catch different fish. Think about the income you make from fishing all throughout the year. Are sharks important to your overall income?
    a. What percent of your total fishing income over the year comes from sharks?

Other information:

16. When did you first start fishing for sharks – how many years ago?
    a. Why did you first start?
    b. Are you a traditional fisher?
    c. If yes, did your father also undertake this shark fishing? Your grandfather?
    d. Did you always use the type of nets you currently use for sharks, or did you use something else?
17. Over the last 10 years (or since you first started shark fishing), has there been any change in shark catch overall? Increase, decrease or no change?

Participation in second round:

18. As I mentioned in the start of the interview, I would like to contact you again to discuss the estimates of shark catches that you gave me, after I have interviewed other fishers. If that is fine, please provide your contact details:

Contact details:

CONFIDENTIAL INTERVIEWER COMMENTS

30. How knowledgeable and experienced did the fisher seem to be? (i.e. confident in identifying species, had lots of additional knowledge about fishing, etc.)

☐Very knowledgeable ☐Reasonably knowledgeable☐Not very knowledgeable

31. How open and honest did the fisher seem about answering questions?

☐Very open/honest ☐Somewhat open/honest ☐Not honest

32. How interested and engaged did the fisher seem with interview?

☐Very interested ☐Moderately interested ☐Bothered/ Not interested

33. How certain did the fisher seem about answers to numerical questions?

☐Very sure ☐Reasonably sure ☐Unsure

34. Any remarks/comments about the interview?

Appendix D2: Details on the methods and analysis

Data imputation

In a few interviews (n=8), interviewees provided an upper and lower bound of their shark catch but were unable to provide a best estimate. In these cases, missing data on best estimate was imputed through mean and interpolation imputation. We used the non-missing data of best estimate and calculated the mean distance of these values from their associated upper and lower bounds. This was then used to impute the missing best estimate values, using the upper and lower bounds of those interviewees.

Standardisation of data:

As part of the IDEA protocol process, interviewees are asked to provide confidence levels in their responses (i.e., how confident were they that the best estimate they provided represented their actual shark catch, and lies between the upper and lower bounds that they provided). During the analysis of data, the upper and lower bound values were subsequently standardised to 80% confidence levels based on these reported confidence levels from interviewees, for each round, to provide credible intervals. This standardisation was done using linear extrapolation, with the formula:

Lower standardised interval: $B - ((B - L) \times (S/C))$

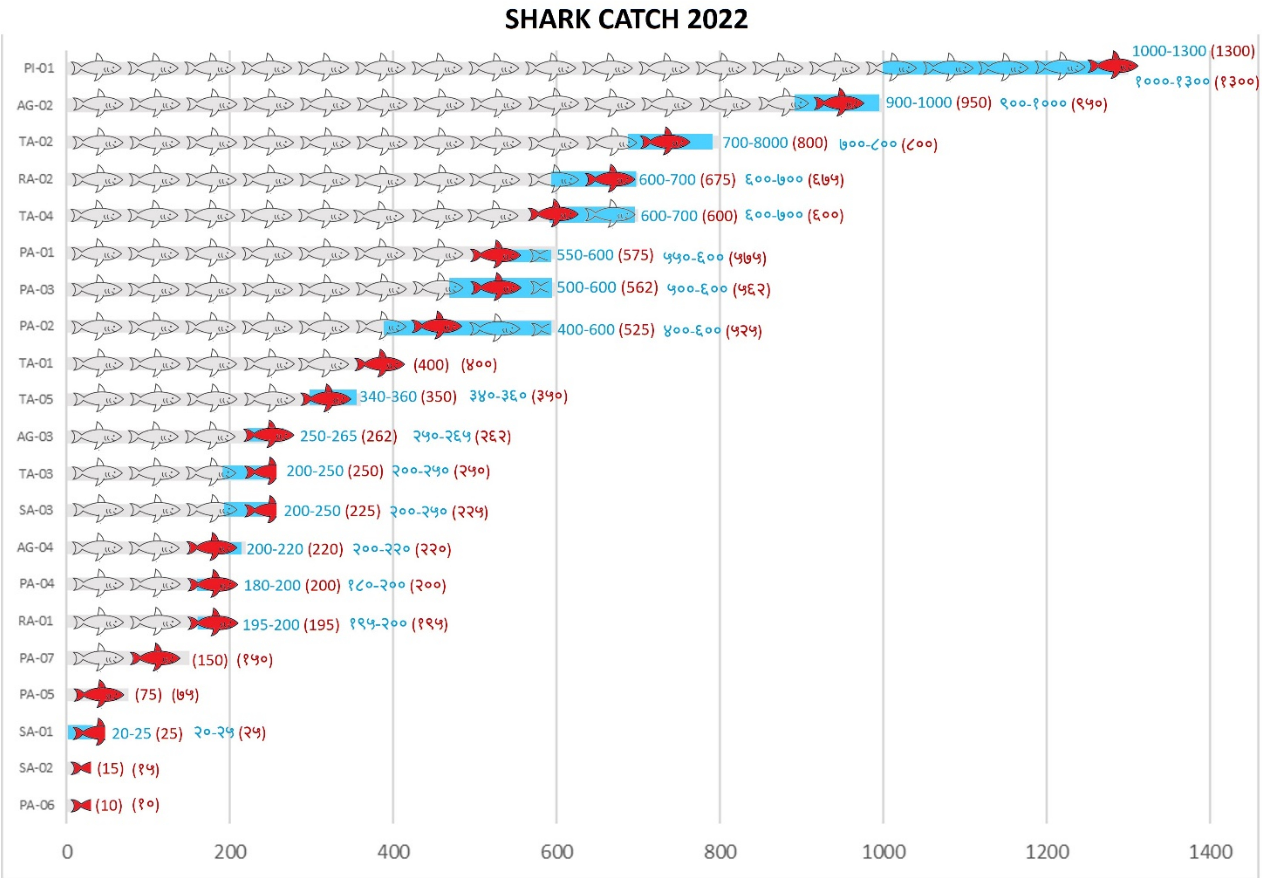
Upper standardised interval: $B + ((U - B) \times (S/C))$

Where B is the best estimate, L is the lower bound, U is the upper bound, S is the level of credible intervals to be standardised to (i.e. 80% in this case), and C is the level of confidence given by interviewees (Hemming et al., 2018). This standardisation is done as studies have found that overconfidence was reduced if experts had to specify their own level of confidence and the credible intervals were subsequently standardised.

Appendix D3: Model details with script for analysis

Annotated R-markdown file with detailed explanation of the steps of the population models can be found at: https://drive.google.com/drive/folders/1danSeYspPLGBMVQYyTh2Iqr6e7CWrc24?usp=sharing. These files will be archived in a public data repository upon publication in a journal.

Appendix D4: Anonymised estimates of shark catches of interviewees from R1



Example of the figure shown to interviewees with a set of R1 data (anonymised upper bounds, lower bounds and best estimates, with values written in English and the local language of Konkani), during the R2 interviews. The red colour represents the best estimate, and the blue represents the range (i.e., upper and lower bounds).

Appendix E1: Questionnaire guide for scenario interviews with shark fishers

These questionnaires served as a guide to interview shark fishers in Canacona. Most of these questions were followed by further questioning and open-ended discussions with the interviewee. The interview only proceeded after obtaining informed oral consent.

Interview code: **Location:** **Date:**

Background and demographics

1. Age
2. Years of shark fishing experience
3. Place of origin
4. Alternate livelihoods (if any)
    i. Which is your main source of income?
5. Education level

Shark fishing

[*This section also contained structured questions to estimate shark catch for this season, using the adapted expert elicitation protocol from Chapter 5*]

6. Can you tell me about your shark fishing season this year:
    i. When did you start shark fishing this season?
    ii. Why did you start (e.g. after seeing other shark fishers go out and get sharks?)
    iii. How many crew members did you have, and where do they come from?
    iv. Where all did you sell your shark catch?
7. How many other fishers in your village [name] fish for sharks?
8. Why do you and these fishers go shark fishing, when majority of fishers in your village don't?

Scenarios

Explanation: Sharks are declining all around the world, and even in India. In many parts of the world, they have developed different measures and schemes to try and protect sharks. For our study, we want to understand what type of measures may work to conserve sharks in Goa. So we're going to present you with some different options, and we want your honest opinion about them – what you think, will you follow each measure, and how it will impact you. These measures are imaginary for the moment, but they may be implemented by the government in the future. [*Graphics were created for each scenario to help the interviewee understand the intervention proposed and provide their feedback. The graphics can be found at the end of this appendix*]

Scenario 0: BAU

In the next year, I want you to imagine that everything remains the same as it is now. Shark fishing continues as it currently is, there are no further regulations, prices remain the same etc.

9. Under this scenario, will you be fishing for sharks next year?
10. If no (if you stop fishing), why?
11. Five years in the future, if everything remains the same, do you think you'll still be fishing for sharks?

Scenario 1: Social disincentive:

(*The social scenarios will always come before the financial scenarios. The order within them – incentive and disincentive – can be changed between interviewees*)

Imagine next year that there will be a government campaign against shark fishing. People around Goa and India hear that you've been fishing sharks and get upset because sharks are threatened. There may be some negative news articles about this. People of your village and community will also get upset about this, and look down on fishers who catch sharks. Everything else will remain the same, prices will remain the same as they are now, and management/enforcement is the same. Only that others in your village/community look down on shark fishers. In this scenario:

12. Will you still be fishing for sharks next year?
13. If no (if you stop fishing), why?
14. Can you explain the reason for your answer?
15. What do you think other fishers in your community would do in response to this scenario?

Scenario 2: Social incentive:

Imagine next year that there will be a campaign to encourage people to stop shark fishing. The government is encouraging fishers to voluntarily give up shark fishing, to stop catching them. For those who give up shark fishing, there will be an article about you in the local newspaper and you'll get an award from the government in a ceremony. Everything else will remain the same, prices of sharks will remain the same as they are now, and management/enforcement is the same. In this scenario:

16. Will you still be fishing for sharks next year?
17. If no (if you stop fishing), why?
18. Can you explain the reason for your answer?
19. What do you think other fishers in your community would do in response to this scenario?

Scenario 3: Financial disincentive (Enforcement)

(*The financial scenarios will always come after the social scenarios. The order within them – incentive, disincentive and indirect – can be changed between interviewees*)
In the next year, I want you to imagine that the government (Fisheries Department) completely bans this practice of shark fishing during this season. There is someone monitoring to see if anyone is breaking the law. If you go out shark fishing during this time, imagine that you will get caught. There is an administrative warning and a fine if you're caught going fishing with the motorised boat. The fine is 5 times the value of the sharks you caught. Eg – if you caught sharks worth Rs. 10,000, the fine will be Rs. 50,000. Everything else will remain the same, prices of sharks will remain the same as they are now. In this case:

20. Will you still be fishing for sharks next year?
21. If no (if you stop fishing), why?
22. Can you explain the reason for your answer?
23. What do you think other fishers in your community would do in response to this scenario?
24. What is your opinion on this measure, overall? How fair or unfair do you think it is?

<u>Scenario 4: Financial incentive (PES)</u>
Imagine next year, the government has a scheme for shark conservation. You will be asked if you would like to stop shark fishing, and the government will buy back your shark nets and provide you with a compensation for exiting the shark fishery. You'll receive a total of Rs. 20,000. If you still go fishing for sharks (buying/borrowing a new net), you will not receive the payment. Everything else will remain the same, prices of sharks will remain the same as they are now, etc. In this scenario:

25. Will you still be fishing for sharks next year?
26. If no (if you stop fishing), why?
27. Can you explain the reason for your answer?
28. What do you think other fishers in your community would do in response to this scenario?
29. What is your opinion on this measure, overall? How fair or unfair do you think it is?

<u>Scenario 5: Cooperative</u>
Imagine that next year, a cooperative for shark fishing is established in Canacona, by the government. All fishers who catch sharks can be a member of the cooperative, and you will all collectively manage this fishery. There will be an effort limit (e.g., 5 days) and you can fish for sharks as much as you want within this. This way, the cooperative can ensure that everyone who wants to can access shark fishing, but it regulates the fishing so that not too many sharks are caught and the fishing is sustainable. The cooperative will provide support with access to labour and information for shark fishing, and access to markets to provide a good rate for sharks.

30. Will you join the cooperative and fish under these conditions?
31. If yes, why?
32. If no, will you still continue shark fishing on your own? Why?
33. Can you explain the reason for your answer?
34. What do you think other fishers in your community would do in response to this scenario?

Scenario 6: Cage Culture

Now imagine that next year, a voluntary scheme by the government where fishers are offered subsidies and training for cage culture for marine fish (for fish like sea bass) in return for exiting the shark fishery. The entire activity will take 6 months. At the end, you can receive profits of between 5-10 lakhs. These cage cultures have been successfully happening in different parts of Goa. So imagine that you had the opportunity to stop shark fishing, and in return you can avail this scheme - get the subsidy and training for cage culture. Under this scenario:

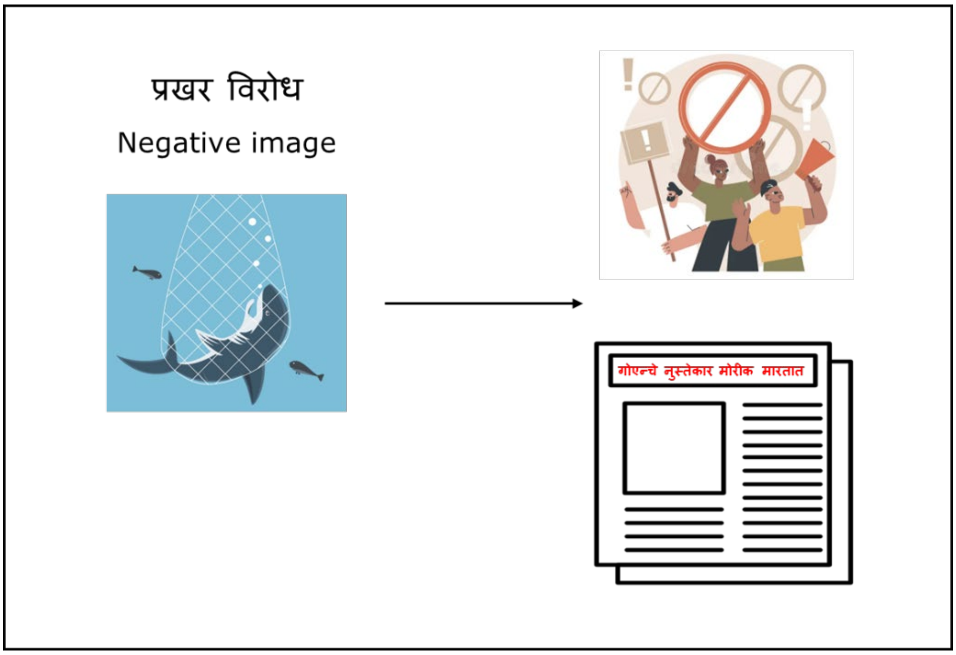
35. Will you still be fishing for sharks next year?
36. If no (if you stop fishing), why?
37. Can you explain the reason for your answer?
38. What do you think other fishers in your community would do in response to this scenario?
39. What is your opinion on this measure, overall? How fair or unfair do you think it is?

Overall opinion:

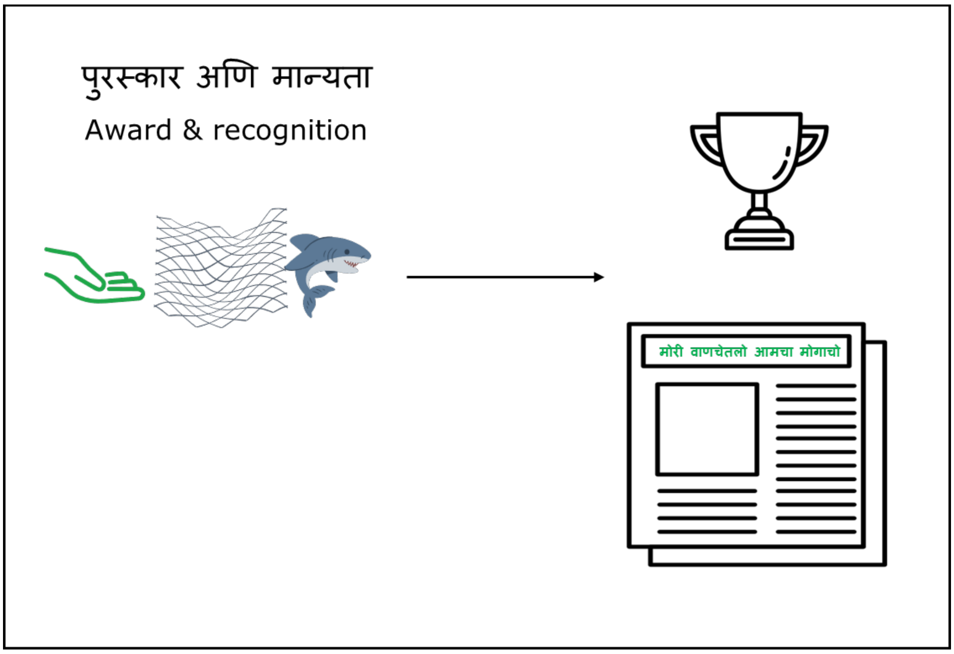
40. What is your overall opinion about the different options I have presented to you? Which one do you like the best, and the least? Why?
41. Do you have any ideas or suggestions for other measures to conserve sharks and reduce shark catch in this village? Something that other fishers will also follow?

Scenario graphics that were shown to each interviewee during the interview:

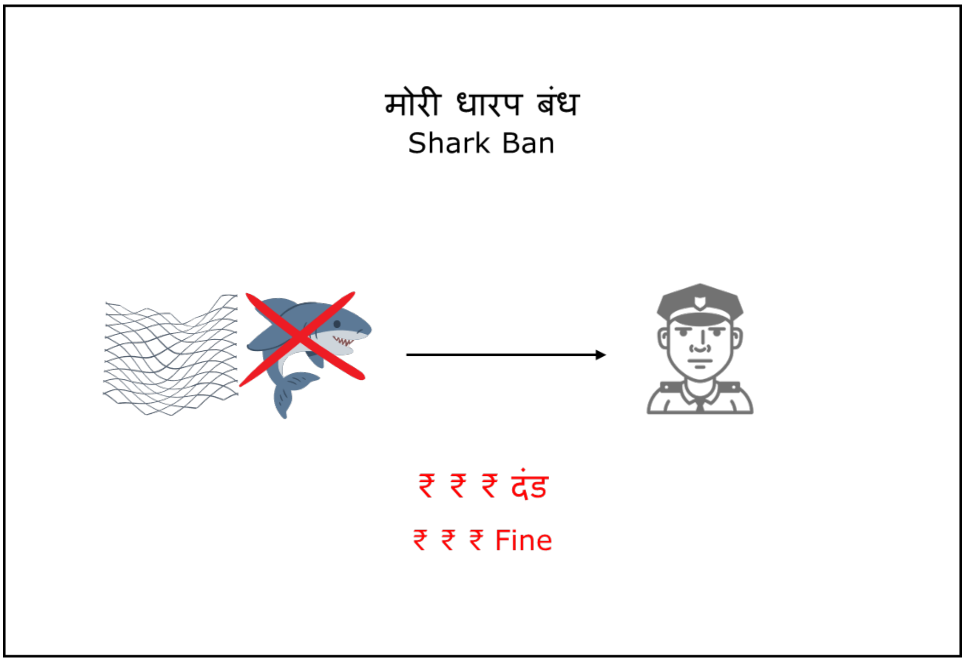
S1: Social disincentive:



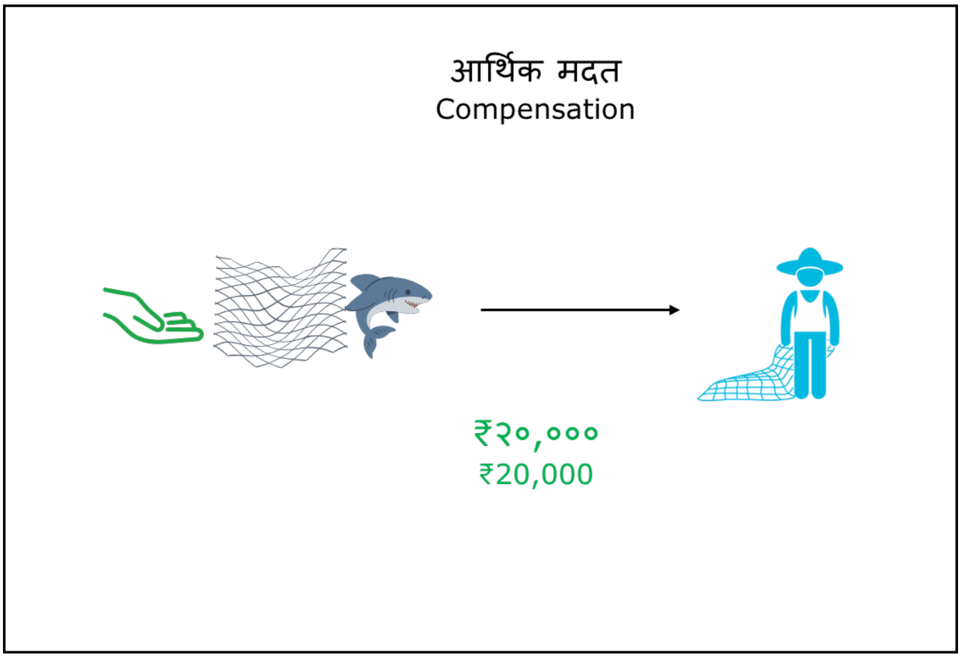
S2: Social incentive:



S3: Financial disincentive (ban):



S4: Financial incentive (PES):



S5: Cooperative:

S6: Cage culture: