Towards sustainable management of sharks and rays in the Bay of Bengal, Bangladesh

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ABSTRACT

Elasmobranchs (hereafter referred to as 'sharks and rays') have declined in landings, species diversity in catch and population size in various regions of the world due to human-driven pressures, primarily unsustainable fishing. Combined with their life history characteristics, these pressures make them extremely vulnerable to ongoing threats. Incidental shark and ray catches (or bycatch) are substantial and essential livelihood options for food security in developing countries. Considerable shark and ray catches and traded products come from countries marked by the perpetual poverty of coastal communities that depend highly on artisanal fisheries. This doctoral research takes the case study of shark and ray fisheries in Bangladesh to understand the key issues and to investigate potential practical conservation and management actions for sharks and rays from a global south perspective. Artisanal fisheries in the Bay of Bengal of Bangladesh contribute to the worldwide fishing pressure on sharks and rays. However, it is also one of the most data-poor regions of the world. Here, the fisheries are heterogeneous and complex, and socio-economic dependence is high, making it extremely challenging to balance fish protection and fishers' livelihoods. I addressed the lack of critical data on sharks and ray fisheries in Bangladesh, considering species diversity, fishery characteristics and trade in detail through a combination of field surveys, observations, and interviews. I also evaluated the risks of different shark and ray species against contemporary fishing pressures by assessing species' ‘area of exposure’ to artisanal fishing. Key findings include the high diversity of sharks and rays within the artisanal landings. However, decreased diversity, abundance, and size of caught specimens was also revealed, attributed to increased fishing intensity, and an accessible market. Furthermore, most southwestern and southcentral shallow waters were found to have a high risk of species encounter with artisanal fisheries; thus, spatiotemporal management needs to be prioritised, particularly in these areas. Gillnet fishing was found to be the most significant threat to bycatch sharks and rays due to its three-dimensional spatial scale and fishing tactics. While the catch and trade of most sharks and rays are regulated under Bangladesh's law, this study revealed an absence of bycatch mitigation strategies and no incentives for fishers to adhere to current laws leading to non-compliance. Likely causes of non-compliance include a dearth of awareness, alternative livelihoods, technical facilities, and the complex nature of the fisheries. Lack of opportunities and information to adhere to regulations and increased enforcement (only) has led to conflicts, non-compliance and unwillingness to report catches by fishers and traders. An imbalanced power and financial structure between actors (e.g., fishers, traders) were also revealed, with actors accessing unequal benefits from the market. Impediments for implementing conservation measures by low-access actors (e.g., fishers) with limited decision-making power or resources were evident. Fishers reported several socio-ecological, technical, and enforcement issues (e.g., policing instead of meaningful monitoring and punitive measures without facilitating compliance). Crucial interventions to address the unsustainability problem include improved taxonomic research, enhanced monitoring of stocks, meaningful protection for threatened taxa and safeguarding fishers to improve compliance. Although legal measures are necessary, this cannot be the only tool to mitigate the significant cumulative effects of fishing on these species. Reducing the risk from fisheries requires pre-emptive measures that minimise the interaction of species with fisheries through improved and better-informed careful management. Encouraging and facilitating the engagement of fishers in science (data collection), local governance (policy-making), and field implementation (bycatch mitigation) is vital, acknowledging that adequate time and resources will be required to change practices. A key recommendation is to focus management efforts in specific coastal locations (i.e., evidence-based spatiotemporal management) while prioritising high-risk species groups benefitting multi-taxa conservation. These interventions must be rooted in sustainable approaches and co-designed with fishers, with appropriate training and resources available.

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Throughout my PhD journey, it was an extraordinary honour and privilege to be a member of a broader academic and conservation community at the University of Oxford and beyond. I can't claim to have finished this journey alone; instead, it was made possible by the assistance and cooperation of numerous people and organizations, which helped me conduct fieldwork in challenging situations, write my thesis and, in doing so, gradually changed the way I look at conservation of species and my life. First, I want to express my gratitude to Professor Nathalie Seddon and Dr Rachel D. Cavanagh, who served as my supervisors. Both are outstanding role models for young and aspiring women scientists who wish to take on challenging environmental issues like climate change and fisheries. Learning about academic topics, professionalism, and answering challenging questions with composure, patience, and honesty, as well as numerous practical lessons from both, has been an incredible pleasure and privilege. I will always carry forward one particular thought from our innumerable conversations: "*There is not ONE way of looking at the world and its problems; the only way we can hope for agreement on conservation and management is if we can see the perspectives of others*."

I was fortunate to have found excellent collaborators, assessors and mentors throughout my PhD journey. Dr Julia LY Spaet was one of the first collaborators who co-authored two chapters with me. Her unquestioning pursuit of shark science inspired me to do better. Dr Will White, a recognized expert in shark taxonomy, assisted in identifying the species for one of my chapters. I had a fantastic learning opportunity working with Dr White. Dr Rodrigo Oyanedel co-authored one of the 'trade' chapters with me, being very generous with his time and expertise in this area. Professor Nicholas K. Dulvy, Glenn Sant, and Dr C. Samantha Sherman co-authored and helped me execute the 'risk' chapter; their knowledge was invaluable. My assessors for the transfer and confirmation of the PhD, Professor EJ Milner-Gulland, Dr Michelle Jackson and Dr Katrina Davis, helped me with their constructive comments in the early stages of my thesis. All of them are brilliant scientists and inspirations to look up to. I am immensely grateful to all of them.

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This study would not have been possible without the generous collaboration and time of the fishers of Bangladesh. The communities with which I have a deep relationship and commitment. They have engaged with me and have given me hundreds of hours while I was interviewing them during hectic work hours. Their wisdom of the waters not only assisted me in finding the answers to my research questions but also helped me realize the critical role of local ecological expertise, locally-driven conservation efforts, and—most importantly—establishing justice and equity within these communities, which are crucial in achieving better conservation outcomes. I am eternally indebted to the fishers for sharing their wisdom with me.

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Not to mention, I will always be grateful to my partner, family, and friends. My enthusiasm, tenacity, happiness, and resolve to fight for the greater good come from my parents and two younger sisters. Even at my lowest, my friends supported me with unconditional love and told me I could achieve my goals; what a fantastic bunch of friends I have! Last but not least, for the past two years, my partner has served as a foundation of stability, tranquillity, and calm in my life. He is always a friend and a sounding board for me. I am fortunate to have such a support system.

All these fantastic people I came to know in my life humbled me and made me question if I deserved all these privileges. While I could never answer that, I can express my gratitude and pledge to continue working on these issues for the fish and fishers of the Bay of Bengal.

Dedication

To the incredible fish and mighty fishers of the Bay of Bengal.
May all three thrive.

Declaration of originality

I declare that this thesis is entirely my own work. Contributions by other authors are stated in section 1.8. None of the work has been submitted, in whole or in part, for any previous degree application.

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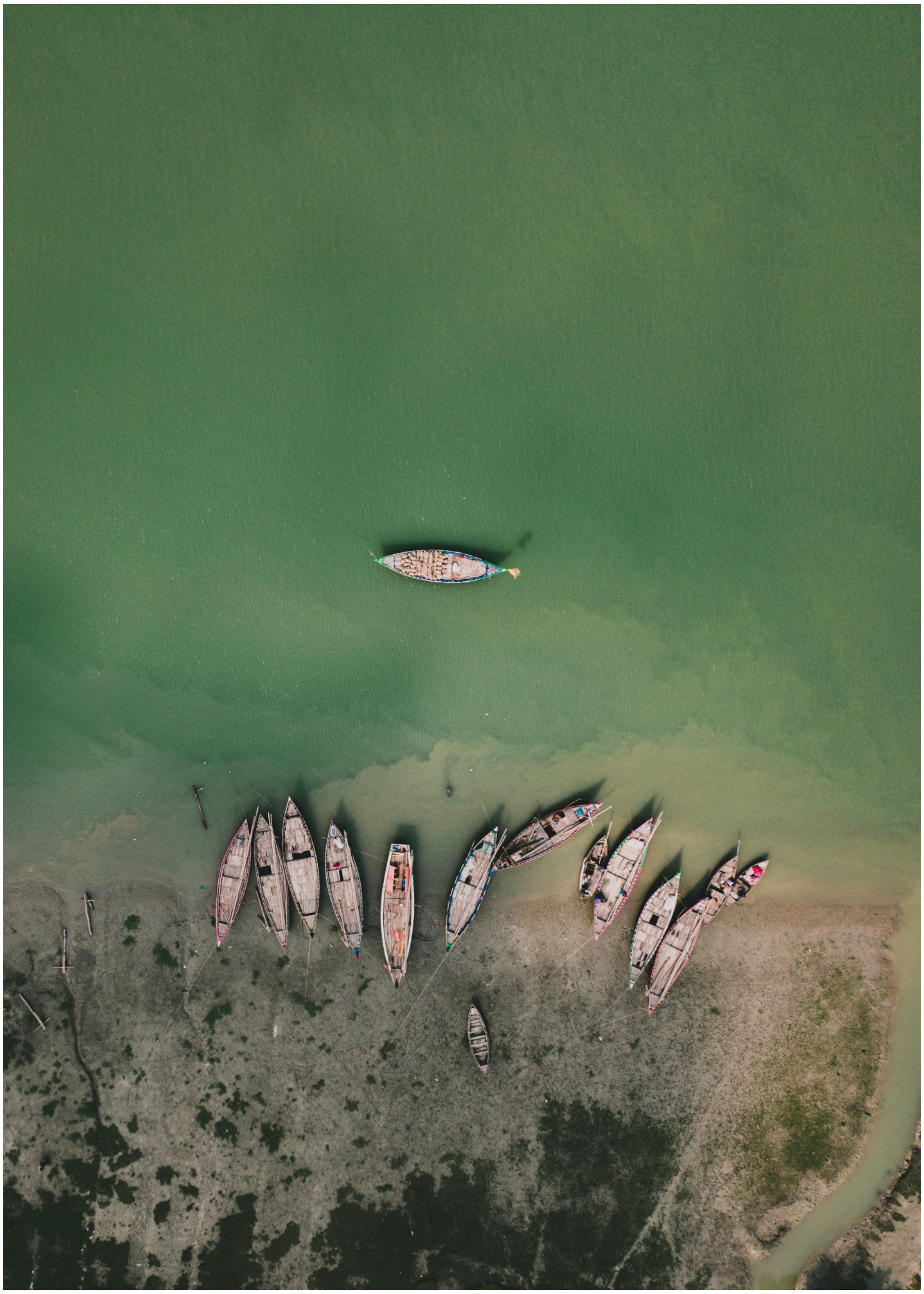
CHAPTER ONE: Introduction



Essence of the Bay of Bengal– aquatic life, soil, water and people ©Bengal Elasmo Lab

1.1. Context and background

The world has entered the 'Anthropocene', a geological epoch characterized by human-dominated threats changing fundamental earth dynamics (Crutzen, 2016). The collapse of fisheries across marine realms is among the most extensive and possibly irretrievable complications in this epoch (Pauly et al., 1998; Myers & Worm, 2003; Pandolfi et al., 2005). It has been reported that around 80% of the world's fisheries are either depleted or have already collapsed, with a prediction that the world's fisheries may collapse by 2048 (Worm et al., 2006; Costello et al., 2008). Factors such as overfishing (Jackson et al., 2001; Lotze et al., 2006), fishing throughout the food chain from lower trophic levels to top predators (Jennings & Kaiser, 1998; Pauly et al., 1998a; Springer et al., 2003) and a substantial economic dependence on fisheries have led to declining catch per unit effort (CPUE) in many fisheries (Myers & Worm, 2003) and the increasing possibility of extinction for many species (Dulvy et al., 2021; Tedesco et al., 2013; Casey & Myers, 1998). There is mounting evidence of the deleterious scenario facing marine ecosystems and species throughout the global oceans at different geographical scales. Hence, sustainably managing fisheries and conserving threatened species is one of the key sustainable development goals (SDGs).

Elasmobranchs (hereafter referred to as 'sharks') are one of the most threatened groups of marine fishes (Dulvy et al., 2021), with widespread and dramatic population declines reported in recent decades (FAO, 1998, 2000; Musick et al., 2000; Stevens et al., 2000). Nearly 37% of all sharks and ray species are now designated as 'Threatened' with extinction according to the International Union for Conservation of Nature (IUCN) Red List of Threatened Species (hereafter referred to as 'the IUCN Red List'), with 7.5% Critically Endangered and 12.9% are categorized as Data Deficient (Dulvy et al., 2021). Shark populations have declined by 80% or more globally, driven by high demand and unsustainable fisheries practices (Schindler et al., 2002; Clarke et al., 2007; Dulvy et al., 2008; Graham et al., 2010; Morgan et al., 2010). For example, Northwest Atlantic sandbar sharks, dusky sharks, hammerhead sharks, blacknose sharks, porbeagle sharks, shortfin mako shark population declins have been reported (Cripps et al., 2015; Cortés et al., 2006; NMFS, 2009; Hayes et al., 2009; Jiao et al., 2009; Campana et al., 2008; ICCAT, 2008). Additionally, some species (e.g., requiem sharks, giant guitarfishes, and guitarfishes) are listed in the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), which regulates the international trade in specimens of wild animals and plants to ensure that trade does not endanger the survival of the species. As such, there is a global need for sustainable stock management and conservation for sharks (Ward-Paige et al., 2013; Dulvy et al., 2014).

A combination of factors, including relatively slow growth rate, low fecundity, and late age of maturity (k-strategic, Camhi et al., 1998), resulted in low recovery rates from exploitation for most shark species. This is reflected in the poor record of biological sustainability (Shivji et al., 2002), which means the chances of rebuilding the stocks once depleted are slim. However, the resilience to fishing pressure differs amongst different species depending on biological parameters. Hence, different species of sharks will respond differently to the same amount of fishing pressure. Simpfendorfer & Dulvy, 2017 suggested that moving towards sustainable fishing is possible for some sharks. They reported that ~9% of the current global catch of sharks, from at least 33 species, is biologically sustainable (i.e., current biomass is greater than what is required to achieve Maximum Sustainable Yield). However, effective management was reported from a few developed countries with ample economic tools and resources to manage fisheries based on scientific information. Even in some countries with effective management strategies, these strategies on paper only sometimes translate into sustainable shark fisheries. Hence, the critical question that remains to be answered is whether existing approaches, including management tools and indicators of their efficacy/success for sustainable shark fisheries, are sufficient to maintain healthy populations at different scales and geographic contexts and if these approaches provide adequate mechanisms for conservation decision-making.

An absolute ban on shark catches and trade have been suggested in some cases to mitigate fishing mortality (e.g., Bangladesh, Haque et al., 2022a). However, substantial catches are incidental (i.e., bycatch) and form essential livelihood options for food security in developing countries (Dent & Clarke, 2015; Fischer et al., 2012; Simpfendorfer & Dulvy, 2017). Considerable shark catches and traded products come from countries marked by the perpetual poverty of coastal communities that depend highly on artisanal fisheries. Here, the fisheries are heterogeneous and complex, and social and economic dependence is high, making it extremely difficult to find a balance between social, economic and biological sustainability. Although some shark species have the potential to support sustainable fishing if adequate science-based management tools are established and implemented (Simpfendorfer & Dulvy, 2017), a balance between biological, economic, and social sustainability is only possible with empirical research. Furthermore, academic recommendations geared towards the biological sustainability of species tend not to address social and economic aspects at appropriate scales. Given all these factors, attaining biological, social, and economic sustainability for this group needs specialized consideration towards a unified sustainability model encompassing all crucial aspects. Information is scarce for both empirical research and the practical application of science-based management tools. Sustainability as a tool for shark conservation needs revisiting from all frontiers (biological, social and economic) at different geographical scales and conditions.

This study aims to address data gaps, establish how sustainable shark fisheries may be envisioned and evaluated under the current circumstances, and pinpoint strategies for that to be accomplished in the context of developing nations. This doctoral research takes the case study of shark fisheries in Bangladesh to understand the key issues and to consider potential practical conservation and management actions from a global south perspective. Here, I addressed the lack of critical data on shark fisheries in Bangladesh, considering species diversity, fishery characteristics and trade in detail through a combination of field observations, surveys and interviews. I also evaluated the risks of different shark species against contemporary fishing pressures.

1.2. Study region

The Bay of Bengal (Bangladesh region) will serve as a case study for this research (Figure 1.1).

The North Indian Ocean, especially the Bay of Bengal, is one of the world's most productive and unique ecosystems (Amaral et al., 2015). Eight countries surround the Bay of Bengal (e.g. Bangladesh, India, Indonesia, Malaysia, Maldives, Myanmar, Sri Lanka, and Thailand). These are developing with varying degrees of economic capacity, high population growth, poverty, and dependency on marine resources for Gross domestic product (GDP) growth (Mozumder & Shamsuzzaman, 2018). As such, all these countries deploy an unprecedented number of fishing fleets to harness marine resources. As a result, the whole ecosystem is lower trophic (comprising of organisms at the lower part of the food web), with 56.1% of the stocks reported to be "fully exploited" while 36.8% are "overexploited" (Ghosh et al., 2015; Dutta et al., 2017). Furthermore, the ecosystem and marine stocks are ever-changing due to both natural and anthropogenic causes. For example, shifting spawning grounds and reduced fecundity have been reported (e.g. in Hilsa *Tenualosa ilisha*, a teleost species, the largest artisanal fishery targeting a single species in Bangladesh) due to factors such as increased turbidity, flooding, changing salinity, and climate change effects (e.g. changing seawater temperature, increased acidity, deoxygenation, increased extreme weather events such as cyclones, and sea level rise). Frequent coral bleaching and increased pollution and toxicity are also reported (Miah et al., 2015; Vivekanandan et al., 2016; Achary et al., 2017; Debnath et al., 2018). These all pose threats to marine fauna in this region.

Despite this, knowledge in this region on shark diversity and their particular threats, habitat use, catch and bycatch trends, and a historical baseline is minimal, leading to the depletion of several species of global conservation concern (e.g. Ganges shark, giant guitarfish, and wedgefish, sawfish) (Haque et al., 2019a; Jabado et al., 2018; Kyne et al., 2020) occurring unnoticed. Hence, chances are high that many species are already depleted without being recorded or receiving any management actions (Jabado et al., 2015). The scenario is exacerbated by the presence of the region's highest shark fishing and product exporter countries (Okes & Sant, 2019), including the biggest hubs of the global shark fin and meat trade. As a result, Southeast Asia has been identified as a high-concern region for sharks (Clarke et al., 2007; Dent & Clarke, 2015). A much-improved regional and country-wise understanding of shark diversities and threats is crucial and urgent.

The scenario is particularly problematic for Bangladesh, situated at the northern tip of the Bay of Bengal. Whereas a number of useful studies have been conducted in India, Myanmar and Sri Lanka (Akhilesh et al., 2010, 2013a, b; Bineesh et al., 2014; Babu et al., 2011; Soundararajan & Roy, 2004; Sutaria et al., 2015), Bangladesh remains a conspicuous data gap in regards to a comprehensive understanding of its shark diversity and their vulnerabilities.

1.3. Case study: Bangladesh

The dynamic coastline of Bangladesh comprises three major regions: the Ganges tidal plain in the west, which includes the Sundarbans Reserve Forest (SRF); the Meghna deltaic plain in the south-central region, and the Chittagong coastal plain in the east (Barua, 1991; Brammer, 2014; Brammer, 2017), along the coastline of 710 km (Quder, 2010) (Figure 1.1). The SRF lies within the Ganges-Brahmaputra delta in the Bay of Bengal, formed by the confluence of the Ganges, Padma, Brahmaputra, and Meghna rivers. It is the world’s largest contiguous halophytic mangrove forest, spanning 10,000 km2, 62% of which is in south-western Bangladesh, and the rest in India (Islam & Wahab, 2005). The highly complex ecology of the SRF includes freshwater, estuarine and marine habitats, thereby making the SRF a unique habitat for many species (Gopal & Chauhan, 2006) including sharks.

With the world's largest flooded wetland and Asia's third-largest aquatic biodiversity after China and India, Bangladesh is known to be one of the most amenable fishing regions in the world. The favourable geographical position of Bangladesh includes a large number of aquatic species and offers plenty of resources to support the production of fisheries (Shamsuzzaman et al., 2017; Ghose, 2014). In 2014-2015, Bangladesh's total fishery production was 3,684,245 metric tons, of which 599,846 metric tons were obtained from marine waters, under which 84,846 metric tons were produced from marine fisheries industrial (trawl fisheries operating from Chattogram) and 515,000 metric tons were produced from artisanal fishing (IPAC, 2010; FRSS, 2016). The majority of the fishing in Bangladesh is conducted by artisanal fishers, employing gears including drift gill nets, set-bag nets, long lines, and trammel nets (FRSS, 2016) targeting hilsa, *Tenualosa ilisha* (Clupeidae) as a major finfish along with other species.

With an annual average export of 95 tonnes of shark fins between 2000 and 2011, the Food and Agriculture Organization of the United Nations (FAO) classified Bangladesh as the 19th-largest exporter of fins (Dent & Clarke, 2015). Due to the scope of IUU (Illegal, Unregulated, and Unreported) fishing, all figures are cautious, with the estimated catch being three to four times larger than the recorded landings (Dent & Clarke, 2015). Additionally, this is reflected in somewhat problematic global datasets. For instance, a reconstruction study indicated that marine landings are 157% higher than FAO's reported estimates (Ullah et al., 2014). According to this reconstruction research, which used data from 1993 to 2007, Bangladeshi seas saw the capture of between 7000 and 11000 t of sharks. The values varied from 5500 to 8500 t between 2008 and 2016. (Pauly et al., 2020). Notably, among the top 20 shark catchers globally, the numbers in some years were greater than Peru, Korea, Yemen, and Ecuador (Okes & Sant, 2019).

1.4. Coastal and marine fisheries

Bangladesh's Coastal and marine fisheries are primarily artisanal, multi-species, and multi-gear (Ullah et al., 2014). Industrial fisheries are also present, especially the bottom and mid-water trawlers (Karim et al., 2019). A total of 67669 boats with 188707 gear units are in operation (FRSS, 2017; Shamsuzzaman et al., 2017). There is substantial Illegal, Unregulated, and Unreported (IUU) fishing in the form of under-reported commercial catch, discarded bycatch, and subsistence catches (Ullah et al., 2014). It is apparent that the increasing number of current mechanized, non-mechanized, and industrial trawlers in the Bay of Bengal is the primary reason for overfishing, resulting in several negative impacts on the marine fisheries sector. The Bay of Bengal fishers use an array of fishing gear, each catching sharks and rays. The majority of the sharks are caught in artisanal fisheries as both bycatch and targeted (Halder, 2010; Ullah et al., 2014) and landed in areas adjacent to designated shark processing centres, especially in the largest landing sites in the south-eastern region (Ullah et al., 2014; Haque et al., 2018). However, most sharks are not targeted by industrial fishing and are often caught as bycatch, and some are not landed at the landing sites, there is a substantial absence of crucial information on the sharks being caught in industrial fisheries in Bangladesh's territorial waters (Zafaria et al., 2018). Despite such high fishing pressure on sharks in the region, it is extremely challenging to implement sustainable fisheries management tools in the absence of the empirical research needed to underpin decision-making.

1.5. Conservation and management of sharks and rays in Bangladesh

Despite international efforts, national research and conservation activities have been tremendously lacking in Bangladesh. In response to concerns regarding globally declining shark populations, limited accessible data and the recognised need for international cooperation for the sustainable management of sharks and rays, the International Plan of Action for the Conservation and Management of Sharks1 (IPOA Sharks) was adopted in support of the Food and Agriculture Organization of the United Nations (FAO) Code of Conduct for Responsible Fisheries (the Code) in 1999 (Fischer et al., 2012). The IPOA Sharks called on all concerned States to participate in the management of shark stocks by developing and implementing national plans of action for the conservation and management of sharks (NPOAs Sharks). A significant purpose of this was to facilitate member states to implement NPOAs. However, owing to a suite of difficulties (e.g. lack of regional taxonomic guides, absence of scientific data on stocks, diversity, distribution, lack of interest and resources and political will), exacerbated by the voluntary nature of the IPOA Sharks, progress during the first decade after the adoption was slow (Cavanag et al., 2008; Lack & Sant, 2011; Davidson et al., 2016). In the late 2000s, this started to gain momentum for the Bay of Bengal region when the Bay of Bengal Program Intergovernmental Organization (BOBP-IGO) in 2008 identified and initiated the importance of appropriate management of the shark fishery resources in the BOBLME countries (Bay of Bengal Large Marine Ecosystem: Bangladesh, India, Indonesia, Malaysia, Maldives, Myanmar, Sri Lanka, and Thailand). The first workshop of the BOBLME Working Group on Sharks, facilitated by FAO towards generating NPOAs, was held in the Maldives in 2011; however, Bangladesh was not present. Through several subsequent workshops, common problems were identified to be a lack of data and research, lack of human resources and trained personnel, poor stakeholder awareness, poor communication (e.g. scientists to politicians), and a shortage of funding for all relevant countries (Fischer et al., 2012).

Although Bangladesh was not present in the earlier project workshops, in 2012, an agreement was reached with the Bangladesh Fisheries Research Institute (BFRI) for implementing the BOBLME Work Plan in Bangladesh. BFRI agreed to carry out a survey of shark fisheries and to draft an NPOA Sharks for the conservation and management of shark resources in Bangladesh through a consultative process. Three Shark Stakeholders' Consultation Workshops were convened in Coastal Bangladesh. The resulting draft NPOA includes provisions for improving legislation and regulations, cooperation and collaboration with international and regional bodies, research, institutional capacity building, and awareness generation. A copy of the NPOA-shark has also been sent to the Department of Fisheries (DoF) within the Ministry of Fisheries and Livestock (MOFL) to validate the draft and endorsement and further necessary actions in 2014. However, no further action was taken after that. On the FAO website, the report is still designated as a draft, and the regional action plan is 'in progress' even after eight years by BFRI or DoF. However, in 2021 an amendment of the national law- the Wildlife (Conservation and Security) Act, 2012, was made protecting most sharks and rays by the Department of Forest under the Ministry of Environment, Forests and Climate Change. A separate National Action Plan for Sharks is underway, led by the Wildlife Conservation Society (WCS) in collaboration with partners.

There are some issues regarding jurisdiction, such as which department is responsible and able to conserve marine fauna. Conflicts over jurisdiction arise because Bangladesh has several jurisdictional entities (Department of Fisheries, Department of Forest, Department of Environment) that oversee wildlife, marine conservation, and fisheries management. Whereas the Department of Forest protects wildlife (both terrestrial and aquatic) through the national Act and designated protected areas, the Department of Fisheries has the responsibility and capacity to manage fisheries. There is a lack of communication and cooperation between them. This is especially true when there are competing goals, such as revenue generation from forestry and fisheries and the conservation of wildlife.

1.6. Aim and objectives

With the rising political interest of Bangladesh and the Bay of Bengal to conserve sharks, it is an important opportunity to create evidence and context-dependent management actions. There has been a history of conservation actions designed in a top-down manner and sometimes without much baseline data due to the absence of fisheries data in this region. Both strategies have the potential to be detrimental, oversimplify conservation efforts, and marginalize coastal populations. Sustainable, evidence-based fisheries management is crucial for conserving sharks and rays regionally and globally (Dulvy et al., 2021). Effective management requires assessing the status and trends of the natural resources (e.g., sharks), with emphasis on the intricacies of the entire ecological (e.g., habitat, fisheries) (Folke et al., 2005) and socio-economic (e.g., community-dependence on fisheries, trade, market dynamics) system. This is required to ascertain which management initiatives are most likely to be successful and whether they have had the desired impact (Jones et al., 2011). In order to prioritize activities in the face of resource limitations—a reality of the global south—assessing the system is also crucial.

As noted in Section 1.2, there have been limited studies on sharks, including fisheries, in the Bay of Bengal (Bangladesh region); therefore, the information required to underpin evidence-based management regimes needs to be improved.

This research, therefore, shall-

I. address the dearth of key data underpinning the understanding of shark fisheries in Bangladesh,
II. characterise fisheries, trade and market components to evaluate the impact of fisheries and trade on shark species,
III. use a risk framework to assess the spatially explicit 'areas of exposure' for threatened shark species to different artisanal fisheries.

1.7. Study system and approach

The empirical work within this thesis focuses on the southern part of Bangladesh (coastal region) (Figure 1.1). For the purpose of the thesis- the coastal region was divided into three regions, and the study sites were selected based on the availability of fishing communities and fish landing sites as follows:

I. South-western region- Khulna, Bagerhat, Sharankhola, Mongla and Dublar char
II. South-central region- Patharghata, Parerhat, Mohipur, Alipur, Kuakata
III. South-eastern region- Chattogram, Cox's Bazar, Teknaf and St. Martin's Island.

Communities in each of these locations are characterized by a heavy reliance on marine resources, with the capture, consumption, and sale of marine and coastal species contributing to fishers' total subsistence. This includes the capture of sharks and rays, both intentional and unintentional (i.e., bycatch). Due to the extremely diverse nature of the world's fisheries, historical variations in how by-catch has been defined nationally, ambiguities associated with bycatch-related terminologies, and individual fisher's decisions regarding the use of various parts of their catch, it is challenging to develop a standard definition of by-catch (FAO, 2011). However, for the purpose of the current study, we define by-catch as a catch that is not directly targeted using any specific gear, resulting in fishing mortality, including discards and unaccounted catches at the landing sites.

Shark and ray use can be categorized as both 'local' and 'commercial,' as some shark products are consumed locally by tribal populations and rays are also used for sustenance (usually meat). As opposed to this, other goods are exported worldwide (including meat, fins, mobulid gill plates, skin, vertebrae and cartilage). Due to interactions between local and worldwide market demand and other social and practical factors, shark and ray catch across the case study sites is driven by complex and varied factors.

I used a mixed-method approach to collect data on the themes and research questions of each chapter. A combination of data collection and analysis methods were used (e.g., literature review, field surveys, interviews). Between 2017 and 2021, I (with the help of field enumerators) conducted monthly field visits to conduct landing site surveys to collect data on the diversity of shark species within the artisanal catch (see methods section in Chapter 2). Additionally, I have conducted individual interviews with fishers, traders, boat owners and other relevant stakeholders and focus group discussions (FGDs) with fishers to characterise fisheries, trade and market for shark species (see methods sections in Chapters 3-6). Although there were many commonalities of the fishery characteristics within these different study sites, including overlapping fishing areas and seasonality depending on the targeted species and the gear employed, fishers used various fishing techniques to catch different taxa and life-stages for sharks and rays in different sites. The fishing communities were also different concerning vulnerabilities, economic capacity, availability of resources and some traditional practices.

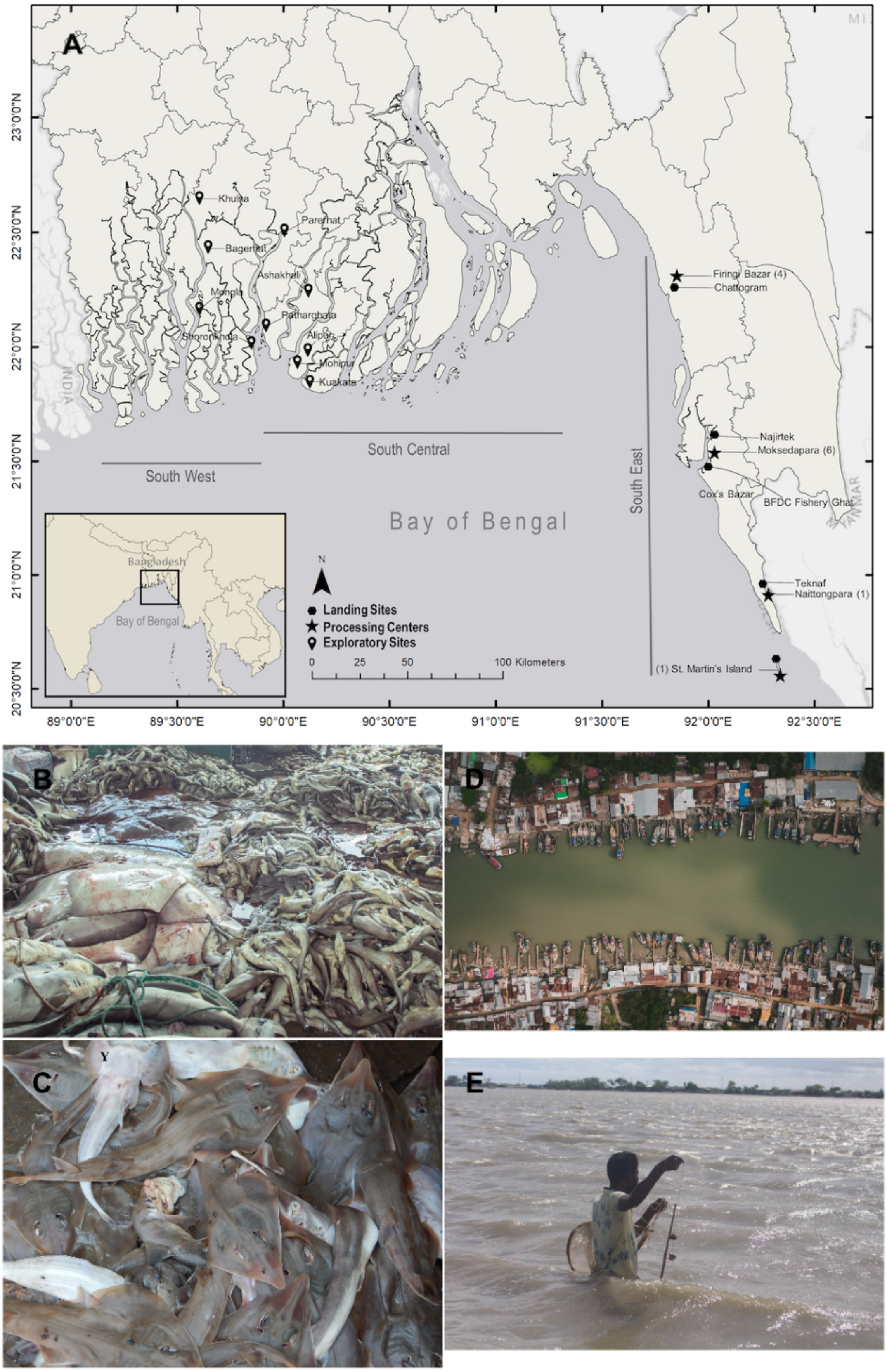


Figure 1.1. (A) The inset map shows the location of Bangladesh in the Bay of Bengal. Map: The Bangladesh coastline showing the northern arm of the Bay of Bengal. Pinpoint icons

show the exploratory field sites; hexagon icons indicate landings sites; and star icons indicate the processing centres, along the south-eastern coastline of Bangladesh. **(B-E)** Artisanal fishing and bycatch sharks and rays in Bangladesh.

1.8. Research in a data-poor region

The Bay of Bengal has limited information about fisheries and fishing operations. This region usually lacks the facilities, skills, and resources to compile and evaluate comprehensive data on fish and fisheries. Because of this, fisheries management plans in places with little access to data typically rest on incomplete knowledge, which can have a negative impact on the ecosystem and the local people and can sometimes promote unsustainable fishing methods. Because of a lack of considerable quality data, evaluating fish stock and stock health, measuring fishing efforts, and monitoring fishing's effects in these regions is challenging. Improvements in data collection, innovation in data collection methods, collaboration at all stages are required in fishery data-poor areas to manage sustainable fisheries and protect marine biodiversity.

Acquiring information on fisheries in areas with little data might be challanging. While used for years, data-gathering techniques like electronic tagging and satellite tracking or other technology-heavy methods may not be practical in these areas owing to a lack of infrastructure and resources, especially when establishing a baseline. As a result, techniques like local ecological knowledge (LEK) of fishers, citizen science, catch monitoring, estimating fishing efforts and biological sampling are frequently utilized to gather information on fish populations. LEK has been increasingly used in research globally. The expertise of fishers may be utilised to comprehend spatiotemporal abundance in the absence of historical data, for instance, to recreate long-term population trends and species distributions. Participatory mapping for identifying fishing grounds, critical habitats and areas of importance has been used by several studies and deemed extremely useful in the absence of long-term data. Furthermore, LEK has been included in conservation sciences to identify and evaluate marine protected areas (MPAs) for effective spatial management. Participation of local actors has been identified as one of the most crucial aspects of conservation success.

Fishing effort estimation entails considering the fishing operations' time, equipment, and locations. In contrast, catch monitoring involves keeping track of the quantity and weight of fish fishers catch. Via onboard sampling and market surveys, biological sampling entails gathering information on fish size, age, and species composition. To achieve proper data collection and analysis using these approaches, local communities, fishers, and researchers must be involved. Notwithstanding their drawbacks and uncertainties, these data-gathering techniques can offer useful information for managing sustainable fisheries in areas lacking data, especially by setting a baseline for more in-depth investigation using advanced methods (e.g., eDNA). It is essential to develop, test, and implement alternative, creative, and cost-effective techniques for monitoring fishing, capture, landing, and trade, such as those that use Environmental DNA (eDNA). The eDNA technologies have drastically changed our ability to locate and map the distribution of terrestrial and aquatic organisms. Recent studies suggest that the concentration of eDNA might be used as a rapid and effective indicator of biomass and/or abundance for fisheries stock assessments (Rourke et al., 2022). In addition, several monitoring methods may be used, such as citizen science, citizen science applications, satellite tagging of species, and merging satellite imaging and remote sensing data.

1.9. Thesis outline

Chapter 1. Introduction- The problem statement, background, study system overview, thesis outline, together with other research and implications that came from my DPhil are included in this first chapter of the thesis.

Chapter 2. Diversity- To advance the understanding of the impacts of artisanal fishing on sharks in the Bay of Bengal, this study addressed critical knowledge gaps in evaluating the shark species composition (with correct and up-to-date taxonomy) of landings across key sites, including seasonal occurrence, distribution, and relative abundance, together with efficacy of gear type and trade information. The findings provide crucial information for conservation and management actions both in this region and globally, including IUCN Red List assessments and the UN Sustainable Development Goals (SDGs). Recommendations are made for conservation and management, as well as priorities for future work.

This chapter is published as: Haque, A. B., Cavanagh, R. D., & Seddon, N. (2021). Evaluating artisanal fishing of globally threatened sharks and rays in the Bay of Bengal, Bangladesh. *PloS one*, 16(9), e0256146. https://doi.org/10.1371/journal.pone.0256146. Here, I was responsible for conceptualization of the study, data collection and curation, formal analysis, investigation, methodology, project administration, visualization, writing – original draft. NS and RDC were responsible for supervision, validation and writing – review & editing

Another paper was published from the same dataset as: Haque, A. B., White, W. T., Cavanagh, R. D., Biswas, A. R., & Hossain, N. (2021). New records of elasmobranchs in the

Bay of Bengal, Bangladesh: further taxonomic research is essential. Zootaxa, 5027(2), 211-230. 10.11646/zootaxa.5027.2.4 . Here, I was responsible for conceptualization of the study, data collection and curation, formal analysis, investigation, methodology, project administration, visualization, writing – original draft. This has been added in the appendix 1.2.

Chapter 3. Fisheries- In this chapter I present the results of a socio-ecological study I conducted in Bangladesh to characterize shark fisheries and evaluate their impact on threatened species based on the knowledge of local fishers. I utilise fishers' knowledge, observations and perceptions to: (1) characterise elasmobranch target and bycatch fisheries; (2) assess population trends of selected elasmobranchs and identify the reasons behind these trends; (3) explore regulations, i.e. the legal framework governing fishers' activities, and levels of compliance within this; and (4) characterise the attitude of fishers towards potential conservation measures. I evaluate these data and demonstrate the valuable role of local stakeholders in conservation decision making and conservation practice. The information presented in this study substantially improves our understanding of the complex dynamics of elasmobranch fisheries in Bangladesh and will inform conservation and management in the region and beyond.

This chapter is published as: Haque, A. B., Cavanagh, R. D., & Spaet, J. L. (2022). Fishers' tales—Impact of artisanal fisheries on threatened sharks and rays in the Bay of Bengal, Bangladesh. *Conservation Science and Practice*, e12704. https://doi.org/10.1111/csp2.12704. I was responsible for conceptualization, data collection and curation, formal analysis, investigation, methodology, project administration, resources, software, visualization, roles/ writing - original draft. RDC was responsible for validation, writing - review and editing and J LYS was responsible for methodology, validation, writing - review and editing.

Chapter 4. Trade- To evaluate trade dynamics of shark and ray (families: Rhinidae, Rhinobatidae and Glaucostegidae) products in Bangladesh, here, I analysed trade data from existing datasets and conducted field surveys and interviews with shark traders at landing sites and shark processing centres. I identified (1) The trade chain of elasmobranch products originating from the region and investigated its extent and dynamics; (2) Target species and products, as well as their values within landings and the trade; and (3) Unreported trade. Existing regulations were also evaluated in the context of global trade to conserve elasmobranchs in Bangladesh. The overarching objective of this chapter is to present information that will substantially improve our understanding of the complex elasmobranch trade dynamics in Bangladesh with important global implications which will inform immediate conservation prerequisites for the Bay of Bengal.

This chapter is published as: Haque, A. B., & Spaet, J. L. (2021). Trade in threatened elasmobranchs in the Bay of Bengal, Bangladesh. *Fisheries Research*, 243, 106059. https://doi.org/10.1016/j.fishres.2021.106059. I was responsible for conceptualization, data collection and curation, formal analysis, investigation, methodology, project administration, resources, software, visualization, roles/ writing - original draft. J LYS was responsible for methodology, validation, writing - review and editing.

Chapter 5. Market- I used an integrated approach to address knowledge gaps in characterising the trade for shark fins in the Bangladesh Bay of Bengal region. To do this, I applied socioeconomic data to the framework developed by Oyanedel et al. (2021a) that connects different market components of wildlife trade and draws together the various elements that influence the dynamics of the market. Using this framework, I evaluated the high-value fin trade market for elasmobranchs (shark and ray) within the data-limited fishery of Bangladesh. Based on the findings, I propose tailored solutions promoting socio-culturally and economically appropriate interventions for mitigating unsustainable trade.

This chapter is published as: Haque, A.B., Oyyanedel, R., Cavanagh, R.D. (2022). Mitigating elasmobranch fin trade: A market analysis for made-to-measure interventions. Science of The Total Environment. https://doi.org/10.1016/j.scitotenv.2022.160716. I was responsible for conceptualization, data collection and curation, formal analysis, investigation, methodology, project administration, resources, software, visualization, roles/ writing - original draft. RO was responsible for methodology and writing - review and editing and RDC was responsible for supervision, validation and writing - review and editing.

Chapter 6. Area of Exposure- I present the first risk assessment by evaluating the 3D spatial distribution of seven different fishing gears within artisanal fisheries and the overkap with distributional ranges of Critically Endangered (CR) taxa of sharks and rays. I developed and presented the assessment technique, showed how it was applied to CR shark and ray species in the Bangladesh region of the Bay of Bengal and discuss regional and global implications, fishery-specific management, caveats, and its potential usage by practitioners.

This chapter is currently with the co-authors for their comments before submitting to *a journal*. I am responsible for conceptualization, data collection and curation, formal analysis, investigation, methodology, project administration, resources, software, visualization, roles/ writing - original draft. C. Samantha Sherman, Nicholas K. Dulvy and Jay H. Matsushiba are responsible for conceptualization, methodology and helping in mapping. Rachel D. Cavanagh and Nathalie Seddon are responsible for conceptualization, supervision, validation and writing - review and editing.

Uncertainties and limitations regarding methods being used in this reseach has been discussed in each chapter.

1.10. Additional research

I have had the opportunity to lead and participate in a number of additional initiatives pertaining to conservation research and practice throughout my DPhil. These efforts resulted in six more lead-author published papers, one peer-reviewed species recovery blueprint, one (co-author) paper and one book chapter as a co-author (listed below) in addition to those included as part of my thesis. In addition, one lead-author and four co-authored papers are currently in review and two have been accepted to be published. I have also co-authored several (n= >68) global IUCN Red List assessments for sharks and rays.

Additional publications

1. Sherman, C. S., Simpfendorfer, C. A**., Haque, A. B.,** Digel, E. D., Zubick, P., Eged, J., Matsushiba, J. H., Sant, G., & Dulvy, N. K. (2022). Guitarfishes are plucked: undermanaged in global fisheries despite declining populations and high volume of unreported international trade. *bioRxiv*. https://doi.org/10.1101/2022.10.05.510982
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3. **Haque, A. (**2021). A Survival Blueprint for the Conservation of the Largetooth Sawfish, *Pristis pristis* in Bangladesh. EDGE of Existence Programme, Conservation and Policy, Zoological Society of London. http://www.edgeofexistence.org/species/largetooth-sawfish/#survival-blueprint
4. **Haque, A. B.,** Washim, M., D'Costa, N. G., Baroi, A. R., Hossain, N., Nanjiba, R., & Khan, N. A. **(2021).** Socio-ecological approach on the fishing and trade of rhino rays (Elasmobranchii: Rhinopristiformes) for their biological conservation in the Bay of Bengal, Bangladesh. *Ocean & Coastal Management*, *210*, 105690.

5. Nelms, S.E., Duncan, E.M., Patel, S., Badola, R., Bhola, S., Chakma, S., Chowdhury, G.W., Godley, B.J., **Haque, A.B.**, Johnson, J.A. and Khatoon, H. **(2021).** Riverine plastic pollution from fisheries: Insights from the Ganges River system. *Science of The Total Environment*, p.143305.
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7. **Haque, A. B.,** Leeney, R. H., & Biswas, A. R. **(2020).** Publish, then perish? Five years on, sawfishes are still at risk in Bangladesh. *Aquatic Conservation: Marine and Freshwater Ecosystems*.
8. **Haque, A. B.,** & Das, S. A. **(2019).** Records of the Critically Endangered Ganges shark *Glyphis gangeticus* (Müller & Henle, 1839) in the territorial waters of Bangladesh: urgency for monitoring rare and threatened species. *Endangered Species Research* (accepted).
9. **Haque, A. B.,** Das, S. A., & Biswas, A. R. **(2019).** DNA analysis of elasmobranch products originating from Bangladesh reveals unregulated elasmobranch fishery and trade on species of global conservation concern. *PloS one*, *14*(9), e0222273.
10. **Haque, A. B.,** & Das, S. A. **(2019).** First confirmed record of the Critically Endangered green sawfish *Pristis zijsron* from Bangladeshi waters. *Journal of fish biology*, *94*(1), 200-203.

Book Chapter

1. Sarker, M., **Haque, A. B**., Islam, M., & Jakariya, M. (2021). Climate Change Impact and the Conservation of Marine Turtles: A Case Study from Teknaf, Bangladesh. In *Climate Change in Bangladesh* (pp. 205-234). Springer, Cham.

IUCN Red List of Threatened Species Assessment (peer-reviewed)

1. Simpfendorfer, C., Fahmi, Bin Ali, A., D., Utzurrum, J.A.T., Seyha, L., Maung, A., Bineesh, K.K., Yuneni, R.R., Sianipar, A., **Haque, A.B.**, Tanay, D., Gautama, D.A. & Vo, V.Q. 2020. *Carcharhinus amblyrhynchos*. *The IUCN Red List of Threatened Species* 2020: e.T39365A173433550. https://dx.doi.org/10.2305/IUCN.UK.2020-3.RLTS.T39365A173433550.en.
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CHAPTER TWO: Diversity

2. Evaluating artisanal fishing of globally threatened sharks and rays in the Bay of Bengal, Bangladesh

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Catch of the day- the incredible variety of elasmobranch species ©Bengal Elasmo Lab

Abstract

Sharks and rays are at risk of extinction globally. This reflects low resilience to increasing fishing pressure, exacerbated by habitat loss, climate change, increasing value in a trade and inadequate information leading to limited conservation actions. Artisanal fisheries in the Bay of Bengal of Bangladesh contribute to the high levels of global fishing pressure on elasmobranchs. However, it is one of the most data-poor regions of the world, and the diversity, occurrence and conservation needs of elasmobranchs in this region still need to be adequately assessed. This study evaluated elasmobranch diversity and species composition in landings within the artisanal fisheries to address this critical knowledge gap. Findings show that elasmobranch diversity in Bangladesh has previously been underestimated. This study recorded over 160000 individual elasmobranchs through landing site monitoring, comprising 88 species (30 sharks and 58 rays) within 20 families and 35 genera. Of these, 54 are globally threatened according to the IUCN Red List of Threatened Species, with ten as Critically Endangered and 22 as Endangered—almost 98% juvenile landings (69–99% for different species). Small-bodied sharks and rays have disproportionately greater relative abundances within the landings. Several previously common species were rarely landed, indicating potential population declines. The catch pattern showed seasonality and, in some cases, gear specificity. Overall, Bangladesh was found to be a significant contributor to shark and ray catches and trade in the Bay of Bengal region. Effective monitoring was not observed at the landing sites or processing centres. A series of recommendations were provided to improve future research and conservation actions. These include the need for improved taxonomic research, enhanced monitoring of elasmobranch stocks, and the highest protection level for threatened taxa.

2.1. Introduction

Elasmobranchs (sharks and rays) are the most threatened marine megafauna: around 37% face extinction, and 7.5% are Critically Endangered (Okes & Sant, 2019; IUCN, 2020), according to the International Union for Conservation of Nature (IUCN) Red List of Threatened Species (hereafter IUCN Red List) (Dulvy et al., 2014; Bräutigam et al., 2015). A combination of factors has led to such high extinction risk e.g., relatively slow growth rate, low fecundity, and late age of maturity which result in low population recovery rates (Schindler et al., 2002). The high vulnerability to overexploitation by bycatch and target fisheries together with habitat degradation have led to many of the world's sharks and rays being threatened with extinction (Dulvy et al., 2008; MacNeil et al., 2020; Yan et al., 2021; Pacoureau et al., 2021). As such, there is a global need for sustainable stock management and conservation (Ward-Paige et al., 2013; Dulvy et al., 2014).

To implement effective management strategies, accurate identification with geographically appropriate taxonomic information, knowledge on diversity, seasonal occurrence, and gear specific catch patterns and trade are crucial (White et al., 2012; White et al., 2017; Arai et al., 2019). Taxonomic information is crucial mainly because of inherent variation in biological characteristics among species influences their vulnerability. For instance, Rhinopristiformes rays (sawfish Pristidae, wedgefish Rhinidae, guitar- fish Rhinobatidae, giant guitarfish Glaucostegidae) were identified to be the most threatened by many studies (Dulvy et al., 2016; Moore, 2017; Jabado, 2019; Kyne et al., 2020) as opposed to many shark species capable of supporting sustainable fisheries (Dulvy et al., 2017). Moreover, this specific information help contextualise the fishery problems that can differ geographically and where catch reports are patchy or conservative. Additionally, misidentified or aggregate catch reports are of limited use for designing effective conservation strategies (Camhi et al., 2009). As such, elasmobranch diversity needs to be well understood to appropriately assess the conservation needs against the exploitation of different species.

Due to difficulties in identifying many commonly fished elasmobranchs (e.g. carcharhinid, centrophorid, and triakid sharks, stingrays, skates, devil rays) (Tillett et al., 2012; Veríssimo et al., 2014; Bineesh et al., 2016), diversity in many parts of the world is undetermined. Given widespread taxonomic issues, sampling constraints and limited local expertise in many areas, there is a clear need for improved taxonomic studies, especially in the developing countries of the Indo-Pacific region (Bonfil, 2003; Fischer et al., 2012; Bineesh et al., 2016; Kyne et al., 2020). Despite being a biodiversity hotspot, elasmobranch diversity of the Indo-Pacific is poorly known (Bonfil, 2003; Fischer et al., 2012; Bineesh et al., 2016; Kyne et al., 2020), especially in south-east Asia (Dent & Clarke, 2015; Arai et al., 2019;

MacNeil et al., 2020), including the Bay of Bengal region. The Bay of Bengal has a high elasmobranch species diversity, including endemic species, making it of high conservation importance. Moreover, a substantial proportion of taxa present here are genetically distinct from their closest relatives in other regions (Naylor et al., 2012), bringing additional conservation challenges.

Limited knowledge of elasmobranch diversity and their particular threats, habitat use, catch and bycatch trend, is leading to depletion of several species with global conservation concern in the Bay of Bengal region (e.g. Ganges shark, giant guitarfish, and wedgefish, sawfish amongst many) (Arai et al., 2019; Kyne et al., 2020; Haque et al., 2019; Jabado, 2018). In addition, a historical baseline is lacking. Hence, the chances are high that several species are already depleted without being recorded or receiving any conservation or management actions (Jabado et al., 2015; Arai et al., 2019). The scenario is exacerbated by the presence of the highest shark fishing and product exporter countries in this region (e.g. India) (Lack & Sant, 2009; Dent & Clarke, 2015; Okes & Sant, 2019). Indeed, India was one of the top shark fishing countries from 2007 to 2017, landing on an average of 73842 tonnes of sharks (Dent & Clarke, 2015), contributing up to 9% of reported global landings (Bineesh et al., 2014; Dent & Clarke, 2015; Kizhakudan et al., 2015; Barnes et al., 2018). Although Bangladesh contributes significantly to the marine fisheries sector in the Bay of Bengal region, surveys regarding elasmobranchs in Bangladesh have been limited (Hoq & Haroon, 2014) with several questionable reports due to misidentified species or less knowledge on the range of these species (Hussain, 1970; Hoq et al., 2011). Only a few studies exist on the taxonomy and diversity of this group with sporadic catch pattern analysis and no or limited biological or ecological studies. Elasmobranchs were excluded from marine fisheries research for a long time due to difficulties in taxonomy, handling large specimens, resource constraints, and, most importantly, an underestimation of value in the formal marine fisheries sector, which has led to Bangladesh to be one of the most data-deficient countries globally.

To advance the understanding of the impacts of artisanal fishing on elasmobranchs in the Bay of Bengal, this study addressed critical knowledge gaps in evaluating the elasmobranch species composition (with correct and up-to-date taxonomy) of landings across key sites, including seasonal occurrence, distribution, and relative abundance, together with efficacy of gear type (i.e. to understand what gears are prone to more bycatch of elasmobranchs) and trade information. On this basis, the current status of the impacts of fisheries on elasmobranchs in the Bay of Bengal is discussed. The findings provide crucial information for conservation and management actions both in this region and globally, including Red List assessments and the UN Sustainable Development Goals (SDGs). Recommendations are made for conservation and management, as well as priorities for future work.

2.2. Materials and methods

2.2.1. Geographic context regarding threats and fisheries of elasmobranchs

The Bay of Bengal is a highly productive and heavily exploited ecosystem (Amaral et al., 2017). Due to the high productivity of this region, the historical fishing pressure has always been high with new and emerging fisheries (Arai et al., 2019). Bay of Bengal is surrounded by eight developing countries (Bangladesh, India, Indonesia, Malaysia, Maldives, Myanmar, Sri Lanka and Thailand) with a high dependency on marine resources (Mozumder & Shamsuzzaman, 2018). Hence, all these countries deploy an high number of fishing fleets to harness marine resources overexploiting the stocks for decades (Ghosh et al., 2015; Dutta et al., 2017; Pauly et al., 2020). In addition to overfishing and harmful fishing techniques, such as industrial bottom and midwater trawling, Illegal, Unreported and Unregulated (IUU) fishing and high discard rates in different fisheries, other anthropogenic activities are problematic, including pollution (e.g. toxic run-off, heavy metal pollution and oil spills), harmful coastal agriculture and aquaculture practices, unregulated tourist activities (e.g. plastic pollution, light and noise pollution) and climate change (Sarwar & Khan, 2007; Debnath, 2009; Miah, 2015; Vivekanandan et al., 2016; Ahammed et al., 2016; Kibria et al., 2016; Achary et al., 2017; Sunny et al., 2017; Pedde et al., 2017; Hassan & Rahimi, 2017; Shamsuzzaman et al., 2017; Kibria & Haroon, 2017; Islam & Bhuiyan, 2018; Kay et al., 2018; Mozumder & Shamsuzzaman, 2018; Alam, 2018; Baki et al., 2018; Islam et al., 2018; Rezaie et al., 2019; Begum et al., 2020; Rani et al., 2020). Documented impacts of these include habitat degradation, shifting spawning grounds, frequent coral bleaching (Debnath, 2009; Miah, 2015; Vivekanandan et al., 2016; Achary et al., 2017), eutrophication, and a range of climate change impacts (e.g. sea-level rise, warming and ocean acidification) (Sarwar & Khan, 2007; Rezaie et al., 2019), all of which augment the problem, leading to shifting baselines and increasing the risk of stock collapse.

Bangladesh is situated at the northern tip of the Bay of Bengal. The dynamic coastline of Bangladesh comprises three major regions: the Ganges tidal plain in the west, which includes the Sundarbans Reserve Forest; the Meghna deltaic plain in the south-central region, and the Chittagong coastal plain in the east (Barua, 1991; Brammer, 2014; Brammer, 2017), along the coastline of 710 km (Quader, 2010). The Sundarbans Reserve Forest lies within the Ganges-Brahmaputra delta in the Bay of Bengal, formed by the confluence of the Ganges, Padma, Brahmaputra, and Meghna rivers. It is the world's largest contiguous halophytic mangrove forest, spanning 10000 km^2, 62% in south-western Bangladesh, and the rest in India (Islam & Wahab, 2005). Its highly complex ecology includes freshwater, estuarine and marine habitats, thereby making it a unique habitat for many species (Gopal & Chauhan, 2006), including elasmobranchs.

The fishing pressure in Bangladesh is substantially high (Shamsuzzaman et al., 2017). The majority of the fishing in Bangladesh is conducted by artisanal fishers, employing gears including drift gill nets, set-bag nets, long lines, and trammel nets (DoF, 2017), targeting mostly hilsa, *Tenualosa ilisha* (Clupeidae) with some number of elasmobranchs either as bycatch or target (Haque in prep.). A total of 67669 boats with 188707 gear units are in operation in the coastal and marine waters with 247 industrial trawlers (in 2019) (Shamsuzzaman et al., 2017, DoF, 2017). There is substantial IUU fishing, in the form of under-reported commercial catch, discarded bycatch (e.g. sharks) (Kumar et al., 2019) and subsistence catches (Ullah et al., 2014), exploiting about a total of 442 species of fish and 915 species of other marine organisms which were reported from the coastal and marine waters (Quader, 2010).

Elasmobranchs are threatened in Bangladeshi waters due to substantial bycatch with unselected gears (Hoq et al., 2011; Begum et al., 2020), opportunistic catch and targeted ray fisheries. This is exacerbated by the existing international fin and meat trade (Haque et al., 2018) and poor landing monitoring mechanisms in place. Most significantly, they receive limited conservation actions due to data deficiency, lack of community awareness, facilitation in taking sustainable approaches, and finally, resource constraints. Bangladesh remains a conspicuous data gap regarding a comprehensive understanding of its elasmobranch diversity and catches despite being a highly fished region (Ullah et al., 2014; Ghose, 2014; Shamsuzzaman et al., 2017; Zafaria et al., 2018; Badhon et al., 2019; Pauly et al., 2020).

The only established full record for elasmobranchs in Bangladesh is presented by the FAO report of the Bay of Bengal Large Marine Ecosystem Project until 2020 (Hoq et al., 2011; Hoq & Haroon, 2014) supplemented by a few research articles (Badhon et al., 2019). These are likely not entirely up to date. Morphological similarities and the presence of undescribed and cryptic species likely hampered identifications (Faria et al., 2013) along with the incorporation of several species with geographical distributions reported outside of this region. The inadequate amount of directed research in elasmobranch diversity, distribution, and biology gives rise to scepticism about the comprehensiveness and precision of the available checklist. This has led to a limited assessment of species-specific vulnerability, which has contributed to uninformed protection of some species under national law regarding species protection (e.g. the Spadenose shark *Scoliodon laticaudus* is listed as Near

Threatened on the IUCN Red List, yet is under national protection in schedule I (highest level of protection against catch and trade) (Haque et al., 2018), whereas the common shovelnose ray *Glaucostegus typus* is Critically Endangered on the IUCN Red List and listed in the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) App. II, yet not protected under national law).

2.2.2. Study sites

Between January and November 2016, exploratory field visits in fourteen landing sites in three coastal regions of Bangladesh were conducted. They were: South-west (Khulna, Bagerhat, Mongla, Shoronkhola), South-central (Mohipur, Alipur, Parerhat, Patharghata, Ashakhali, Kuakata) and South-east (Chattogram, Cox's Bazar, Teknaf, St. Martin's Island) regions (Figure 2.1). These exploratory visits were conducted to identify the sites with the highest concentration of elasmobranch landings, processing centres and trade hubs. The south-east region was selected as this region is the hub for international elasmobranch trade (Haque et al., 2018), including 12 sizeable exclusive shark processing centres with substantially high production and trade capacity and contributing to landing from all other regions. This region was also identified as harbouring the biggest landing sites by volume of marine fish landing (Ullah et al., 2014).

The current research project was primarily a fishery-dependent assessment enabling a comprehensive study in the south-east coastal region. The focus was on large landing sites that landed fish from vessels through-out the three zones. Small, informal landing sites were excluded from the study as the landing were negligible compared to the sites selected for ensuring better time efficiency covering the most landings within the study period.

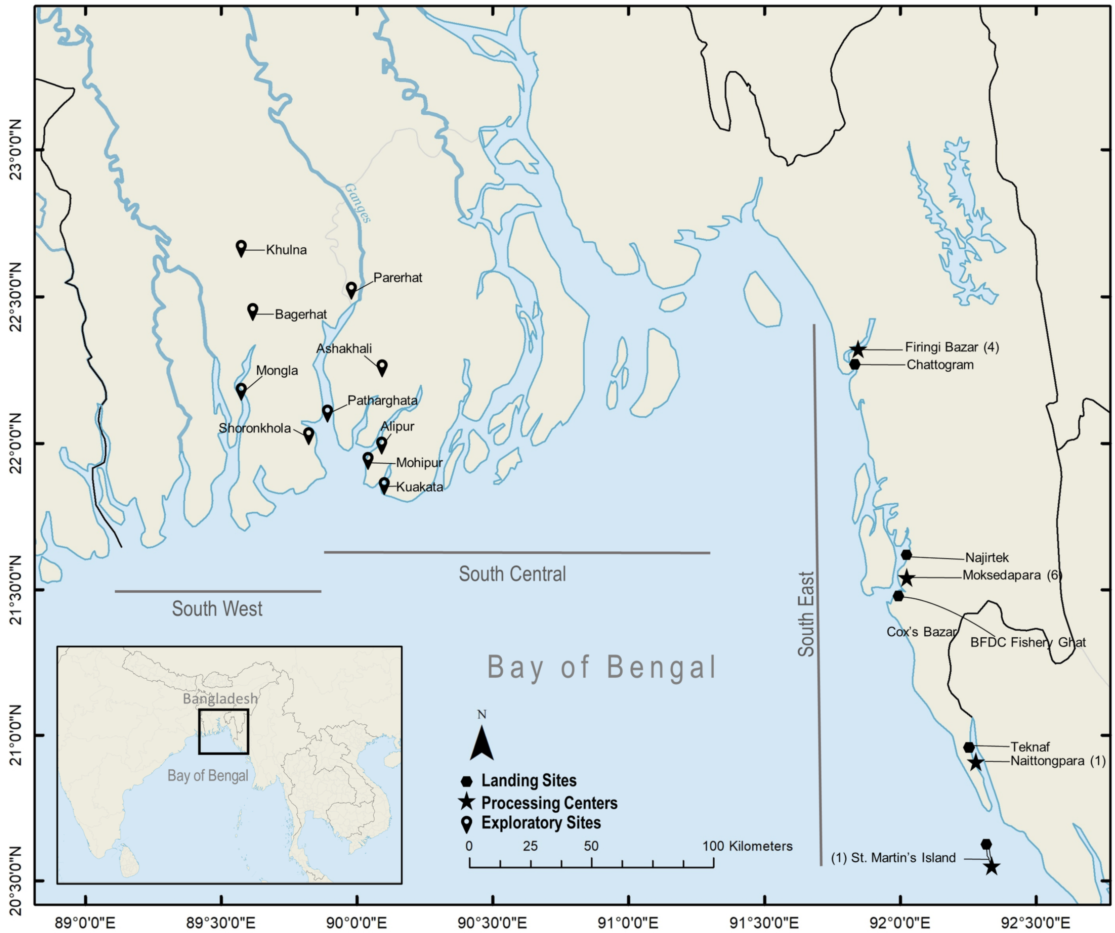

Fig 2.1. The inset map shows the location of Bangladesh in the Bay of Bengal. Map: The Bangladesh coastline showing the northern arm of the Bay of Bengal. Pinpoint icons show the exploratory field sites; hexagon icons indicate landings sites; and star icons indicate the processing centres, along the south-eastern coastline of Bangladesh.

2.2.3. Preparation of an annotated checklist

Before the field studies, an annotated checklist of all elasmobranchs reported from Bangladeshi waters was prepared from published documents found through a literature review (Compagno et al., 2005; Froese & Pauly, 2009; Hussain, 1970; Hoq et al., 2011; Roy et al., 2012, 2013, 2014, 2015; Hoq & Haroon, 2014; Ghose, 2014; Last et al., 2016; Hasan et al., 2017; Haque et al., 2018; Zafaria et al., 2018; Haque et al., 2019a, 2019b; Ahmed et al., 2020; Dutta et al., 2020; Habib et al., 2020; Habib & Islam, 2020).

For this review, all available peer-reviewed articles from the Web of Science were collected using the search terms 'Bay of Bengal* elasmobranchs', 'Bay of Bengal* elasmobranchs or sharks', 'Bangladesh* elasmobranchs or sharks or rays or batoids or sawfish', Bangladesh*elasmobranchs', Bangladesh*sharks and rays', 'Bangladesh* sharks' and 'Bangladesh* sharks or rays'; and reviewed. Government reports (Department of Fisheries, Fisheries Resource Survey System (FRSS) reports), Non-government Organisations (NGO), International Non-government Organisations (iNGO), the Bay of Bengal Large Marine Ecosystem (BOBLME) Project report, Indian Ocean Tuna Commission (IOTC) reports and other grey literature (newspaper articles) were searched from their websites, Google search engine and Google Scholar for completeness. Elasmobranch scientists in Bangladesh were personally contacted for any unpublished data or non-peer-reviewed works. Websites with global fisheries data [(e.g. Fish- base, Fishbase Bangladesh, the CITES trade database, the United Nations Commodity Trade Statistics Database (UN Comtrade)] were searched for additional information. Comments on previously misidentified reported species, possible occurrences, and species requiring further confirmation were made. Species have also been added to this list which considered as possible presence as the Bay of Bengal has been reported to be a range but was not yet reported in any national studies. The IUCN Red List assessment category, CITES, CMS and National protection statuses for each species are also listed. Validity status and occurrence from the region was confirmed and evaluated following recent publications and globally accepted range studies (Last et al., 2016).

The checklist was modified after the field surveys conducted during 2015–2020 by the authors when a new record was made. Information shared by colleagues with evidences was also included when needed for completeness until December 2019.

2.2.4. Surveys

2.2.4.1. Landing site and processing centre surveys

Between the 4th of January 2017 and the 30th of June 2017, surveys targeting elasmobranchs' (classified as shark, Rhinopristiformes ray and other rays) morphometric data were conducted at landing sites for 15 days each month. Additionally, between 2018 and 2019, opportunistic landing data were collected specifically on the diversity of elasmobranchs. Large piles of landings comprising hundreds of small- sized rays were excluded from the study due to difficulties in accurately sampling these. Thus, the results of this study are limited in regared to species-specific comparison of relative abundance in landings.

The identifications were conducted by following a process of two-fold identifications. First, easily identifiable species (such as tiger sharks, giant freshwater rays, etc.) were readily identified and documented on the data sheet at landing sites. Species with similar morphological characteristics were preliminarily identified at landing sites; genetic samples were taken, and three to four photos were taken to morphologically identify them at the second stage and compare them with the landing site preliminary ID. Eight local data collectors helped with the data collection process, and two research assistants maintained the data quality and curation whom the first author trained. Apart from that, experts were consulted with photos to confirm representative IDs. Genetic analysis of 500 samples was completed (Haque, unpubl. data), which also aided the identification.

The number of elasmobranchs were counted in the landing sites. The range of the lengths of species landed was documented, and a sub-set of the counted individuals was measured for detailed biological parameters such as total length (TL) to the nearest cm and weighed (body weight, BW) in kg. TL for all specimens was measured when fins in caudal and/or tail parts were present, while BW could not be measured for several specimens because the specimens were too heavy and/or their fins had been cut. Photographs of all available whole-bodied elasmobranchs were taken for identification to the lowest possible taxonomic level using the keys of Compagno et al., 2005 and Last et al., 2016.

Landing site surveys (Figure 2.2) were made between 7 am and 2 pm when all landed species were either locally bought or packaged and sent to the processing centres. Here, a particular corner of the landing area was designated for elasmobranch landing and trade. On several occasions, a substantial number of sharks were landed at night, and the data was collected when possible. In Chattogram the survey was conducted in four exclusive shark processing centres, as no designated landing area was found, and all elasmobranch catches were brought to these centres after being purchased in auctions.

A total of twelve processing centres in Chattogram, Cox's Bazar, Teknaf and St. Martin's Island were visited to collect information on any additional landings and/or landings that were transported to these centres from the south-central or south-west regions. Traders and workers in the centres were asked to differentiate amongst the landings to avoid double counting any specimens. Although the presence of largetooth and green sawfish has been presented and discussed in other studies (Haque et al., 2019a, 2021a), this record has been incorporated here for a complete understanding of species composition in artisanal catch and diversity.

Study permit

A permit was granted by the Department of Forest to study the landed elasmobranchs in the different landing sites and for the collection of DNA samples (reference number of letter permitting DNA sampling- 22.01.0000.101.23.2020.1055). Permission was taken verbally to sample specimens from private elasmobranch processing centres from the owners. No permit was needed from any Institutional Animal Care and Use Committee or equivalent animal ethics committee as only fishes already dead were sampled, and the method of sacrifice was not applicable.

Fig 2.2. Species at landing site surveys. The piles of elasmobranchs in Cox's Bazar (A-B) include more than 3000 individuals; (C) Assorted landing of rays (*Mobula* spp. *Gymnura* sp.); (D) *Himantura* spp. and *Maculabatis* sp.; (E) Neonates of *Rhina ancylostoma*; (F) *Sphyrna lewini* and *Scoliodon laticaudus*; (G) *Glaucostegus granulatus* and *G. obtusus* and (H) Dried smaller sharks at a processing centre in Cox's Bazar.

2.2.5. Additional data on seasonality, distribution, and gear used

Information on the landing dates (i.e. season), distribution of landing (i.e. where it was landed), and gear used to catch the particular elasmobranchs was documented where possible. To understand the relationship between species total length (TL), gear mesh size, and seasonality, multiple one-way ANOVA tests comparing TL ~ season, and TL ~ gear were performed. The aim being to recommend potential measures such as gear modification or temporal conservation measures (e.g. fishing bans or quota for a certain season).

Further analysis was also performed to evaluate which gear was catching more elasmobranchs than others, and to the species-specific level where the data was available. One-way ANOVA tests were performed to estimate how different quantitative dependent variables (i.e., total number of specimens landed and the total length (TL for sharks and rhino rays) of landed specimens) changed following the different levels of categorical variables or factors (i.e., season, gear and species). Graphical checks of the assumption of the models were carried out for constancy of variance, normality of errors and homoscedasticity using the *plot(aov(model))* function in R (R Core team, 2020). To investigate the effects of the different factor levels, the *summary.lm* function was used. For evaluating the effect size of the ANOVA model, Eta Squared, Omega Squared and Cohen's F measure were calculated using *anova_stats(model)* function. Finally, a Tukey's Honestly Significant Difference (Tukey's HSD) post-hoc test for pairwise comparisons was performed. For all data analysis and visualisation preparation, R (R Core team, 2020) was used.

2.2.6. Relative aggregate landing analysis

Elasmobranch landing data from Sea Around Us (http://www.seaaroundus.org/data/) was downloaded and analysed to compare Bangladesh's landing data with other Bay of Bengal countries and to evaluate Bangladesh's contribution to the elasmobranch fishery in this region.

2.3. Results

2.3.1. Annotated checklist

Elasmobranchs were recorded from within almost all ecosystem and habitat types of the Bay of Bengal (Figure S2.1). An annotated checklist was made. However, it is assumed that the list is still incomplete and needs further taxonomic work for several families.

2.3.2. Surveys: Species composition at landing sites and processing centres

2.3.2.1. General findings. A total of 162198 individual elasmobranchs were counted. These belonged to 88 species (30 species of sharks, ten species of Rhinopristiformes rays and 48 species of other rays). The total number of species documented were approx. 77.3% of all species present in Bangladesh (Figure 2.3) belonging to 20 families (eight families of shark and 12 families of rays; seven species need further taxonomic confirmation).

Among all the elasmobranchs that were counted, 94.24% (n = 152849) were sharks, and 5.76% (n = 9349) were rays since rays were more challenging to identify as a result of being lying on their dorsal side except for Rhinopristiformes rays which were landed on their dorsal side making it easier to identify. Almost 29.26% of sharks were identified to species level as piles of smaller individuals were identified to species level (Table 2.1). The number of rays was lower than sharks as data on rays were collected when they are landed on their dorsal side hence identifiable, and therefore does not reflect relative abundance. A total of 1120 individuals belonging to 28 species of sharks and Rhinopristiformes rays were sampled for detailed biological and morphometric information (Table 2.2).

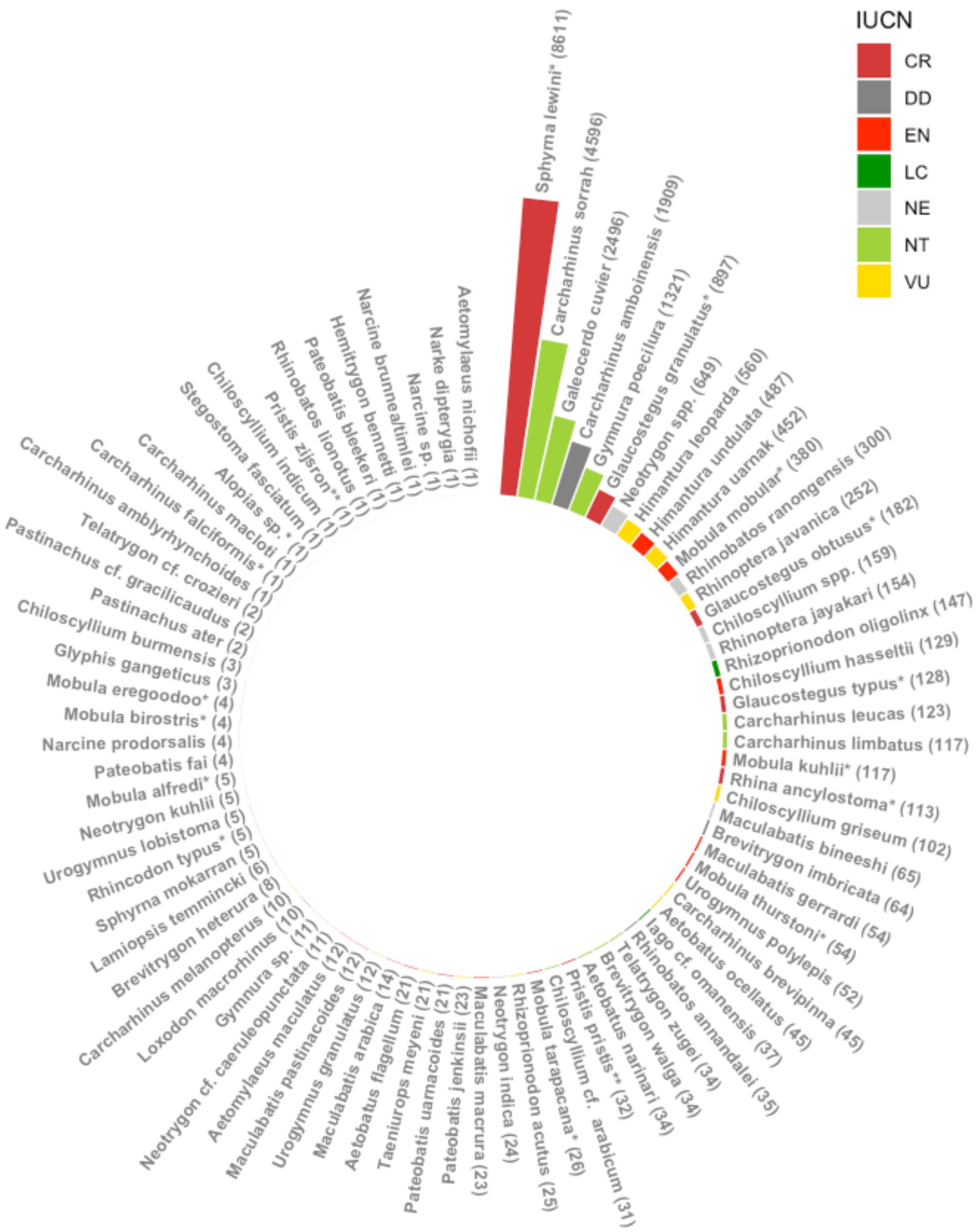

Fig 2.3. Elasmobranchs documented from the landing sites. Species composition of total elasmobranchs for both sharks and rays recorded by the authors from Cox's Bazar, Chattogram and St. Martin's Island during the study period. Species are listed and grouped according to frequency (highest to lowest). *Scoliodon laticaudus* (n = 26280) was not added to this figure for ensuring better visual for the graph. IUCN Red List status is given for each species, or a higher taxon, and colour coded. Here, LC—Least Concern (bottle green), NT—Near Threatened (light green), VU– Vulnerable (yellow), EN- Endangered (red), DD- Data

Deficient (grey), NE—Not Evaluated (light grey). Species with ** means listed in CITES app. I and * means listed in CITES CITES App. II.

2.3.2.2. Sharks. A total of 152849 individual sharks belonging to 30 species of eight families were counted and recorded between 15 January 2017 and 21 June 2017 at the four landing sites. Of these, 44722 (29.26%) were identified to species level based on morphological characteristics. The most commonly observed shark species in the landings were the Spadenose shark *Scoliodon laticaudus* (n = 26280; 58.85%), followed by the Scalloped hammerhead shark *Sphyrna lewini* (n = 8611; 19.29%). The Spottail shark *Carcharhinus sorrah*, the Tiger shark *Galeocerdo cuvier* and the Pigeye shark C. *amboinensis*, comprised approximately 10.29%, 5.59% and 4.27%, of the total sharks, respectively (Table 2.1). Bamboo sharks *Chiloscyllium sp*., Blacktip sharks *C. limbatus*, Bull sharks *C. leucas*, and Grey sharpnose sharks *Rhizoprionodon oligolinx* were also present in lower number. Milk sharks *Rhizoprionodon acutus*, Hardnose shark *C. macloti*, Spinner sharks *Carcharhinus brevipinna*, Graceful sharks *Carcharhinus amblyrhynchoides*, Ganges sharks *Glyphis gangeticus*, Broadfin sharks *Lamiopsis temminckii* and the Thresher shark *Alopias* sp. were in low numbers, with each species comprising less than 1% of the total landings.

Occasionally, individuals of *S. laticaudus*, *R. acutus*, *R. oligolinx* and pups of *C. sorrah*, *C. limbatus*, *C. macloti* and several unidentified requiem sharks were landed in piles of up to 10000 individuals. Identification of all individuals within the pile was difficult though a total of 107743 such individuals were labelled as unidentified smaller sharks.

Table 2.1. List of all shark and ray species recorded between January 2016 and December 2019, Global IUCN Red List of Threatened status (EN: Endangered; NT: Near Threatened; VU: Vulnerable; DD: Data Deficient; LC: Least Concern); NE: Not evaluated), assessment dates, CITES, CMS and National protection status are given with commented on their identifications.

Family	**Scientific name**	**Common name**	**Local name, Bangla**	**Number**	**Notes**	**CITES**	**IUCN (Year of last assess.)**	**National protection**	**CMS**
				Sharks					
Carcharhinidae	*Scoliodon spp.*	Spadenose Shark and New Spadenose Shar	Churi hangor, Kala hangor	26280	Gravid females with embryos (embryos, n=11; TL=5.08 cm in one individual) in January. Fully grown pups upon dissention in April (5-9 pups, TL= 12.7 cm), gravid female TL= 45.72-53.34 cm. *S. macrorhynchos* was relatively uncommon.	Not listed	NT (2005)	Schedule I (*Scoliodon laticaudus)*	Not listed
Carcharhinidae	*Carcharhinus sorrah*	Spottail Shark	Lota hangor	4596	40 gravid females in March and April (TL=106.68-158.5; mean=128.12±20.16). Two dissected, 5 pups each, all female (TL= 45.2-76.2; mean= 57.9±10.54)	Not listed	NT (2007)	Schedule I	Not listed
Carcharhinidae	*Lamiopsis temmincki*	Broadfin Shark	-	16		Not listed	EN (2008)	Not protected	Not listed
Carcharhinidae	*Galeocerdo cuvier*	Tiger Shark	Bagha hangor	2496		Not listed	NT (2018)	Schedule I	Not listed
Carcharhinidae	*Carcharhinus amboinensis*	Pigeye Shark	Bhota/ Moilla/	1909	18 gravid females between February and April. Upon	Not listed	DD (2005)	Not protected	Not listed

			Mohila/Goh/ Gundum/ Gongi / Boli hangor		dissection (n=3), 16-17 pups (8 f and 8 m in one; 10 f and 7 m in another)				
Carcharhinidae	*Carcharhinus leucas*	Bull Shark	Bhota hangor	123	One gravid female in April	Not listed	NT (2005)	Not protected	Not listed
Carcharhinidae	*Carcharhinus melanopterus*	Blacktip reef shark	Illissha boli hangor	10		Not listed	VU (2020)	Not protected	Not listed
Carcharhinidae	*Rhizoprionodon acutus*	Milk Shark	-	25		Not listed	VU (2020)	Schedule I	Not listed
Carcharhinidae	*Rhizoprionodon oligolinx*	Grey Sharpnose Shark	Shonali hangor/ shonali lota	147	31 gravid females (20 in March and April and 11 in January, TL=60.96-71.12; mean= 68.07±5.8). 5 dissected, (2-8 pups, mostly all females, in one 2f and 2 m; TL=17.78-27.94; mean= 23.24±6.18)	Not listed	LC (2003)	Schedule I	Not listed
Carcharhinidae	*Carcharhinus limbatus*	Blacktip Shark	Lota boli hangor/ bhota hangor	117	6 gravid females in March and April (TL=143-152.2)	Not listed	NT (2005)	Schedule I	Not listed
Carcharhinidae	*Carcharhinus brevipinna*	Spinner Shark	Athailla/ illissha boli hangor	45		Not listed	VU (2020)	Not protected	Not listed
Carcharhinidae	*Glyphis gangeticus*	Ganges Shark	Bhota/ Illissha hangor	3		Not listed	CR (2007)	Schedule I	Not listed
Carcharhinidae	*Carcharhinus amblyrhynchoides*	Graceful shark	-	1		Not listed	NT (2005)	Not protected	Not listed
Carcharhinidae	*Carcharhinus falciformis*	Silky shark	Lota hangor	1		App. II	VU (2017)	Schedule I	App. II
Carcharhinidae	*Carcharhinus macloti*	Hardnose Shark	-	15		Not listed	NT (2003)	Schedule I	Not listed

Sphyrnidae	*Sphyrna mokarran*	Great Hammerhead shark	Haturi hangor/ Kaunna	3	All adults and found in winter, further photographic evidence neeeded	App. II	CR (2018)	Schedule I	App. II
Sphyrnidae	*Sphyrna lewini*	Scalloped Hammerhead Shark	Haturi hangor/ Kaunna	8611	46 gravid females between March and May (TL=198.12-372; mean= 280.25±55.33), upon dissection pup number 13-17 (in one 11f and 6 m)	App. II	CR (2018)	Schedule I	App. II
Rhincodontidae	*Rhincodon typus*	Whale Shark	Timi hangor	5		App. II	EN (2016)	Schedule I	App. I & II
Alopiidae	*Alopias* sp.	Thresher Shark	-	2		App. II	VU (2018)	Not protected	App. II
Stegostomatidae	*Stegostoma fasciatum*	Zebra shark	-	1		Not listed	EN (2015)	Schedule I	Not listed
Triakidae	*Iago* cf. *omanensis*	Bigeye Houndshark	-	37		Not listed	LC (2008)	Not protected	Not listed
Hemiscyllidae	*Chiloscyllium hasseltii*	Hasselt's bambooshark	Bashpata hangor/Bash hangor/Hanno /Bang	129		Not listed	EN (2020)	Not protected	Not listed
Hemiscyllidae	*Chiloscyllium burmensis*	Burmese Bambooshark		3		Not listed	VU (2020)	Not protected	Not listed
Hemiscyllidae	*Chiloscyllium griseum*	Grey Bamboo Shark		102		Not listed	VU (2020)	Schedule I	Not listed
Hemiscyllidae	*Chiloscyllium* cf. *arabicum*	Arabian carpetshark		31	Needs genetic analysis to distinguish species	Not listed	NT (2017)	Not protected	Not listed
Hemigaleidae	*Hemipristis* sp.	Snaggletooth Shark		3	Presumably *H. elongata*. Need further specimen collection.	Not listed	VU (2015)	Not protected	Not listed
Rhinopristiformes rays									

Pristidae	*Pristis pristis*	Largetooth sawfish	Khotok/Khorkhor/Aissha/Korat mach	32	One gravid female in April, 5 pups.	App. I	CR (2013)	Schedule I	App. I & II
Pristidae	*Pristis zijsron*	Green sawfish	Khotok/Khorkhor/Aissha/Korat mach	1		App. I	CR (2012)	Schedule I	App. I & II
Rhinobatidae	*Rhinobatos annandalei*	Bengal Guitarfish	Pitambori/Gerenja	35		Not listed	DD (2008)	Not protected	Not listed
Rhinobatidae	*Rhinobatos lionotus*	Smoothback guitarfish	Pitambori/Gerenja	1		Not listed	DD (2008)	Not protected	Not listed
Rhinobatidae	*Rhinobatos ranongensis*	Ranong guitarfish	Pitambori/Gerenja	300+	Mostly juveniles and adults in bulk landing	Not listed	NE	Not protected	Not listed
Glaucostegidae	*Glaucostegus granulatus*	Sharpnose Guitarfish	Pitambori/Gerenja/ Nangla	897	150 gravid females with embryos (egg cases consisting of 40-60 eggs) in April. A mix of both *G. granulatus* and *G.* cf. *granulatus*	App. II	CR (2018)	Schedule I	Not listed
Glaucostegidae	*Glaucostegus* cf. *granulatus*	Sharpnose Guitarfish	Pitambori/Gerenja/ Nangla	-	A slightly morphologically different specimen of *Glaucostegus* was encountered and reported as *Glaucostegus* cf. *granulatus*	-	-	-	-
Glaucostegidae	*Glaucostegus obtusus*	Widenose Guitarfish	Pitambori/Gerenja/ Nangla	282	1 gravid female, 3 pups (2f and 1 m)	App. II	CR (2018)	Not protected	Not listed
Glaucostegidae	*Glaucostegus typus*	Giant Shovelnose Ray	Pitambori/Gerenja/ Nangla	28	Rarely sighted, a few times recorded in piles	App. II	CR (2018)	Not protected	Not listed
Rhinidae	*Rhina ancylostoma*	Bowmouth Guitarfish)	Bang hangor	113	3 gravid females in January (TL=182.9 cm), 8 pups, all	App. II	CR (2018)	Not protected	Not listed

					female (TL=50.5-52.3; mean= 51.5±0.64)				
				Rays					
Dasyatidae	*Urogymnus granulatus*	Mangrove whipray	-	12		Not listed	VU (2015)	Not protected	Not listed
Dasyatidae	*Urogymnus polylepis*	Giant freshwater whipray	-	52		Not listed	EN (2016)	Not protected	Not listed
Dasyatidae	*Urogymnus lobistoma*	Tubemouth Whipray		68	1 gravid female (5 pups, 4f and 1m) in January.	Not listed	EN (2020)	Not protected	Not listed
	Urogymnus asperrimus	Porcupine Ray		1		Not listed	VU (2015)	Not protected	Not listed
Dasyatidae	*Maculabatis bineeshi*	Short-tail whipray	Shaplapata	65	Several specimens were reported as *M.* cf. *bineeshi* (n=7)	Not listed	NE	Not protected	Not listed
Dasyatidae	*Maculabatis gerrardi*	Whitespotted Whipray	Fut shaplapata	54		Not listed	EN (2020)	Not protected	Not listed
Dasyatidae	*Maculabatis arabica*	Pakistan/ Arabic whipray	-	14	Better photographic evidences needed. Several speciemens were designated as *M.* cf. *arabica*	Not listed	CR (2017)	Not protected	Not listed
Dasyatidae	*Maculabatis pastinacoides*	Round whip ray	-	12	Several specimens were reported as *M.* cf. *pastanicoides* (n=5)	Not listed	EN (2020)	Not protected	Not listed
Dasyatidae	*Pastinachus ater*	Broad cowtail ray	-	2	Due to the absence of the tail at the time of sampling, two specimens were reported as *Pastinachus* cf. *ater* (n=2)	Not listed	LC (2015)	Not protected	Not listed
Dasyatidae	*Pastinachus* cf. *gracilicaudus*	Narrow cowtail ray	-	2	Differences were found between the NADH2 sequences of the Bangladesh as compared to Borneo	Not listed	EN (2020)	Not protected	Not listed

					specimens. This species is tentatively referred to as *Pastinachus* cf. *gracilicaudus*				
Dasyatidae	*Pastinachus gracilicaudus*	Narrow cowtail ray		8	Morphologically identified.	Not listed	EN (2020)	Not protected	Not listed
Dasyatidae	*Pastinachus* cf. *sephen*	Cowtail ray		4	Though a recent taxonomic study found that *P. sephen* is only found in the Western Indian Ocean (Red Sea to Pakistan) (Last & Manjaji-Matsumoto 2010). However, four specimens were morphologically very close to *P. sephen* and referred to as *P.* cf. *sephen*	Not listed	NT (2017)	Not protected	Not listed
Dasyatidae	*Pastinachus solocirostris*	Roughnose cowtail ray		18		Not listed	EN (2020)	Not protected	Not listed
Dasyatidae	*Telatrygon zugei*	Pale-edged stingray	-	13	Need better taxonomic work.	Not listed	NT (2016)	Not protected	Not listed
Dasyatidae	*Brevitrygon imbricata*	Bengal whipray	-	64	Several specimens were reported as *Bevritrygon* cf *imbricata*	Not listed	VU (2020)	Not protected	Not listed
Dasyatidae	*Brevitrygon walga*	Scaly whipray	-	34		Not listed	NT (2017)	Not protected	Not listed
Dasyatidae	*Brevitrygon heterura*	Dwarf whipray		8		Not listed	NE	Not protected	Not listed
Dasyatidae	*Himantura leoparda*	Leopard whipray	Bagha shaplapata	560		Not listed	VU (2015)	Not protected	Not listed
Dasyatidae	*Himantura uarnak*	Coach Whipray	Bagha shaplapata	452	1 gravid female in April. Fine spotted variants were also reported however, as *H. tutul*	Not listed	VU (2015)	Not protected	Not listed

					is not a valid species, they are designated as *H. uarnak*.				
Dasyatidae	*Himantura undulata*	Honeycomb whipray	Bagha shaplapata	487		Not listed	EN (2020)	Not protected	Not listed
Dasyatidae	*Pateobatis jenkinsii*	Jenkins' whipray	-	23		Not listed	VU (2015)	Not protected	Not listed
Dasyatidae	*Pateobatis uarnacoides*	Whitenose whipray	-	21		Not listed	EN (2020)	Not protected	Not listed
Dasyatidae	*Pateobatis bleekeri*	Bleeker's whipray	-	61	Several specimens were reported as *Pateobatis* cf. *bleekeri*	Not listed	EN (2020)	Not protected	Not listed
Dasyatidae	*Taeniurops meyeni*	Round ribbontail ray	-	21		Not listed	VU (2015)	Not protected	Not listed
Dasyatidae	*Neotrygon* cf. *caeruleopunctata*	Bluespotted maskray	-	11		Not listed	NE	Not protected	Not listed
Dasyatidae	*Neotrygon indica*	Indian Ocean blue-spotted maskray	-	24		Not listed	NE	Not protected	Not listed
Dasyatidae	*Neotrygon kuhlii*	Blue-spotted stingray	-	5		Not listed	DD (2017)	Schedule II	Not listed
Dasyatidae	*Neotrygon* spp.	Mask rays (Bay of Bengal variants)	Nil fut shaplapata	649	19 gravid females (1-2 pups, 1m, 1f), couldn't identified to species level. Consisting of *N. caeruleopunctata, N. kuhlii or N. indica*.	Not listed	NE	Not protected	Not listed
Dasyatidae	*Hemitrygon bennetti*	Bennett's stingray		13		Not listed	VU (2020)	Not protected	Not listed
Narcinidae	*Narcine prodorsalis*	Tonkin numbfish	-	4		Not listed	DD (2007)	Not protected	Not listed
Narcinidae	*Narcine brunnea/timlei*	Brown numbfish	-	1		Not listed	DD (2007)	Not protected	Not listed

Narcinidae	*Narcine* sp.	Andaman numbfish	-	1	Potential undescribed species.	Not listed	NE	Not protected	Not listed
Gymnuridae	*Gymnura poecilura*	Long-tailed butterfly ray	Podoni/ Projapoti	1321	130 gravid females, 33 sampled between November and April (DW= 61-86.36). Pup number 4 (2f and 2 m, DW= 12.5-13 cm).	Not listed	NT (2006)	Schedule II	Not listed
Mobulidae	*Mobula kuhlii*	Shortfin Devil Ray	Shing Chowain/ Badura	117		App. II	EN (2020)	Not protected	App. I & II
Mobulidae	*Mobula mobular*	Giant Devil Ray	Shing Chowain/ Badura	380	5 gravid females in April (1 f pup, DW=91.44 cm)	App. II	EN (2018)	Not protected	App. I & II
Mobulidae	*Mobula birostris*	Giant Manta Ray	Shing Chowain/ Badura	4	1 gravid female in April (1 f pup)	App. II	EN (2019)	Not protected	App. I & II
Mobulidae	*Mobula eregoodoo*	Longhorned Pygmy Devil Ray	Shing Chowain/ Badura	4		App. II	EN (2020)	Not protected	App. I & II
Mobulidae	*Mobula tarapacana*	Sicklefin Devil Ray	Shing Chowain/ Badura	26		App. II	EN (2018)	Not protected	App. I & II
Mobulidae	*Mobula thurstoni*	Bentfin Devil Ray	Shing Chowain/ Badura	54		App. II	EN (2018)	Not protected	App. I & II
Aetobatidae	*Aetobatus ocellatus*	Spotted eagle ray	-	45	5 gravid females (one pup each, pup's DW= 30.5 cm). Several specimens were reported as *Aetobatus* cf. *ocellatus*	Not listed	VU (2015)	Not protected	Not listed

Aetobatidae	*Aetobatus flagellum*	Longhead Eagle Ray	-	21		Not listed	EN (2006)	Not protected	Not listed
Aetobatidae	*Aetobatus* spp.	Whitespotted Eagle Ray	-	34	Comprising of *A. narinari* and *A. ocelletus*. Further field studies are need to determine appropriate characteristics to distinguish species	Not listed	NT (2006)	Schedule II	Not listed
Myliobatidae	*Aetomylaeus maculatus*	Mottled eagle ray	-	12		Not listed	EN (2020)	Not protected	Not listed
Rhinopteridae	*Rhinoptera javanica/ Rhinoptera jayakari*	Javanese Cownose Ray/ Oman cownose ray	Chowain	406	3 gravid females in January and April	Not listed	VU (2006)	Not protected	Not listed
				Species needing further photographic and genetic evidences					
Hemiscyllidae	*Chiloscyllium indicum*	Ridgebacked Bamboo Shark		1	No photographic evidence could have been collected	Not listed	VU (2020)	Not protected	Not listed
Hemiscyllidae	*Chiloscyllium punctatum*	Brownbanded bamboo shark		1	A juvenile was encountered, however, needs further genetic work to separate from juveniles of *C. griseum*		NT (2015)		
Carcharhinidae	*Loxodon macrorhinus*	Sliteye shark	-	10	Rare in comparison to *Scoliodon laticaudus*. Difficult to identify in piles on smaller sharks	Not listed	LC (2003)	Not protected	Not listed
Dasyatidae	*Maculabatis macrura*	Sharpnose whipray	-	23		Not listed	EN (2020)	Not protected	Not listed
Dasyatidae	*Telatrygon* cf. *crozieri*	Indian sharpnose ray	-	2		Not listed	NE	Not protected	Not listed
Narkidae	*Narke dipterygia*	Numbray	-	1		Not listed	DD (2007)	Not protected	Not listed
Dasyatidae	*Pateobatis fai*	Pink whipray		4		Not listed	VU (2015)	Not protected	Not listed

Mobulidae	*Mobula alfredi*	Alfred manta	Shing Chowain/Badu ra	5	Needs further genetic identification as whole specimens were not encountered	App. II	VU (2018)	Not protected	App. I & II
Myliobatidae	*Aetomylaeus nichofii*	Banded eagle ray	-	1		Not listed	VU (2015)	Schedule II	Not listed
				Unidentified					
	Aetobatus sp.			>243	1 gravid female in January; Couldn't identified to species level, Consisting of *A. ocellatus or A. narinari*. It is difficult to confirm identification for *A. ocellatus* or *A. narinari* without genetic sampling. Most of these specimens were landed ventrally and sometimes in piles precluding the possibility to individually sample them.				
	Mobula sp.			>243	Smaller specimens. For larger specimens, they mostly landed ventrally and also in a busy landing sites it was only possible to count without sampling each specimen.				
	Maculabatis sp.			>324	Lack of standardised photos and the difficulties in differentiating *M. macrura*, *M. gerrardi* and *M. arabica* in large piles preclude the authors for species-specific identification.				
	Pateobatis sp.			>265	3 gravid females between February and April. Species-specific identification was not possible due to ventral landing, in many cases absence of tails and inability of individual sampling in the crowded landing sites				
	Glaucostegus sp./ *Rhinobatos* sp.			>1350	Comprising of *G. typus, G. granulatus and R. ranongensis, R. lionotus, R. annndalei*> Ventral landing in piles of hundreds of specimens precluded species-specific identification.				
Gymnuridae	*Gymnura* sp.	Butterfly ray		11	Absence of tail and ventral landing precluded species-specific identification.				
Hemiscyllidae	*Chiloscyllium* spp.	Bamboo shark		159	Piles of many specimens and absence of standardised photos precluded species-specific identification.				
		Small unidentified requiem sharks		107743	Piles of thousands of specimens landing precluded individual sampling and species-specific identification.				

	Unidentified large requiem shark	225	Absence of standardised photographs, morphologically similar species landing where only ventral side is visible, absence of fins while landing and inability to individually sampling each specimen in a busy and crowded landing site precluded species-specific identification.
	Small unidentified rays	Were not counted	Sometimes landed in baskets or as piles in landing sites. We were unable to sample these due less time given to sample these specimens.

Table 2.2. Total number (n) and percentage of total (%) of species (elasmobranchs) identified to species level and recorded from Chattrogram, Cox's Bazar and St. Martin's Island during the study period (January 2017 to June 2017).

Species	n (Cox's Bazar)	N (Chattogram)	n (St. Martin's Island)	Total number of individuals	% total of all species combined	Estimated total weight (kg)	n sampled with precision, size range (mean±S.D.cm)
Scoliodon laticaudus	22535	3625	120	26280	58.86	~ 8919	n= 262; 15.24-81.44 (38.33±9.82)
Sphryna lewini	7404	1192	15	8611	19.29	~ 31041.5	n= 264; 15.24-304.8 (39.67±19.81)
Carcharhinus sorrah	4572	23	1	4596	10.29	~ 671.1	n= 53; 24.38-204.22 (73.31±42.83)
Galeocerdo cuvier	2440	31	25	2496	5.59	~ 3177	n= 81; 33.53-550 (124.31±60.55)
Carcharhinus amboinensis	1812	86	11	1909	4.28	~ 7019.9	n= 117; 33.53-292.61 (116.14±46.94)
***Chiloscyllium* spp.**	461	12	22	234	<1	-	n= 46; 43-75.5 (64.47±9.49)
Carcharhinus limbatus	41	76	0	117	<1	~695	n= 19; 45.72- 259.08 (130.98±56.07)
Carcharhinus brivipinna	45	0	0	45	<1	358	n=28, 76.2-121.92 (102.73±16.15)
Rhizoprionodon oligolinx	135	12	0	147	<1	-	n= 17; 61-65.5 (63.43±1.88)
Carcharhinus leucus	121	2	0	123	<1	-	n=33; 91.44-176 (155.23±27.85)
Iago* cf. *omanensis	37	0	0	37	<1	13.09	n=37; 34.30-53.34 (44.95±4.86)
Glaucostegus granulatus/ G.* cf. *granulatus	619	278	0	897	53.12	~ 4300.80	n= 137; 42.67-213.36 (105.40±32.53)
Glaucostegus typus	1	127	0	128	7.58	-	n= 1; 106.68

Glaucostegus obtusus	157	25	0	182	10.78	~ 533.2	n= 22; 60.96-137.17 (97.40±21.82)
Rhina ancylostoma	101	9	3	113	6.69	~102	n= 13; 198.12-155.45 (168.66±25.56)

2.3.2.3. Rays

a. Rhinopristiformes rays: A total of 1689 individuals of Rhinopristiformes rays, comprising ten different species, were identified. The most commonly caught species was the Sharpnose guitarfish *Glaucostegus granulatus* and *G.* cf. *granulatus* (n = 897, 53.12%) followed by the Ranong guitarfish *Rhinobatos ranongensis* (n = 300+, ~18%) and Widenose Guitarfish *Glaucostegus obtusus (*n = 282, 16.58%), *the* Bowmouth Guitarfish *Rhina ancylostoma* (n = 113, 6.69%), the Bengal Guitarfish *Rhinobatos annandalei* (n = 35, 2.07%) and the Giant Shovelnose Ray *Glaucostegus typus* (n = 28, 1.66%). Thirty-four sawfishes, including two species (the Largetooth sawfish *Pristis Pristis*, the Green sawfish *P. zijsron*), were recorded. However, the sawfish records were presented and discussed separately (Haque et al., 2019a, 2021a).

b. Other rays: A total of 5224 individual (from 6310) rays belonging to 48 species of nine families were counted and identified to species level between January 2016 and December 2019 at the four landing sites. The most common rays were whiprays and stingrays (family: Dasyatidae), comprising the highest number of species. This was followed by the family Mobulidae (6 species) and Aetobatidae (3 species). The families of Mylobatidae, Narcinidae, and Rhinopteridae each had two species recorded, and Mylobatidae, Gymnuridae and Narkidae each had one species documented (Figure 2.3, Table 2.1).

Although the majority of the species were from the family Dasyatidae, the most commonly observed ray species by the relative number landed was from the family Gymnuridae (the Longtail butterfly ray *Gymnura poecilura*, n = 1321, 26.23%). This was followed by Bluespotted maskray *Neotrygon* spp. (n = 689; 13.68%). The Leopard whipray *Himantura leoparda*, Honeycomb whipray *Himantura undulata*, Reticulate whipray *Himantura uarnak* each contributed approximately 11.12% (n = 560), 9.67% (n = 487) and 8.97% (n = 452), respectively. Within the family Dasyatidae, other common species found were the Short-tail whipray *Maculabatis bineeshi* (n = 65), the Bengal whipray *Brevitrygon imbricata* (n = 64) and the White-spotted whipray *Maculabatis gerrardi* (n = 54), Arabic whipray *Maculabatis acabica* (n = 14) and other whiprays *Pateobatis* spp., and the rest were of minor abundance, with each species comprising less than 1% of the total landings. Coastal and freshwater species dependent on mangroves were also quite frequently found and included the Giant freshwater stingray *Urogymnus polylepis* (n = 52), Tubemouth whipray *U. lobistoma* (n = 68) and mangrove whipray *U. granulatus* (n = 12), a number of unidentified individuals of the same genus.

Cownose rays (family: Rhinopteridae) were also frequently landed. From these, the most common species found were the Flapnose ray or Javanese cownose ray *Rhinoptera javanica* (n = 252, 5%) and Oman cownose ray *R. jayakari* (n = 154, 3.06%). From the family Mobulidae six species (585; 11.61%) were identified to species level based on morphological characteristics. The most commonly observed species in the landings was the Giant devil ray *Mobula mobular* (n = 380), followed by the Shortfin devil ray *M. kuhlii* (n = 117), the Bentfin devil ray *M. thurstoni (n = 54)* and the Chilean devil ray *M. tarapacana* (n = 26). Of the species the Giant oceanic manta ray *M. birostris* and the Longhorned pygmy devil ray *M. eregoodoo*, each contributed fewer than ten individuals.

Eagle ray landings from two families were commonly recorded (Aetobatidae and Myliobatidae), with five different species identified. The most commonly caught species was the Ocellated eagle ray *Aetobatus ocellatus* (n = 45), followed by the *Aetobatus* cf. *ocellatus (*n = 34), the Longheaded eagle ray *Aetobatus flagellum (*n = 21), the Mottled eagle *Aetomylaeus maculatus* (n = 12) and the Banded eagle ray *Aetomylaeus nichofii* (n = 1) (needing further confirmation). A total of 2425 individuals belonging to the genus *Aetobatus*, *Mobula*, *Maculabatis*, *Pateobatis*, *Glaucostegus* and *Rhinobatos* could not be identified to the species level.

2.3.2.4. Maturity in recorded species. Based on length at first maturity (Last et al., 2016; Froese & Pauly, 2020) of the sampled specimens for large species, the majority of landed sharks and rays were juveniles (n = 18663 out of 18999 sampled); *C. amboinensis* (n = 1481, 99.6%), *C. sorrah* (n = 3482, 99.5%), *S. lewini* (n = 10107, 99.7%), *C. limbatus* (n = 23, 67.65*%)*, *G. cuvier* (n = 3225, 100%), *G. granulatus* (n = 343, 69.4%). However, no specimen of *G. obtusus* (n = 121) sampled was juvenile, whereas <1% (n = 750 out of 32970 sampled) of the individuals of *S. laticaudus* was found to be juveniles (Figure 2.4). Weight varied according to species. The majority of the individuals were less than 25 kg for large specimens; however, for smaller specimens like *S. laticaudus* and pups of other species, many individuals were less than one kg (Figure 2.5).

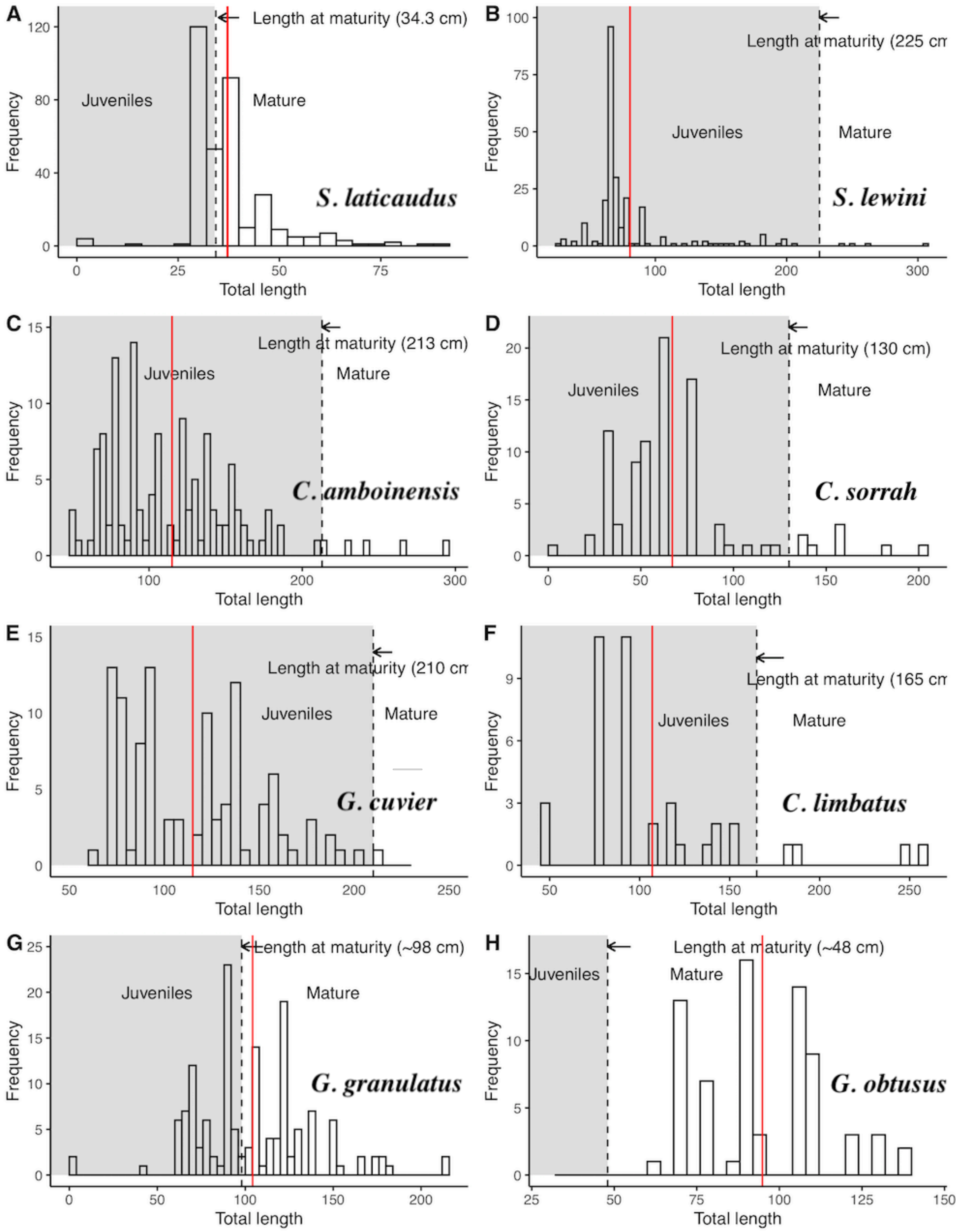

Fig 2.4. Length frequency with mean(redline), juveniles (shaded grey) and mature specimens of (A) *S. laticaudus*, (B*) S. lewini* (C) *C. amboinensis*, (D) *C. sorrah*, (E) *G. cuvier*, (F) *C. limbatus*, (G) *G. granulatus* and (H) *G. obtusus*. The dashed line indicates the proportion of juveniles and the red line indicates the mean length (TL for sharks and rhino rays) of each species.

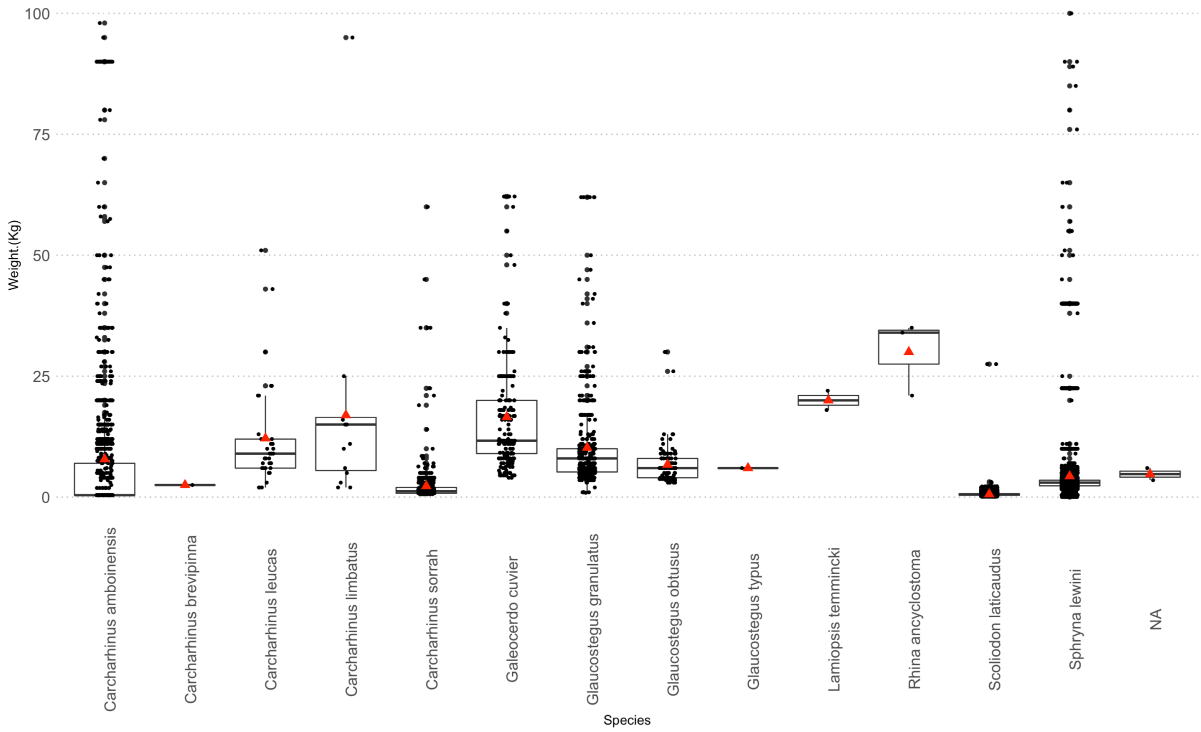

Fig 2.5. Range of weights of elasmobranch species landed during the study period with mean (red triangle). Weights of greater than 100 kg were mostly estimated hence are not shown in the figure. The weight range in kg for sampled specimens were as follows: *C. amboinensis* (0.4–estimated >300, mean = 9), *C. brevipinna* (2.5), *C. leucas* (2–51, mean = 12.14), *C. limbatus* (2–95, mean = 26.44), *C. sorrah* (0.6–60, mean = 2.28), *G. cuvier* (4–62.14, mean = 16.54), *G. granulatus* (0.9–62, mean = 10.21), *L. temmincki* (18–22, mean = 20), *S. laticaudus* (0.09–2, mean = 0.604), S. lewini (0.4–200, mean = 4.38).

2.3.3. Insights on seasonality, distribution, gear used and trade

a. **Seasonality.** There was a significant difference in the number of specimens landed in different months ($p < 0.001$, F-statistic 9.081 on 7 and 1174 DF, Intercept 95.76, etasq 0.051, partial.etasq 0.051, omegasq 0.046, partial.omegasq 0.46, cohens.f 0.233, power 1: 100% chance of finding a statistically significant difference) and season ($p < 0.001$, F-statistic: 11.68 on 2 and 1179 DF, Intercept 362.95, etasq 0.019, partial.etasq 0.019, omegasq 0.018, partial.omegasq 0.018, cohens.f 0.141, power 0.994: 99% chance of finding a statistically significant difference). Here the effect size of the model is small. The number of sharks landed was substantially higher in the pre-monsoon and monsoon season, followed by summer for both large and small species (Figure 2.6A). The Tukey's HSD test showed, there was a significant difference between summer-monsoon ($P < 0.004$) and winter- monsoon ($p < 0.0001$). However, no significant difference was found between winter and summer regarding the number of landing. The model validation graph showed no large outliers that would cause bias in the model, and the mean of the residuals was horizontal and centered on zero.

However, as detailed data could only be collected for one month during winter (i.e. January), this result shows the frequency mostly from summer to monsoon. The most considerable bulk of smaller species (e.g. *S. laticaudus*) were observed in May and June (Figure 2.6B). The larger specimens were mostly caught in summer and pre-monsoon (Figure 2.6C and 2.6D).

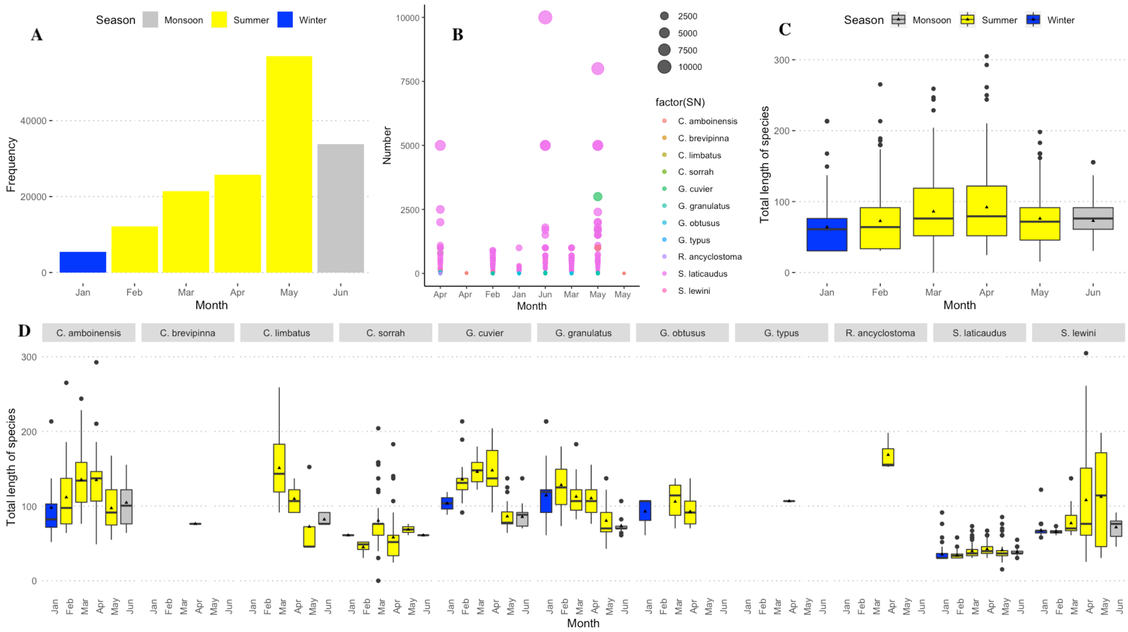

Fig 2.6. Seasonality:**(A)** Relative frequency of recorded specimens of elasmobranchs per month of the study period, (**B**) species-specific frequency of landing for each month, where the size of the circle denotes the number of bulk landings in a single day, (**C**) overall range of length (TL for sharks and rhino rays) of landed elasmobranchs in each month, and (**D**) length-specific landing for each species per month of the study period.

b. Distribution. The highest number of sharks and rays were landed in Cox's Bazar, followed by Chattogram, and the lowest in Teknaf followed by St. Martin's Island (Figure 2.7).

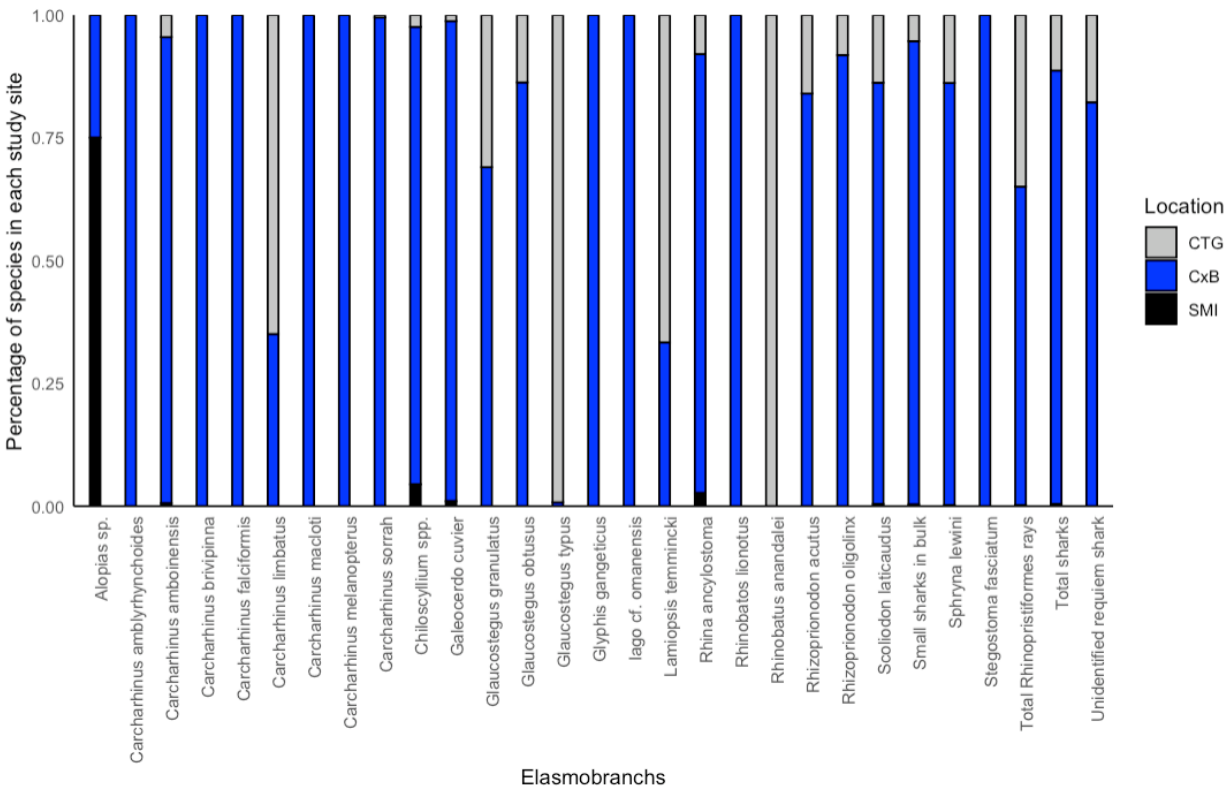

Fig 2.7. Distribution of sharks studied (at landing sites). Here, CTG = Chattogram, CxB = Cox's Bazar and SMI = St. Martin's Island.

c. **Gear.** Sharks were caught by gillnets (mesh size between ~10 and 32 cm), set bag nets and longline hooks or individual hooks. Less than 1% of the individuals (n = 1387) were caught by using non-baited long lines targeting rays or other smaller fish, or individual bigger iron hooks targeting groupers or any opportunistic big fish. In several cases (n = 21), bigger elasmobranch species (*C. amboinensis*, *C. leucas*, *G. cuvier*, *G. granulatus*) were documented while the hooks were still attached to the jaws. Floating drifting gill nets caught 14.9% of the individuals (n = 15175), predominantly targeting Hilsa (*Tenualosa ilisha)*, and 2.71% (n = 2754) were caught using submerged gill nets. Less than 1% (n = 143) were caught in the Lakkha net (mesh size larger than 30 cm), and 66.45% (n = 67084) were caught by either seine net or gillnets targeting different fishes. In 14.92% of cases, the gear used to catch the individuals could not be recorded (Figure 2.8A).

Floating gill nets and seine nets caught significantly more sharks than any other nets (but mostly smaller specimens in seine nets) ($p<0.001$, F-statistic: 10.93 on 5 and 1167 DF, Intercept 100.93, etasq 0. 045, partial.etasq 0. 045, omegasq 0.041, partial.omegasq 0.041, cohens.f 0.216, power 1: 100% chance of finding a statistically significant difference) (Figure 2.8B). Other rays are predominantly caught in targeted non-baited long lines deployed in the shallow water coastal areas. They are also caught in other gears as bycatches. There was a significant positive relationship between gear type (mesh size of the nets used) and the increasing length of (TL for sharks and rhino rays) the elasmobranchs (Figure 2.8C). ANOVA models resulted in positive relationships with gears and increasing total length ($p<0.001$, F-statistic: 99.34 on 5 and 1158 DF, Intercept 63.3, etasq 0.300, partial.etasq 0.300, omegasq 0.297, partial.omegasq 0.297, cohens.f 0.655, power 1: 100% chance of finding a statistically significant difference). The model effect size is moderately large. The positive relationship was found for generally gillnets ($p<0.03$) both for floating gill- nets ($p<0.001$), large mesh gillnets ($p<0.0001$), hooks ($p<0.0001$). For seine nets ($p<0.0001$) negative relationship was reported. However, no significant relationship was found for particularly hilsa gillnets, probably because they catch all size of sharks in abundance. Species-specific length concerning gears is shown in Figure 2.8D.

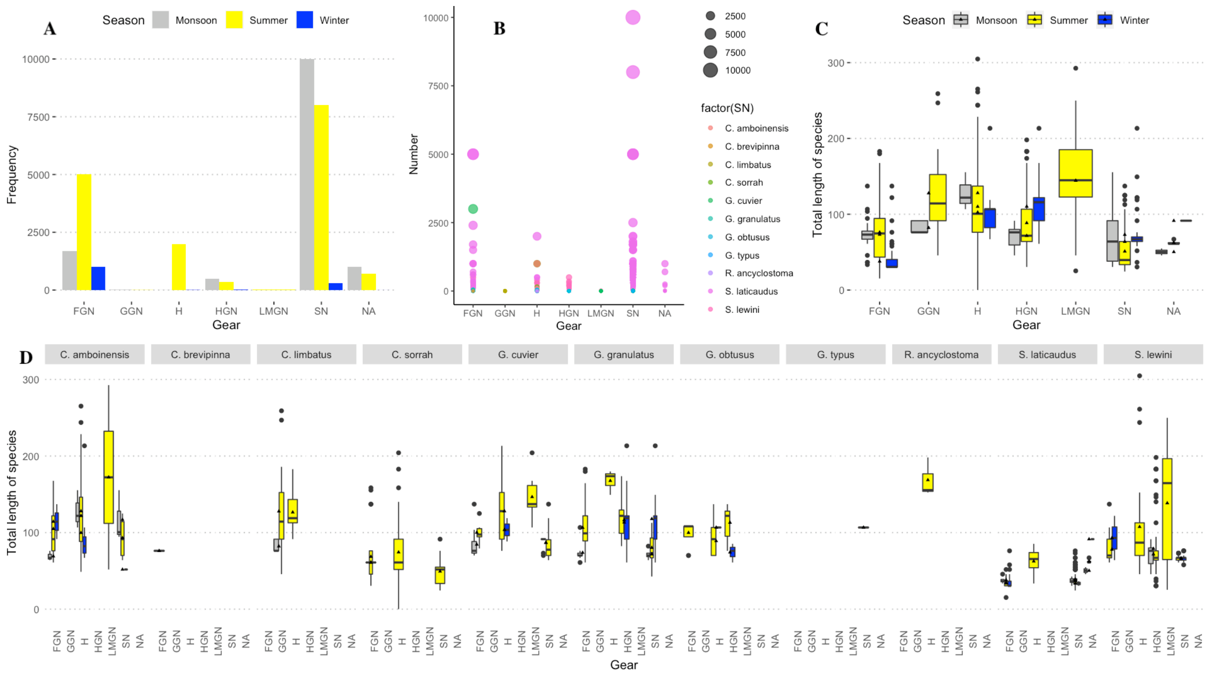

Fig 2.8. (A) Frequency of species caught in each documented gear type, (B) species-wise bulk landing in each gear type, (C) overall length- specific landing in each gear type, and (D) range of total length of different elasmobranch (TL for sharks and rhino ray species) and different gear used to catch the reported specimens (species-wise). Here, FGN = floating gillnet, GGN = general gillnet with varying mesh sizes, H = hooks, HGN = hilsa gill net, LMGN = large mesh gillnet (Lakkha jal), and SN = seine net.

2.3.4. Threatened status and protection of species recorded

The majority of the species recorded are threatened according to IUCN Red List (CR = 10, EN = 22 and VU = 22), 12 are NT, seven are Data Deficient, with the remainder Not Evaluated. Amongst all, only 37 species receive some level of global or national protection. Nineteen species are protected under national law: The Wildlife (Conservation and Security) Act, 2012 (Schedule I = 15 species and Schedule II = 4; until 2021) (Table 2.1).

Regarding international trade regulation, 16 species are listed in App. II (*Glaucostegus* spp., *Mobula* spp., *C. falciformis*, *R. typus*, *S. lewini*) and two are in App. I (sawfishes) of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) (until 2022). Furthermore, ten species are designated in App. I and II and four in App. II of the Convention on Migratory Species (CMS) (Figure 2.9).

The highest level of protection is given to sawfishes, *Mobula mobular* (mentioned as *M. japanica* in the Wildlife (Conservation and Security) Act, 2012), *C. falciformis*, *R. typus*, *S. lewini* by all three mechanisms (i.e. national law, CITES and CMS). The rest of the *Mobula* spp. are protected by both CITES and CMS. Eleven of the CITES listed App. II species are not protected by the national law, and seven CR, 18 EN and 15 VU species are also not protected by the national law (Table 2.1).

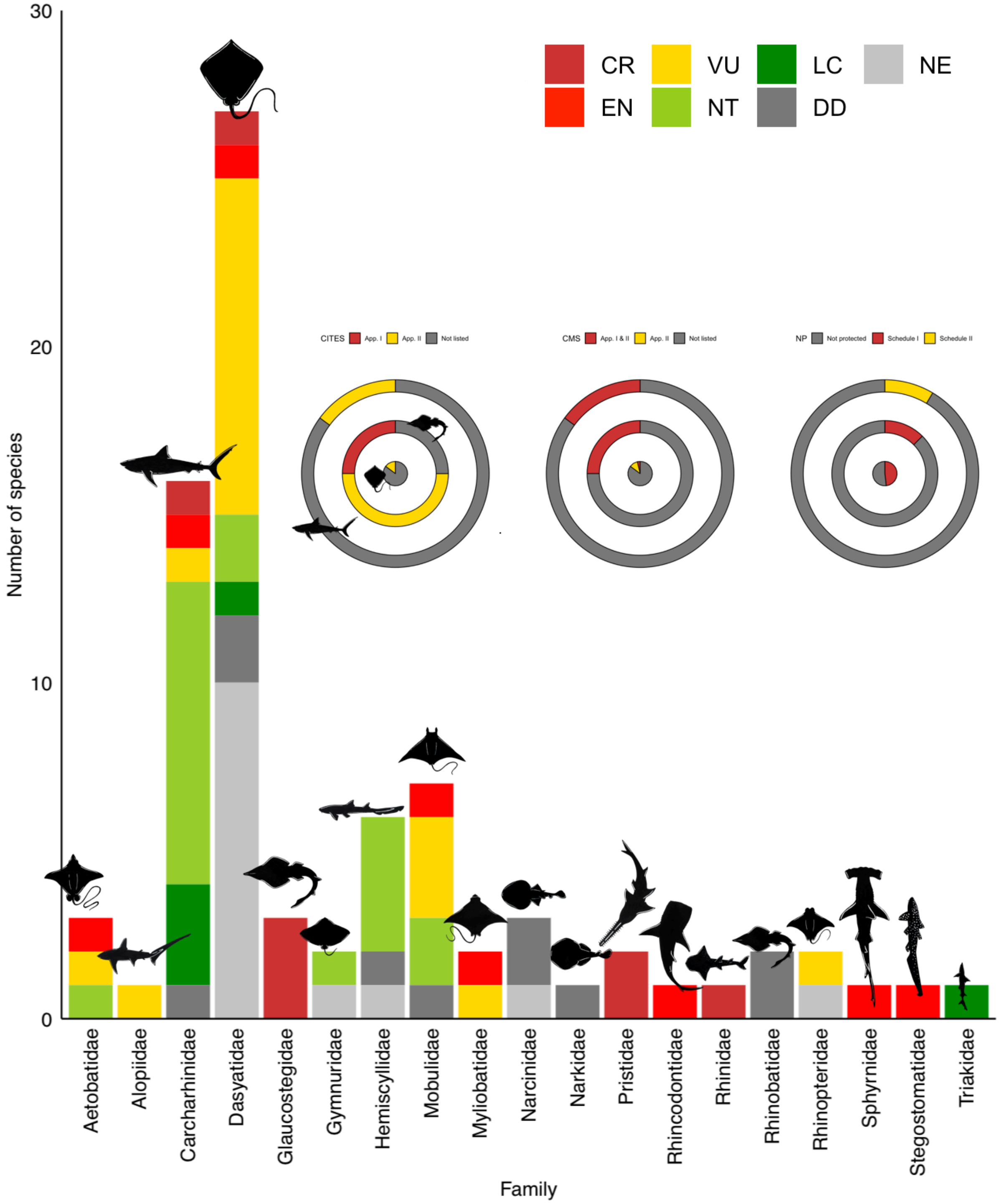

Fig 2.9. Threatened status of each species within each family recorded in the study. Number of species recorded for each elasmobranch family from artisanal fisheries of south-eastern Bangladesh. IUCN Red List status, CITES App. Listings and CMS listings are also shown in circular graphs, including level of national protection under the Wildlife (Conservation and Security) Act, 2012.

2.4. Discussion

The study reveals that elasmobranchs are caught and landed in unmonitored sites in the Bay of Bengal, Bangladesh, including globally threatened and nationally protected species. The total diversity of elasmobranchs is higher than previously reported, and catch, and landing monitoring is needed. The study provides enhanced knowledge of elasmobranch species composition, abundance, seasonality, and gear used in the artisanal fishery. An essential initial baseline for encouraging evidence-based decision-making in the Bay of Bengal, Bangladesh, has been offered. By collaboratively combining our knowledge base to inform ecology, socioeconomics, conservation, and trade concerns, a suite of next steps for effective governance and priority research can be initiated to stop the collapse of the most depleted species and promote sustainable approaches for others.

2.4.1. High diversity of elasmobranchs in the Bay of Bengal

Previous estimates of elasmobranch diversity in Bangladeshi waters have been significantly underestimated, with estimates ranging from 35 to 81 (Rahman et al., 2009; Froese & Pauly, 2009; Hoq et al., 2011; Hoq & Haroon, 2014; Roy et al., 2012, 2015; Haque et al., 2018; Badhon et al., 2019; Ahmed et al., 2019; Dutta et al., 2020; Habib et al., 2020). The study, which recorded artisanal catch, has increased the number of reported elasmobranch species by thirteen. Total diversity report increased by including previously misidentified species and unreported deep-sea species and addressing underestimation due to poor coverage of migratory, deep-water, rare, and discarded individuals in the industrial catch (Kumar et al., 2019) in previous studies. Lack of exploratory surveys and limited trained workers at landing sites in Bangladesh have hampered accurate elasmobranch accounts. Aggregated landing recording systems (DoF, 2017) may have underestimated elasmobranch species richness and endemicity, suggesting the potential for additional evolutionary important species (Naylor et al., 2012). Bangladesh is a highly biodiverse region with 111 confirmed elasmobranch species, surpassing neighboring countries like the Arabian Gulf, Sri Lanka, Maldives, and Andaman and Nicobar Islands (Moore et al., 2012; Moron et al., 1998; De Silva, 2006; Anderson & Hafiz, 2002; Tyabji et al., 2020; (Vidthayanon & Premcharoen, 2002; White et al., 2006; Fahmi, 2012; Akhilesh et al., 2014; Jaiteh et al., 2017). This diversity is possibly higher than in Thailand, and similar levels are reported in India and Indonesia.

The Bay of Bengal provides a diverse marine habitat, with the Sundarbans, the world's largest contiguous halophytic forest, providing essential habitats for freshwater and brackish species (Ganges shark and Largetooth sawfish). The southcentral waters are murky due to the Ganges, Meghna, and Brahmaputra rivers, while alluvial plains created by their sediment deposition create habitats for species like Guitarfishes and Dasyatid rays. Coral patches and seagrass beds in the southeast provide crucial habitats for species like bamboo sharks and mask rays.

2.4.2. Relative abundance in artisanal catch

The relative abundance of elasmobranchs was disproportionately higher for small-bodied sharks and rays. This might be explained by the fact that many elasmobranch species use inshore nutrient-rich waters and mangroves as nursery grounds (Heupel et al., 2019). Carcharhinids were the most abundant sharks reported in this study. The spadenose shark *S. laticaudus* was the most commonly documented shark species, likely due to its relatively high fecundity and occurrence in shallow-water (10-13 m) demersal habitats (Froese & Pauly, 2009). As such, spadenose sharks are frequently exploited by large numbers of artisanal boats, which deploy gear in great numbers (Shamsuzzaman et al., 2017), including the small mesh monofilament gillnet. After spadenose shark, other abundant shark species were spottail shark *C. sorrah*, blacktip shark *C. limbatus*, tiger shark *G. cuvier* and pigeye sharks *C. amboinensis*, followed by bull shark *C. leucas* with very low landing of *Carcharhinus falciformis*, *C. amblyrhynchoides*, *C. brevipinna* and *C. macloti*. Similarly, whereas the scalloped hammerhead shark was very commonly caught at all landing sites, other hammerhead sharks (e.g. winghead shark *E. blochi*, great hammerhead shark, *S. mokarran*) (Hoq et al., 2011; Roy et al., 2015), were either not recorded or very rarely found. However, they were previously reported as being abundant in this region. This discrepancy may be due to a severe population decline in the region, possibly driven by extremely valuable fin trade (Haque et al., 2018) (see details in Table S2.2).

Deep-sea, pelagic and migratory elasmobranchs are quite unlikely to be caught in abundance in the shallow depths predominantly fished by Bangladeshi artisanal fisheries. For example, whale sharks and thresher sharks were poorly reported, though there were anecdotal whale shark reports in industrial fisheries (news articles, pers. comm. 2019). However, pelagic species may use inshore waters as breeding grounds (Camhi et al., 2009); hence the abundance of species like the tiger shark, *Galeocerdo cuvier* or scalloped hammerhead sharks, *Sphyrna lewini* while they were pregnant or in their adult stages were common. The case was similar to Devil rays, Cownose rays and Eagle rays. They were comparatively less common as they are pelagic or benthopelagic and may not overlap with the artisanal fisheries.

There is an acute lack of fisheries data and research surveying industrial fisheries. Similarly, this study did not consider the industrial catches by the bottom and mid-water trawlers that exploit waters of 200m depth and beyond, meaning that the Bay's deepest waters are still unrepresented. It is, therefore, possible that deep-water elasmobranchs not previously recorded in the Bay of Bengal may be present, such as hound sharks. Whereas *Mustelus mosis*, a deep-water hound shark, was reported for the first time from the southwest coast (Habib et al., 2020), *Mustelus manazo*, *Mustelus kanekonis/ Mustelus griseus*, *Iago garricki*, *Iago* cf. *omanensis* were also recorded previously but were not commonly encountered at all (Compagno et al., 1971; Hoq et al., 2011; Hoq & Haroon, 2014). Although landing data is not a perfect proxy to understand the abundance of these species at sea (Kyne et al., 2020), these can give us an idea about the impacts of fishing if long term data is unavailable.

Rays from the family Dasyatidae were the most abundant, consistent with previous reports (Rahman et al., 2009; Hoq et al., 2011; Roy et al., 2012, 2015; Hoq & Haroon, 2014), likely because it comprises a large group of rays consisting of 19 genera and 86 species (Last et al., 2016), which inhabit an array of habitats and depths. The most commonly found ray was *G. poecilura* from this family, potentially due to higher breeding potential than many other elasmobranch species (Raje & Zacharia, 2009). The number of juveniles of this species encountered was highest in the winter and pre-monsoon season, probably due to overlapping breeding season and fisheries and the presence of inshore nursery grounds (Raje & Zacharia, 2009). The second most abundant species sampled belonged to the genus *Neotrygon*, which is characterised by reef-associated or demersal inshore species. *Neotrygon* habitat overlaps with artisanal bottom net fisheries and longline hooks, resulting in high numbers of landings, although demand is comparatively low. The stingrays and whiprays (e.g. *Himantura* spp., *Maculabatis* spp., *Brevitrygon* spp., and *Pateobatis* spp., were found to be heavily exploited. Numbfishes were found to be rare in landings, potentially due to discards and lower market value.

Rhinopristoformes rays were abundantly landed, especially *G. granulatus and G. obtusus* followed by *R. ancylostoma* and *Rhinobatos ranongensis* was not frequent. These species were frequently targeted using non-baited longlines due to high fin price and meat consumption (Kyne et al., 2020). Although G. *granulatus*, *R. ancylostoma*, *G. typus* and *R. djiddensis (*probably *R. lavies* or *R. australie*, as *R. djiddensis* doesnot occur in this region) were commonly previously reported (Hoq et al., 2011; Roy et al., 2012, 2013, 2014, 2015; Hoq & Haroon, 2014, Karim et al., 2012), the current study reported no *Rhynchobatus* spp., presumably due to extreme population decline. A potential population depletion is corroborated by fishers, who commonly referred to as a white-spotted guitarfish, which is not found anymore; however, a more comprehensive investigation is required to confirm this. Throughout the study period, a total of 33 largetooth sawfish was also recorded, indicating the landing is higher than documented previously by Haque et al., 2020, and needs immediate conservation action (Haque et al., 2020). It is likely that the occurrence of highly vulnerable rays, such as the largetooth sawfish, is unreported in most recent studies as incidental bycatch does not land in the formal landing sites (Haque et al., 2020).

2.4.3. Uncertainty in identification

Identification on the scale of thousands of species is challenging, especially in busy landing sites where only a few minutes are available for the researcher to collect the data and photos. As a result, only specimens where identifications were possible with clear photographs and where expert opinions could have been secured were included in this study. The absence of standardized photographs, morphologically similar species where only the ventral side is visible, the absence of fins, and the inability to individually sample each specimen precluded species-specific identification for many specimens. For instance, the lack of standardized photos and difficulties differentiating M. macroura, M. gerrardi, and M. arabica in large piles prevent species-specific identification in many cases. Confirming identification for A. ocellatus or A. narinari without genetic sampling is difficult. Sometimes species landing in piles precluded the possibility of individually sampling them. Identification of small-sized animals was difficult. Identification of all individuals within such a pile was difficult; as a result, a total of 107743 such individuals were labeled as unidentified smaller sharks. Furthermore, large piles of landings comprising hundreds of small-sized rays were excluded from the study due to difficulties in accurately sampling these. Thus, this study's results regarding the species-specific comparison of relative abundance in landings are limited.

This study sheds light on the relative abundance of specimens that could have been sampled. When possible, we used photos, expert opinions on initial identification, and the relative dorsal fin size (anterior margin) for bull and pig-eye sharks. As the relative abundance of the sampled specimens was presented in the results, some uncertainty remains regarding the true relative abundance of landings of different species.

2.4.4. Conservation challenges

A high proportion of the species recorded in this study are threatened with extinction, according to the IUCN Red List. However, while IUCN assessments include species found in the Bay of Bengal, they lack regional risks and threats information and require updating in a regional context. This study can help address this, providing regional data to underpin the assessments, reliable data is a prerequisite for management (Bonfil, 1997; Ainsworth et al., 2008; Jaiteh et al., 2017). Furthermore, although Bangladesh is a signatory for both the

CITES and the CMS, implementation and enforcement are lacking. Bangladesh national law only protects a total of 29 elasmobranch species under the Wildlife (Conservation and Security) Act, 2012, omitting eleven CITES species. There is a clear need to amend and expand the single act protecting vulnerable species in Bangladesh and at the same time increase the enforcement of relevant laws. While doing so, Bangladesh's main challenge will be to ensure pre-cautionary and proactive approaches for policies, implementation, and enforcement of laws.

2.4.5. Further research

Identifying species at landing and trading sites is challenging due to the absence of national species lists and guides and poorly curated reference collections. However, this study improved the field identification of morphologically similar sharks and rays using reference photographs and genetic sampling. Further research is needed to resolve taxonomic problems for many elasmobranch species, identify morphologically different or geographic sub-populations with endemic or cryptic species, and study geographically isolated population variants for better taxonomic understanding. Taxonomic problems need resolving for many elasmobranch species, with a large number of descriptions by earlier ichthyologists recently synonymized (White et al., 2017; Froese & Pauly, 2009; Last et al., 2016) or not yet identified to species level (e.g., Iago spp. and Narcine sp. (Bineesh et al., 2016; Psomadakis et al., 2019). To conclusively resolve elasmobranch taxonomy, more extensive geographic sampling may be required (Marshall et al., 2009; Ebert et al., 2010; White & Dharmadi, 2010; White & Kyne, 2010; White & Sommerville, 2010; Last et al., 2016) and in conjunction with genetic and morphological sampling (e.g. for Carcharhiniformes, *Neotrygon* spp., many Dasyatids, *Iago* spp.*)*. Such an approach could lead to the discovery of greater diversity in the Indian Ocean (Fischer et al., 2012; Akhilesh et al., 2014).

The long-term resource requirements of such a wide range of activities at numerous landing locations and fishing vessels must be taken into consideration. Thus, it is vital to design, test, and deploy alternative, innovative, and affordable methods of monitoring fishing, catch, landing, and trade, for instance, with strategies like Environmental DNA (eDNA). Our capacity to identify the occurrence and distribution of terrestrial and aquatic species has been completely transformed by eDNA technologies. According to recent research, the concentration of eDNA may serve as an efficient, quick measure of biomass and/or abundance for fisheries stock assessments.

2.4.5. Recommendations

Based on the results of this study, Table 2.3 presents a series of recommendations for enhancing the conservation status of elasmobranchs in Bangladesh. These recommendations are rigorously prepared and was in accordance with the International Plan of Action for the conservation and management of sharks (FAO, 1999; Fischer et al., 2012).

Table 2.3. Priority recommendations for elasmobranch research and conservation actions.

Stakeholders	Recommendations
Government/ state authoritative bodies	1. Amend national legislation to protect the most vulnerable species by managing catch and trade, and instating catch limits, size limits, and areal and/or seasonal closures for those capable of some level of fisheries; 2. Implement an improved accounting system for both landing sites and fishing vessels (e.g. logbooks, vessel trackers, observers, trained accountants in the landing sites) for transparent catch estimations and improved monitoring.
Researchers	1. Combine taxon specific biological (e.g. breeding biology and season) and ecological studies (e.g. trophic level interactions) for better understanding of populations and the intrinsic and extrinsic threats; 2. Enhance taxonomic research and local research capacity through universities and research institutes; 3. Conduct habitat level studies.

2.5. Conclusion

This study provides information on elasmobranch species richness and distribution in the Bangladeshi Bay of Bengal, revealing the identification of previously misidentified and cryptic species. The findings highlight inadequate monitoring and research in elasmobranchs in Bangladesh and the need for urgent improvements in conservation and fisheries management. Measures are recommended to address unmonitored catch and trade. The study places the Bay of Bengal, Bangladesh, on the global seascape as a critical area for elasmobranch species.

CHAPTER THREE: Fishers and Fisheries

3. Fishers' tales—Impact of artisanal fisheries on threatened sharks and rays in the Bay of Bengal, Bangladesh

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Tradition and identity- fishers at work ©SOSF/Oliver Deppert

Abstract

Increasing fishing pressure has negatively impacted elasmobranch populations globally. Despite high historical and current fishing pressure levels, the Bay of Bengal region remains data-poor. Focusing on Bangladesh, we conducted a socio-ecological study to characterize elasmobranch fisheries and evaluate their impact on threatened species. The results demonstrate that fishers employ a multi-species and multi-gear strategy for fishing within the study area (e.g., submerged or floating gill nets, set bag nets, seine nets, and long lines). The gears were selected based on seasonality and the target species by fishers. In addition to their primary gear, most fishing vessels carried three to five extra hooks to catch bigger fish opportunistically, sometimes including sharks. Sharks and rays were targeted in unbaited longline fisheries and taken as bycatch in other teleost fisheries. The fishers within this study were not active in targeted shark fisheries, except for one exclusive shark trader in Cox's Bazar, who had a fleet of 7-8 medium to large-sized fishing vessels with modified gill nets. However, a targeted ray fishery exists. Fishers perceived several globally threatened elasmobranch species had experienced substantial population declines (e.g., wedgefishes, sawfishes, large carcharhinid sharks) over the past decade. A decreased elasmobranch diversity, abundance, and size of caught specimens were also reported, attributed to the increased fishing intensity and an accessible elasmobranch market. While the catch and trade of several elasmobranchs are regulated under Bangladesh's law, and several fishers were willing to engage in conservation measures, non-compliance is widespread. Likely causes include a dearth of awareness, practical alternative livelihoods, technical facilities, and the complex nature of the fisheries. The expertise of fishers is an invaluable information source that can be used to design management and conservation strategies and better understand exploited species and historical trends. Encouraging and facilitating the engagement of fishers in science (data collection), local governance (policy-making), and field implementation (bycatch mitigation) is vital.

1.1. Introduction

Elasmobranch (sharks and rays) populations have declined by 80% or more in many regions across the globe, predominantly due to unsustainable fisheries driven by high demand for fins and meat (Schindler et al., 2002; Clarke et al., 2007; Dulvy et al., 2008; Graham et al., 2010; Morgan & Carlson, 2010; Kyne et al., 2020), together with high levels of bycatch especially in the tropics (Dulvy et al., 2021). Most elasmobranchs have slow growth rates, late age-at-maturity and low fecundity meaning they are vulnerable to fishing pressure and have a longer recovery time to overfishing compared to most bony fish (Schindler et al., 2002; Bräutigam et al., 2015). Nearly 37% of all elasmobranch species globally are now listed as threatened with extinction, according to the International Union for Conservation of Nature (IUCN) Red List of Threatened Species (Dulvy et al., 2014; Bräutigam et al., 2015; Dulvy et al., 2021; IUCN, 2021). Sustainable elasmobranch fisheries are possible, and a number of developed countries manage some elasmobranch fisheries sustainably (e.g. School Shark, *Galeorhinus galeus*; Gummy Shark, *Mustelus antarcticus*; Alaskan Skate, *Bathyraja parmifera* in the USA and Australia) (Prince, 2005; Dulvy et al., 2017; Simpfendorfer & Dulvy, 2017). However, the sustainable management of these fisheries is underpinned by data, enabling effective monitoring and assessment, and a good understanding of the fishery, together with high levels of compliance to regulations (Prince, 2005; Dulvy et al., 2017; Simpfendorfer & Dulvy, 2017; Dulvy et al., 2021; Haque et al., 2021c). Despite initiatives such as the UN Food and Agricultural Organisation (FAO) to develop sustainable management plans for elasmobranchs (https://www.fao.org/ipoa-sharks), many developing countries face challenges resulting from limited research and resources (e.g., Bornatowski et al., 2014; de Mitcheson et al., 2018; Haque et al., 2020; Haque et al., 2021a, 2021b, 2021c, 2021d).

The Northern Indian Ocean region includes some of the world's largest shark fishing nations (Davidson et al., 2016). In countries bordering the Bay of Bengal, an expansion of fisheries has led to overfishing of many species and populations in recent decades and is likely the cause for observed steep declines in elasmobranch catch and landings together with population shifts from larger long-lived species to smaller short-lived species (Lam & Sadovy de Mitcheson, 2011; Krakstad et al., 2014; Krajangdara & Vibunpant, 2019; Pauly et al., 2020; Haque et al., 2021c).

This study focuses on Bangladesh, a developing country situated at the northern tip of the the Bay of Bengal, where elasmobranchs have been exploited for decades. Fisheries expansion has increased catch levels to some extent; however, recent declines have been observed (Hoq et al., 2011; Haque et al., 2020; Haque et al., 2021a, 2021b, 2021c, 2021d). All the Bay of Bengal coastal and marine fisheries catch elasmobranchs, in either targeted or bycatch fisheries (Haque et al., 2020; Haque et al., 2021a, 2021b, 2021c, 2021d). Yet, Bangladesh is one of the most data-poor countries in the the Bay of Bengal regarding elasmobranch fisheries (Haque et al., 2021c, 2021d). Vital knowledge including information on fishery characteristics, catch trends, baseline data and stakeholder information is lacking (Zafaria et al., 2018; Haque et al., 2021a, 2021b, 2021c, 2021d), and currently hampers informed conservation decision making. This combination of high fishing pressure, data paucity and limited resources (Fischer et al., 2012) makes it challenging to devise and implement sustainable fishery management.

In the absence of historical data, the knowledge of fishers can be used to understand spatiotemporal abundance, for example, to reconstruct long-term population trends and species distributions (Dulvy & Polunin, 2004; Daw, 2008; Foster & Vincent, 2010; Macdonald et al., 2014; Frezza & Clem, 2015; Irigoyen & Trobbiani, 2016; Lavides et al., 2016; Colloca et al., 2020). Moreover, fishers can also offer important socio-ecological insights on conservation, legislation and aspects related to improved compliance (Jabado, 2014; Liao et al., 2019; Patankar, 2019; Spaet, 2019; Booth et al., 2020; Gupta et al., 2020; Mason et al., 2020; Ward-Paige et al., 2020; Collins et al., 2021). However, fishers' meaningful participation in research and fisheries decision-making processes is absent in Bangladesh.

Here, we present the results of our socio-ecological study in Bangladesh to characterize elasmobranch fisheries and evaluate their impact on threatened elasmobranch species based on the knowledge of local fishers. This adds to data being collected through concurrent scientific fieldwork and helps to validate the results (Haque et al., 2021a, 2021b, 2021c), especially where knowledge gaps exist such as historical accounts and population trends in the face of increasing fishing pressure. We utilise fishers' knowledge, observations and perceptions to: (1) characterise elasmobranch target and bycatch fisheries; (2) assess population trends of selected elasmobranchs and identify the reasons behind these trends; (3) explore regulations, i.e. the legal framework governing fishers' activities, and levels of compliance within this; and (4) characterise the attitude of fishers towards potential conservation measures. We evaluate these data and demonstrate the valuable role of local stakeholders in conservation decision making and conservation practice. The information presented in this study substantially improves our understanding of the complex dynamics of elasmobranch fisheries in Bangladesh and will inform conservation and management in the region and beyond.

3.2. Methods

3.2.1 Interview surveys

Between 03 May 2017 and 28 January 2019, 66 semi-structured (Table S3.1) and 80 structured (Table S3.2) interviews with Bangladeshi nationals involved in elasmobranch fisheries were conducted in Bangla language. Interviewees were either identified randomly or through snowball sampling (Atkinson & Flint, 2001; Etikan et al., 2016) and based on availability and interrest to participate in an interview. Interviews were conducted with fishers from 21 fishing villages (66 semi-structured, 39 structured), at two fish landing sites (Cox's Bazar and Teknaf; 21 structured) and two shark processing centres (Cox's Bazar and Teknaf; 20 structured) (Figure 3.1A and B) in south-eastern Bangladesh (Cox's Bazar, Teknaf and St. Martin's Island).

Ethical approval

This study was conducted with the ethical approval by the Ethical review committee of the Faculty of Biological Sciences, University of Dhaka (reference number- 59/Biol.scs.). Free Prior and Informed Consent (FPIC) standards were maintained. The data was protected and saved in a manner that it can not be traced back to individuals and no personal information was used or saved within the data. Before each interview, verbal permission to conduct the interview and use the data for scientific purposes was obtained from each interviewee. Research questions, purpose of the interviews, and data usage were explained to the interviewees prior to each interview. The anonymity of interviewees was guaranteed to avoid biases and data was protected. Furthermore, the interviews were not restricted to set durations of time nor were interviewees given any directions or instructions.

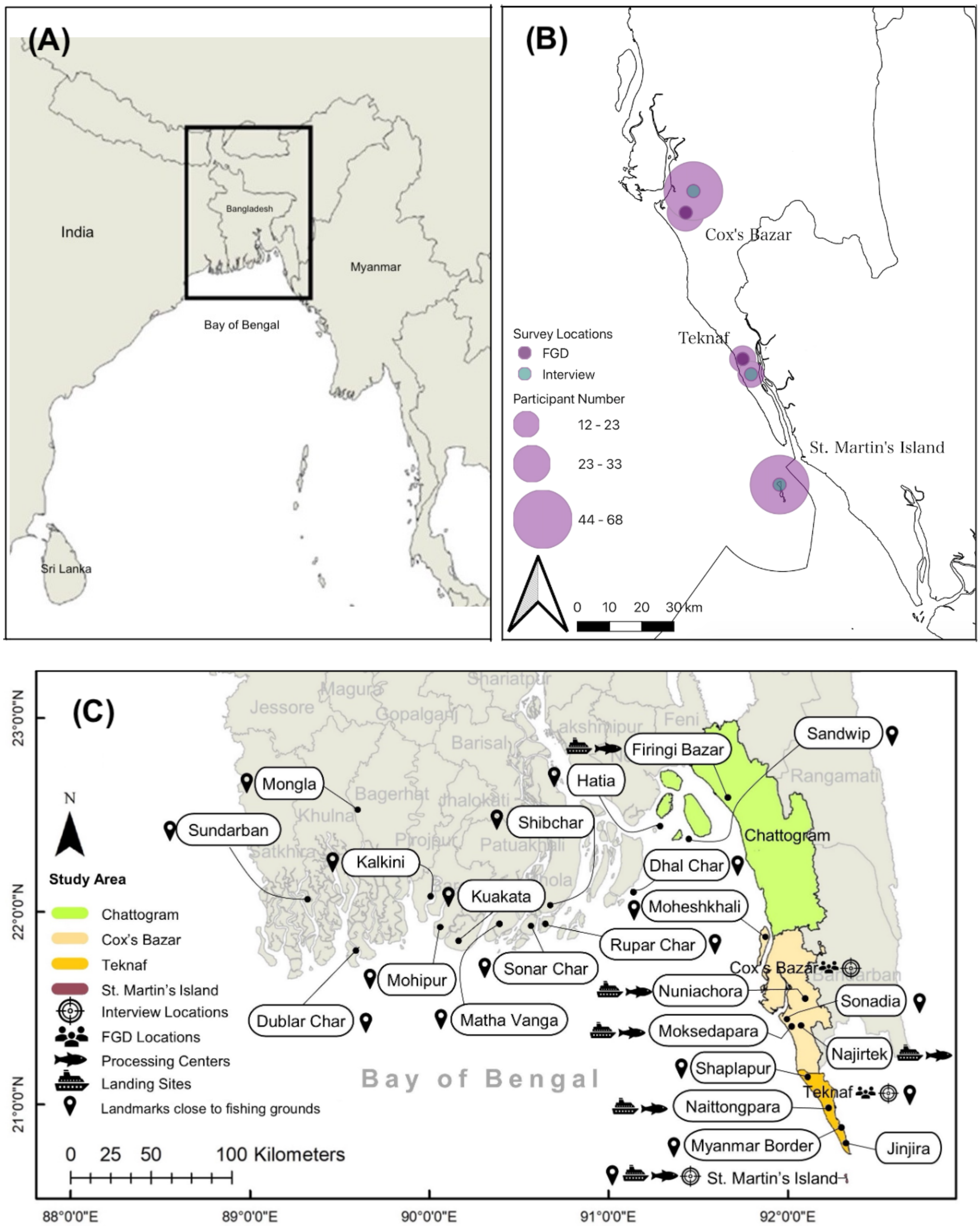

Figure 3.1. (A) Map of the study region- Bangladesh within the Bay of Bengal region (Inset). (B) Survey locations of focus group discussions (FGD) and interviews with number of participants. (C) Study area indicating survey sites, processing centres, landing sites, and landmarks close to the fishing grounds along the coast of Bangladesh as identified by fishers. The map was created using QGIS version 3.22.

The semi-structured questionnaire comprised predetermined questions to enable comparison of responses, with allowance for questions that were not planned in advance. The latter provided flexibility to explore subjects important to individual respondents on an informal level, helping to characterize the system qualitatively. Stakeholder-specific semi-structured questionnaires to evaluate: 1) Fishing practices; 2) target and bycaught species and their value; 3) legal frameworks governing fishing activities and compliance to these; and 4) the attitude of fishers towards conservation measures were designed partially based on Jabado et al., (2015), Jaiteh et al., (2017), and Haque et al. (2021a, 2021b). In some instances, related questions were grouped together (e.g. questions regarding the value or species) to aid both the information gathering and analysis. The knowledge shared by fishers was obtained either through their own experiences or shared legacies from fishing families. Additionally, to supplement this information, four focus group discussions (FGD) comprising a total of 43 participants (8- 13 participants in each) were conducted in four fishing communities with targeted ray fisheries (Table S3.3).

Within the structured interviews, interviewees were asked a set of predefined standardized questions in the same order (Table S3.2). Questionnaires for structured interviews (Table S3.2) were designed to evaluate the perception of fishers on elasmobranch population trends (e.g. historical exploitation and observed changes in catch numbers over time). To evaluate these trends as accurately as possible, a species-identification exercise was conducted with a group of 25 experienced fishers of the Cox's Bazar District Fishing Boat Labourer Union prior to the interviews. In an FGD format, fishers were shown photographs of 65 shark and ray species reported from Bangladesh (Hoq et al., 2011) and asked questions related to species identification, species-specific fisheries and local species names. Fishers were encouraged to discuss their knowledge of each species within the group. Nine unanimously identified species/species groups (i.e. *Galeocerdo cuvier* tiger shark, hammerhead sharks (*Sphyrna lewini* scalloped hammerhead shark, *Sphyrna mokarran* great hammerhead shark, *Sphyrna zygaena* smooth hammerhead shark, *Eusphyra blochii* winghead shark), *Rhincodon typus* whale shark, sawfishes (Pristidae), wedgefishes (Rhinidae) guitarfishes (Glaucostegidae and Rhinobatidae), *Carcharhinus sorrah* spottail shark, *Carcharhinus falciformis* silky shark and other large Carchariniform sharks) were selected for further taxa-specific questions regarding population trends. Additionally, most of the information on shark species provided by the fishers was corroborated by observations at landing sites (Haque et al. 2021c; Haque unpubl. data). Limitations of the study methods are detailed in Supplementary Information S3.1, for example, accuracy of identification, map-reading ability (See S3.1). Deep-water (>60 m) fishers were not included in this study due to small sample sizes, therefore the deep-sea fishery is not characterised here.

In addition, interviewees were engaged in conversations beyond the questionnaires' capacity as a means of capturing additional information (e.g. detailed perceptions and personal experiences about the reasons for population decline, personal stories encountering specific species, information on potentially extinct species, and information on species not included in the species photo compilation). Further details on the interview process and interviewee selection processes are provided in Haque & Spaet (2021).

3.2.2. Data Analysis

All interview results were translated into English. Descriptive (e.g. age, fishing experience) and inferential (e.g., monthly and annual average number of elasmobranchs caught) statistic routines were performed in R (R core team, 2020, version 3.6.1). For open-ended questions where multiple responses were recorded, each response was categorised and counted under a designated broad category. For example, we asked if the fishers have observed any changes in the populations of sharks in different timelines. If they have answered that they observed any declines, then we asked the reasons for that. In response to the question, "What are the main reasons for shark population decline in Bangladesh?"; fishers generally provided multiple answers such as overexploitation, increased number of boats, increased number of ports, new gear usage, greater distances covered. Each of these answers was placed within the broad category of overexploitation. Responses were categorized for several variables (e.g. reasons for elasmobranch population declines, list of target species, list of retained bycaught species, fishing grounds) (Table S3.3 & S3.4, Table 3.1 & S3.5, Figure 3.1C and Figure S3.1).

The average number of elasmobranchs caught monthly can also be associated with different variables such as gear used, fishing homeport, seasonality of fishing (monsoon (June to September), winter (October to January), summer (February to May) and all seasons), the mesh size (cm) of nets used, fishing depth (m), monthly fishing days and distance covered from homeport (km). To determine if the number of elasmobranchs caught was associated with these independent variables, we fitted generalized linear models (GLM, Poisson regression) (R Core team, 2020). Poisson regression is a form of regression analysis in statistics used to model count data (Cameron & Trivedi, 2013). A GLM (Poisson regression) was selected as the dependent variable (number of elasmobranchs caught) was count data and had a poisson distribution. The mean and variance of the dependent variable were checked. Overdispersion of the data observed (variance>mean). As a result, the quasipoisson family was used to deal with the overdispersion of data. Quasipossion regression keeps the coefficients the same as the poisson regression; however, it adjusts the standard errors to avoid Type I errors in p-values. The model fit was checked by comparing the model with a null model (without any predictors) using the *summ*() function in the jtools package (Long, 2020).

To test for the presence of a progressive shift in accepted standards for the state of the natural environment (Pauly, 1995; Soga & Gaston, 2018), and evaluate whether observed elasmobranch population changes were associated with age and experience of interviewed fishers, a GLM (Poisson regression) was performed using the same methods described above.

A linear regression model was performed to establish whether mesh size was related to fishing depth (see section 3.3.3.2).

3.3. Results

3.3.1. Elasmobranch fisheries

Fishers used a multi-species and multi-gear approach (e.g. submerged or floating gill nets, set bag nets, seine nets and long lines) in all areas and on all vessel types (Table 3.1, Table S3.5). Gear selection was primarily driven by the seasonality of the target species and sea condition. The majority of fishing boats (83%) carried 3-5 additional big hooks in addition to their primary gear to opportunistically catch large fish including sharks (Table 3.1, 3.2). According to fishers, an estimate of >8,000 boats operated from three sites (St. Martin's Island, Teknaf and Cox's Bazar) on a daily basis. Targeted species generally included demersal and/or pelagic fish species (Figure S3.1A, Table 3.1). Elasmobranchs were caught as bycatch in other teleost fisheries, such as the hilsa fishery, and were targeted in ray fisheries (Figure S3.1B; see section 3.3.2). According to fishers, a range of 0.5 to >1,000 kg of whole bodied sharks was landed by each vessel per day (94% stated that between 300-600 kg of sharks were landed by each vessel per day in the winter months). With the exception of one exclusive shark trader in Cox's Bazar, who operated a fleet of 7-8 medium to large sized fishing vessels with modified gillnets, none of the interviewees were involved in targeted shark fisheries. Based on interviewers with three fishers who targeted rays, guitarfishes and wedgefishes, it was inferred that at least 480 motorised fishing vessels targeted rays (e.g., *Glaucostegus* spp. giant guitarfishes, *Gymnura* spp. butterfly rays; Table S3.6), mostly from ports of the south-central region and 60 in the south-east region. FGD participants indicated that bottom-dwelling rays were targeted in bottom long line fisheries, using 10,000 to 30,000 unbaited 3.8 – 5 cm hooks per km of line, at a depth between 4.8 m - 36.5 m (Table S3.6, Figure S3.2). Ray fisheries target multiple species, although guitarfishes and large-sized rays were the most desirable (Table S3.6).

Table 3.1. Characteristics of fishing trips, vessel types, primary and secondary gear, catch locations of fishing vessels operating in Cox's Bazar, Teknaf and St. Martin's Island. Primary gear type indicates gear used to catch the main target species; secondary gear type indicates additional gear used to catch non-target species. Further details are in table S3.6.

Bycatch elasmobranch fishery (%) indicates the percentage of respondents.						
Fishing trips per month	1-3 (19.7%)	4-10 (24.24%)	11-20 (31.86%)	20-25 (24.24%)		
Days at sea per trip	1-5 (34.8%)	5-10 (31.8%)	10-15 (22.7%)	>15 (10.6%)		
Distance covered from homeport (km)	1-10 (18%)	10-50 (13.6%)	50-100 (28.8%)	100-200 19.7%)	200-250 (16.7%)	>250 (3%)
Vessel size (m)	Small 5-10 (16.7%)	Medium 10-15 (36%)	Large 15-20 (25.8%)	>20 (21%)		
Engine power (HP)	7-25 (32%)	25-45 (56%)	45-65 (6%)	>65 (6%)		
Primary Gear type						
	Respondents (%)	Mesh size (cm)	Length (m)	Deployment depth (m)	Target species (Respondent number)	
Submerged and floating gill nets (hilsa gill nets)	34 (51.4)	7.62- 22.86	4.5-6,100	10-116	Demersal (19), Pelagic (23), both (22), don't know (2)	
Set bag nets	18 (27.3)	7.62- 15.24	4.5-3,600	4-20		
Others*	14 (21.3)	7.62- 17.78	3-3,900	4-24		
Secondary gear type						
	Respondents (%)	Length (m)	Number of hooks	Depth (m)	Target species	
Baited hooks	55 (83.3)	-	3-5	No selected depth	Multi-species fishery	
Unbaited long line	2 (3)	4,569-6,092	100-15,000	<40m	Smaller fish and ray species	

*(seine nets, trammel nets, modified gill nets for specific species, bottom-set nets, rock nets)

Table 3.2. Percentage of respondents (n=66) and their answers to selected questions pertaining to Bangladeshi shark fisheries.

Question related to	**Answers (in %)**			
Average no. of big sharks caught per trip	1-50 (26)	50-100 (39)	100-150 (23)	> 200 (12)
Monthly average catch	Tiger sharks	Hammerhe-ad sharks	Whale sharks*	Sawfish
	15-20	40-60	1-3	0
	Guitarfishes	Spadenose sharks	Wedgefishes	Other large Carcharhinifor mes
	1-50	500-600	0	1-65
Discards and sales	Auction (14)	Sale to middlemen/ traders (83)	Discard (3)	
Shark parts offered for sale	Whole body (94)	Fins (6)		
Estimated daily amount (kg) of landed sharks	0.5-300 (38)	300-600 (39)	600-1000 (9)	>1000 (6)
Sale to specific buyers	Yes (6)	No (94)		
Is it desirable to catch sharks as bycatch?	Yes (74)	No (17)	Sometimes (9)	
Monthly income from shark bycatch (US$)	12-120 (44)	120-235 (20)	235-353 (6)	Negligible to no income (30)
Willingness to use methods to mitigate bycatch	Yes (41)	No (23)	Only if alternatives are available (27)	Inconceivable (unsure) (9)
Reasons for shark population decline	Overfishing (36)	Bottom trawling (13)	Destructive net use (12)	Anthropogenic development, pollution, biological reasons (5)
Awareness on national laws	No (94)	Yes (6)		
Awareness on public outreach campaigns	No (100)			

*sightings

3.3.2. Catch composition

Almost all gear types used caught elasmobranchs. While smaller specimens (<70 cm) were relatively common in the catch throughout the year, large specimens (>150 cm) were generally only caught in the winter, spring and summer months. The catch size was dependent on the season, fishing gear used and geographic location of homeports and fishing grounds.

The most commonly bycaught elasmobranchs were *Scoliodon laticaudus/ macrorhynchus* spadenose shark, small-sized whiprays and stingrays (*Pateobatis* spp. whiprays, and *Brevitrygon* spp. stingrays), followed by *Gymnura* spp. and other small-sized sharks. Fishers also commonly caught *Sphyrna* spp. hammerhead sharks, and several species of requiem sharks. Between 100 to 1,000 small (<70 cm) and 1 to 200 medium (71-150 cm) and large sharks (> 150 cm), respectively, were reportedly caught per fishing trip, although 12 fishers stated catches of more than 200 sharks per trip. Monthly average sightings in coastal waters were highest for spadenose shark (500-600 individuals) and lowest for sawfish (0) (Table 3.1). With the exception of sharks >2.5m, all sharks were reportedly landed whole, although cases of finning and carcass discarding of larger catches around 15-20 years ago were reported by three fishers. The most commonly caught species in longline fisheries were *Glaucostegus* spp., *Gymnura* spp., *Himantura* spp. stingrays, and other dasyatid rays (*Urogymnus* spp. mangrove rays, *Maculabatis* spp. whiprays, *Neotrygon* spp. maskrays)

The number of elasmobranchs caught per month was dependent on area, fishing homeport and season ($p < .001$) (details in Table S3.7). For example, fishers in St. Martin's Island caught significantly lower numbers of elasmobranchs than fishers from Cox's Bazar (beta= -1.7043, p= 0.00123 **). Fishers, who fished during all seasons caught a higher number of elasmobranchs than fishers fished during the winter (beta= -2.9219, p =0.02886 *), summer (beta= -1.9137, p= 0.10585) and monsoon (beta= -1.2293, p= 0.27906) seasons; however, the relationship of the number of elasmobranchs caught in all seasons with summer and monsoon was not significant. Quasipoisson regression model results showed that set-bag nets using fishers (beta= 2.2301, p= 0.00424 **) caught a higher number of elasmobranchs than fishers who used floating gill nets. Fishers using hilsa gill nets (beta= -0.9191, p= 0.04002 *) on the other hand caught lower number of elasmobranchs than fishers who used floating gill nets (detail in Table S3.7 for quasipoisson regression results for all gear types). The quasipoisson regression model was a good fit (Nagelkerke's R2 = 1.00; Pseudo-R^2 (Cragg-Uhler) = 1.00; Pseudo-R^2 (McFadden) = 0.39). Another quasipoisson regression model results showed, the number of elasmobranchs caught per month was also negatively related to mesh size of gear used (beta = -0.151837, p= 0.0172 *) (Table S3.7). This quasipoisson regression model was also a good fit (Nagelkerke's R2 = 1.00; Pseudo-R^2 (Cragg-Uhler) = 1.00; Pseudo-R^2 (McFadden) = 0.16). Linear regression results showed that with increasing depth, larger mesh sizes were used (beta = 0.05, $p < 0.01$). Here, the beta coefficient is the degree of change in elasmobranch catch numbers for every 1-unit of change in the predictor. As the effect sizes in the models are small, these results need to be interpreted with caution.

3.3.3. Fishers' species identification skills

Elasmobranch identification skills varied among fishers. Identification capacities were particularly low when obvious traits, such as body markings or a distinctive body shape were absent. Elasmobranch identification was particularly poor for morphologically similar species, and overall fishers grouped most large Carcharhiniformes without any distinctive marks (e.g. black tips on fins) into one category. Additionally, all rhinopristiformes rays (guitarfishes, giant guitarfishes, wedgefishes, except for *Rhynchobatus laevis/ australiae* smoothnose wedgefish/ bottlenose wedgefish and *Rhina ancylostoma* bowmouth guitarfish), all sawfishes (*Pristis pristis* largetooth sawfish, *Anoxypristis cuspidate* narrow sawfish, *Pristis zijsron* green sawfish) and all hammerhead sharks, respectively were grouped together. Although several fishers were able to identify at least 4-5 different Rhinopristiformes and at least 2-3 hammerhead sharks, this identification capacity was not consistent, for example, smaller guitarfishes (Rhinobatodae) and giant guitarfishes (Glaucostegidae) were mostly identified as the same species, as were *Carcharhinus amboinensis* pigeye shark, *C. leucas* bull shark and *Glyphis* spp. ganges shark (Table S3.8).

3.3.4. Bycatch

Despite the fact that the broad categorization of elasmobranch catches as "target" and "bycatch," fishers' interviews revealed nuanced perceptions about these complex catches (Box 1). Most shark and ray species are unintentional catches, including high- and low-value catches. The high-value species can also be regarded as secondary catches because of their desirability and high prices at the landing sites. Once captured, all species of the same size are handled uniformly at the landing sites, with the same prices and sale conditions. However, if the secondary catch is very sought-after (like large hammerhead sharks), the price and selling dynamics change depending on size. Alternatively, they may occasionally be discarded if they are merely unwanted bycatch (such as bamboo sharks or electric rays). Even the sought-after secondary catches are not specifically targeted; nor the fishing efforts are changed to increase the catches; they are desirable because there is a market for them.

The treatment of a species at landing sites is the same whether it is a target catch or a bycatch. Hence, the term "bycatch" was used for any unintended catch, and "target" was used if they were specifically targeted using modified gears (e.g., unbaited longlines).

Box 1. The bycatch complex of elasmobranch catches in Bangladesh.

<table>
<tr><th>Target catch</th><th colspan="3">Bycatch</th></tr>
<tr><td rowspan="2">Intentional catch using modified unbaited longline including opportunistic catches with large iron hooks</td><td colspan="3">Unintetional cactch in any gear intended to catch a different target species. Not directly targeted using any specific gear or techniques, resulting in fishing mortality, including discards</td></tr>
<tr><td>High value/ highly desirable unintentional catch</td><td>Low value/ undesirable non-discarded unintentional catch</td><td>Discarded unintentional catch</td></tr>
<tr><td>Guitarfishes, dasyatid rays, seldome large-bodied sharks</td><td>Hammerhead sharks, sawfishes, guitarfishes</td><td>Bamboo sharks, small-bodied sharks caught in small numbers</td><td>Electric rays, seldom small-bodied rays</td></tr>
</table>

3.3.5. Population trends

Fishers observed a decline in diversity, individual size and catch size of elasmobranchs during their fishing careers. One fisher stated, "*there was a time a few decades ago when we could not keep all the sharks caught due to limited storage capacities; now the size of catch has declined tremendously*" (Table S3.9). Reports of the disappearance of several species from the catch were also reported unanimously. The majority of fishers associated the decline primarily with overfishing and bottom trawling.

The vast majority of interviewees (98%) reported a change in elasmobranch catch and abundance over time, with a decrease in catch size (total catch) of all valuable species (large and high priced; see Haque & Spaet, 2021). A reduction in the size of individual species within the past 20 years (mean=14.21 ± 5.6 SD) was also mentioned by fishers (80%; mean=14.21 ± 5.6 SD) (Figure 3.2A and B). 68% of fishers suggested changes occurred over the last two decades and 95% indicated accelerated declines over the past 5-10 years. In contrast, 25% of fishers were unaware of any changes in population size over the past 10-20 years, whereas 3.75% had not observed any change in population size over the past 5-10 years. Changes were reported for both, species diversity (34% of fishers) and total catch (41% of fishers). 17% reported a reduction in valuable species only (e.g. sawfishes, wedgefishes). Fishers identified at least 12 species or species groups which had become less common over their career (Figure 3.3A) with the disappearance of some species such as sawfishes (75% fishers) and wedgefishes (especially smoothnose wedgefish/ bottlenose wedgefish) (15%) from their catches (Figure 3.3B). Fishers also reported, lower catches of large sharks (e.g., whale sharks, large hammerhead sharks, and large carcharhinid sharks), now, compared to 10-20 years ago (Figure 3.2A). 24% of fishers reported an increase of smaller hammerhead sharks (likely juveniles, corroborated by unpublished landing data) over the past ten years. All fishers reported a steep decline in ray populations, especially after the late 1990s (Table S3.9). Fishers targeting rays also reported an overall decline in larger ray species. Reported catch sizes varied, with fishers reporting 1 to 20 individuals (per 7-day trip in recent times). A steep decline in catch rates between 2000-2010 was reported (e.g. recent one individual caught in 2018, compared to >1,000 large dasyatid rays in one trip in 2000s). For instance, fishers mentioned that fishing trips were cut short due to a lack of storage capacity caused by catching large numbers of rays 10 to 20 years ago.

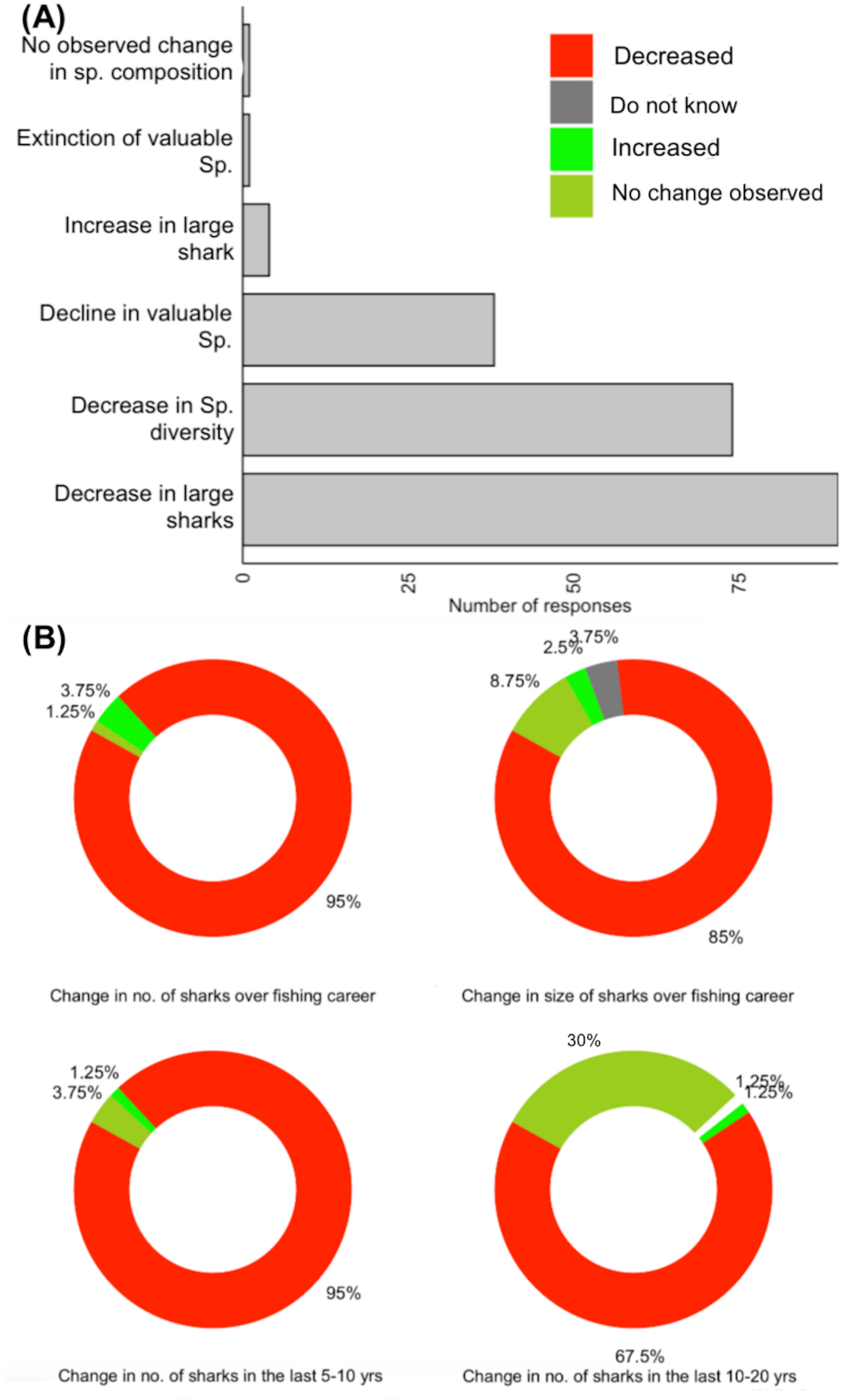

Figure 3.2. Observed changes in the catch composition of sharks (A) Observed change in catch composition over individuals' fishing careers (n=66). (B) Observed changes in the number and size of caught sharks over the entire fishing career of interviewed fishers [2-55

years (mean= 26.5±13 SD)]. Observed changes in the number of caught sharks over the past 5–10 and 11–20 years, respectively.

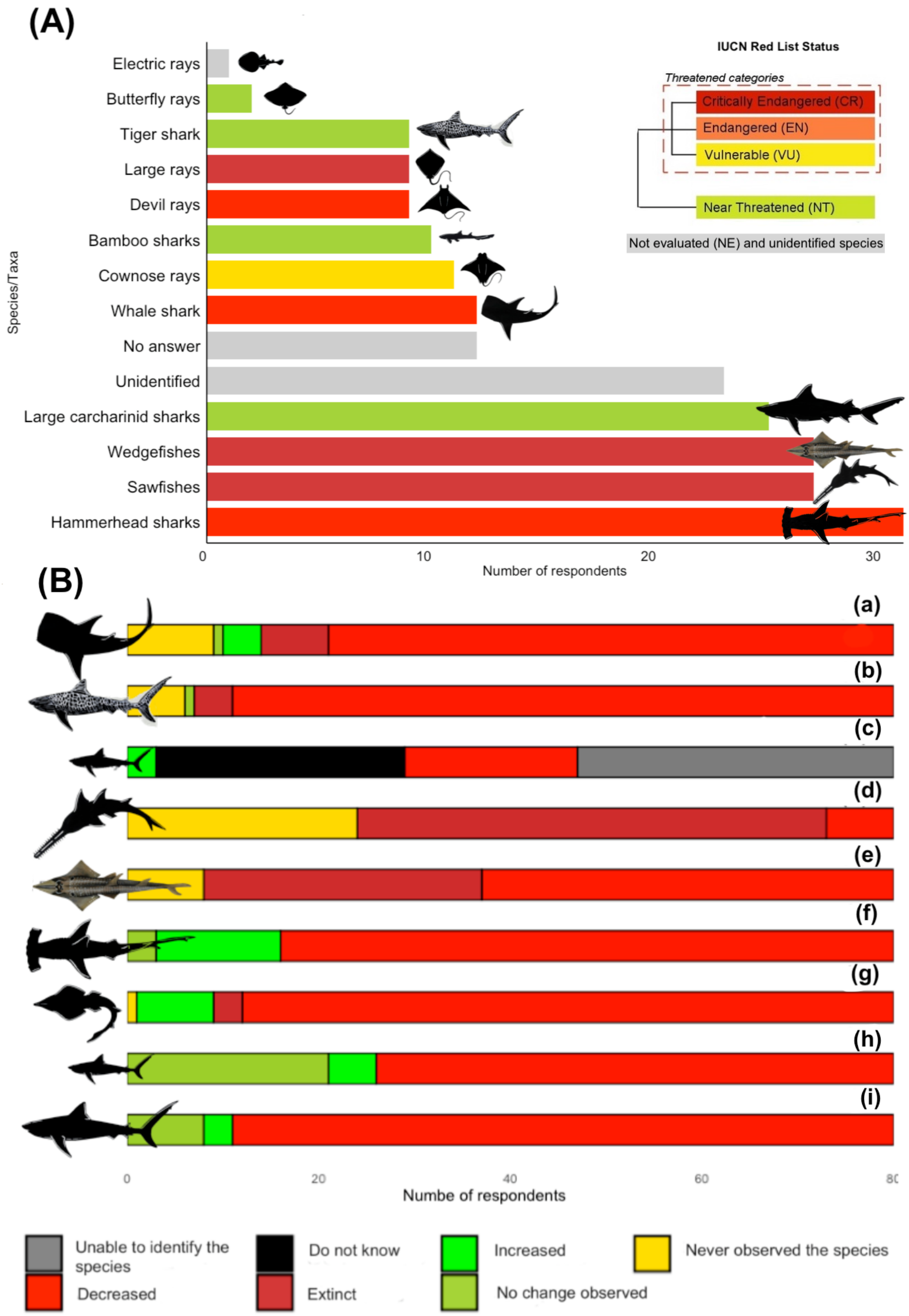

Figure 3.3. (A) International Union for Conservation of Nature (IUCN) Red List of Threatened Species status of species that have shifted from common to uncommon. Fishers were asked to list the species which were common at the beginning of their fishing careers,

but became uncommon in recent years (total no. of respondents = 80). 12 species/taxa that fitted this description were identified by the fishers; these are presented in the graph. The colours represent the IUCN Red List categories for the status of these species/taxa, whereby CR = Critically Endangered; EN = Endangered; VU = Vulnerable, NT = Near Threatened, NE = Not Evaluated. Species that could not be determined based on local names are labelled as unidentified and coloured grey. Number of fishers who did not respond were also coloured grey. (B) Observed population trends of selected elasmobranch species, over the past ten years. (a) whale shark, (b) tiger shark, (c) silky shark, (d) sawfishes, (e) wedgefishes (Rhynchobatus spp.), (f) hammerhead sharks, (g) guitarfishes and wedgefishes, (h) small carcharhinid sharks (e.g., spottail shark), (i) large carcharhinid sharks.

The reported main drivers of change in elasmobranch abundance were overfishing by artisanal fisheries (cited by 55% fishers; e.g., introduction of modified gears and methods targeted to increase catch sizes (e.g., smaller mesh size, bottom longlines), commercial mid-water and bottom trawling, unselective fishing gear, as well as an expansion of fishing areas, an increase in numbers and size of vessels, as well as the introduction of negative subsidies to industrial fisheries. Coastal habitat degradation by other anthropogenic drives (e.g., coal-based power plant, industries) and the K-selected life history of elasmobranchs were also considered important (62%).

3.3.6. Cross-generational differences in perception

Fisher age was positively and significantly related to the perception of the timeline since a change in elasmobranch population size was observed (beta = 0.02, 95% CI [8.45e-03, 0.02], p= 7.56e-05 ***). Correlations of fishing experience and perception of the timeline since a change in elasmobranch population size was observed were positive but non-significant (beta = 7.45e-03, 95% CI [-1.04e-03, 0.02], p = 0.0817). This suggests that older fishers observed a change in population earlier than the younger fishers (Figure S3.3). The quasipoisson regression model was a good fit (χ^2 (2) = 114.08, p = 0.00) and 84% of the variation in the outcome was explained by covariates (Nagelkerke's R2 =0.84) (Nagelkerke, 1991) (Table S3.10).

3.3.7. Fishers' attitudes towards fisheries management and conservation

94% of interviewed fishers were unaware of Bangladesh's national Wildlife (Conservation and Security) Act, 2012 (WCSA). Those who were aware of the Act were unable to elaborate on existing laws (Table 3.2). While several fishers stated that some sharks might be protected, they were unable to provide details on their protection status. None of the fishers were familiar with CITES (the Convention on International Trade in Endangered Species of Wild Fauna and Flora). Fishers stated that permits to trade shark products were not required. Ray fishers in the FGD group were unaware of any national and international laws or treaties protecting ray species. Reportedly awareness campaigns on declining ray populations and conservation had not been conducted. Additionally, fishers claimed that they were compelled to pay bribes to avoid punishment for trading certain undefined species.

Fishers showed a genuine interest in national laws. During interviews and FGD, they were eager and compassionate about the recovery of elasmobranch populations in Bangladesh. Several participants (n = 15) asked about ways to concurrently conserve elasmobranchs and their livelihoods. Over 75% of fishers acknowledged the importance of sharks to ocean health and 41% were willing to employ new methods to stop shark and ray catch or mitigate bycatch with alternative livelihoods provided. A fifth (22%) were unwilling to change fishing practices mainly because of the unavailability of required support. The remaining fishers either did not answer the question (33%), or were not sure of the actions needed for shark conservation, but showed interest by inquiring about appropriate conservation approaches. Fishers mentioned the potential unsustainability or failure of conservation measures due to insufficient income of affected fishers leading to non-compliance. Fishers noted that trading had become minimally profitable due to declining elasmobranch populations. As a result, they showed willingness to change to more sustainable fishing methods if facilitated (e.g. through financial support, social security, training, ownership of vessels and nets) and incentivised. Many fishers (n= 35) also stated that a better and equitable share of profit or salaries from fish catches in coastal waters may improve their decision making regarding best practices and conservation of threatened species. Fishers also mentioned, the possibilities of including existing cooperatives in managing resources. For instance, one fisher in Cox's Bazar stated, "*We have a cooperative with 500 registered fishers but we never participated in any conservation actions regarding elasmobranchs*". Mechanical (e.g., diverse net use, variation in season and fishing practices) and social complexities (e.g., poverty, unequal profit sharing, oppression by fishing companies, limited access to fundamental rights) were mentioned as hurdles to conservation planning (e.g., live release, possible temporal or spatial closure or trade ban). Additionally, interviewees requested specific information regarding bycatch mitigation, the release of bycaught species. Fishers also wanted to understand governance issues regarding potential regulations impacting their livelihoods. For instance, they requested information on authorities responsible for potential compensations or alternative livelihood facilitation if targeted ray fisheries were to be banned. Interviewed fishers also showed interest in understanding the possible monitoring mechanisms for ensuring adherence to regulations at sea (e.g., 'what if, in fear of being fined or jailed, fishers discarded dead sharks at sea?'; 'Who will monitor what is happening at sea and how?'). Finally, several fishers were eager to learn about the ecological benefits of healthy shark and ray populations.

3.4. Discussion

Our study highlights that in data-poor regions such as Bangladesh, fishers' knowledge provides an invaluable information source for an increased understanding of exploited species, current and historical trends, and to inform the development of conservation and management measures. The insights gathered by this study highlight the benefits of fishers' participation in conservation and the importance of co-designing management regimes for better sustainability and success.

3.4.1. Elasmobranch: Fisheries and Population Trends

Elasmobranch catch is prevalent in every gear used in Bangladesh, either as targeted or desirable bycatch. Monthly catch and daily landings reported during the interviews indicate higher catch numbers than those reported in national statistics (DoF, 2018; Haque & Spaet, 2021). Catches have perpetually declined over the past decade, indicating size distribution change, stock depletion due to overexploitation (see section 3.3.3.4) and increasing fishing effort potentially leading to stock collapse.

Most fishers reported changes in elasmobranch species composition and/or catch rates over time. Several fishers identified species that were commonly present in the past but had not been caught over the past 5-10 years or more, e.g., bottlenose wedgefish/smoothnose wedgefish, and sawfish potentially indicating extreme rarity. According to IUCN Red List criteria (IUCN, 2021) at least 21 of the elasmobranch species that were frequently caught and traded by interviewed fishers are currently threatened with extinction (12 Critically Endangered, 7 Endangered, and 2 Vulnerable) (Table 3.1 & S3.9) and several were listed in different CITES appendices (Haque & Spaet, 2021). None of these species are currently managed in Bangladesh. Fisher's responses were corroborated by recent studies that recorded the disappearance or reduced landings of several elasmobranch species at these sites (Haque et al., 2021c; Haque unpublished data, 2022). Changes in abundance were emphasised for largetooth sawfish, narrow sawfish, bottlenose wedgefish/smoothnose wedgefish, great hammerhead shark, and smooth hammerhead shark, amongst several others. This corroborates declines of these species globally (IUCN, 2021). For instance, largetooth sawfish populations have been depleted by more than 80% throughout their range across the Indo-West Pacific (Kyne et al., 2013; Yan et al., 2021). At least 30 nations within this region have declared largetooth sawfish as locally extinct owing to an array of threats, particularly fisheries (Harrison & Dulvy, 2014; Yan et al., 2021). The case is similar for wedgefishes and giant guitarfishes (Rhinidae and Glaucostegidae). Exploited by targeted and incidental catch, these species have gone through severe population depletion and even localized disappearances (Dulvy et al., 2016; Moore, 2017; Jabado et al., 2018). For instance, in neighbouring Pakistan, a 99% population decline was reported for all rhinids and glaucostegids (Kyne et al., 2020). These species are particularly vulnerable to extinction due to their limited biological productivity (Kyne et al., 2020), intense coastal fisheries overlapping their habitats and ensuing food security for vulnerable communities (Moore, 2017). Similarly, in Bangladesh, fishers stated that declines in elasmobranchs were primarily associated with bottom trawling practices and unselective net use.

The decreases in catch rates over the past two decades reported in this study coincide with an estimated 34% decrease in reconstructed Bangladesh elasmobranch landings over 15 years starting in 2000 (Pauly et al., 2020), and a four-fold increase in overall fishing effort between 2000 and 2014 (Ullah et al., 2014; Pauly et al., 2020). Although there is evidence that gear modification for increased capture rates can lead to overfishing, the direct quantitative relationship between gear modification and elasmobranch population change could not be determined. However, it is commonly accepted that fisheries expansion (e.g., overfishing) is the primary cause of worldwide elasmobranch population reduction (Dulvy et al., 2021).

Reported decreases in size and number of caught elasmobranchs in this study, corroborate findings across Southeast Asia, where large sharks have declined and landings of small-bodied sharks (e.g. bamboo sharks) have increased over the past few decades (San San Khine, 2010; Lam & Sadovy de Mitcheson, 2011; Lack & Sant, 2012; Krakstad et al., 2014; Arunrugstichai et al., 2018). At the same time many resilient and small-bodied shark populations have either declined or collapsed, e.g. in India, spadenose shark, *Rhizoprionodon acutus* milk shark, *Carcharhinus limbatus* blacktip sharks (Mohamed & Veena, 2016), highlighting the problem of fishing for elasmobranchs in the absence of practical regulations. Fishers also cited overexploitation of juvenile and pregnant individuals as reasons for the observed population declines. It is of critical importance to connect the conservation of early life-stage individuals, in nursery areas, with management strategies safeguarding all life-stages (Kinney & Simpfendorfer, 2009). Interventions such as large-scale net/mesh-size modification, fishers' involvement in live release programmes and designating species-specific quotas are crucial for limiting catch. For habitat level interventions spatial co-management of critical habitats are key. This study found that the size of catch is associated with gear, mesh size of net used, total fishing days, depth at the catch, fishing homeports, seasonality and distance covered from homeports. These results can be applied to help co-design appropriate quotas to curb unsustainable catches by introducing location, depth and gear selectivity within these fisheries.

3.4.2. Fishers’ attitude: Conservation and Challenges

Changes in elasmobranch populations were observed by all age classes of fishers, signifying that overexploitation has been occurring for decades. This also suggests that the perceived changes are occurring at such a rapid pace that all age groups are experiencing it. It is likely that the fishers may have attuned to the increasing scarcity of the elasmobranchs and perceived this as ‘natural’ when they started their careers. Because prior reductions are ignored or discounted and "decline" is seen as "normal" or "unavoidable," these diminished or "shifted" expectations can lead to systemic environmental degradation. This is a situation that is quite similar to observer bias. Whatever the explanation, the incredible consistency in view regarding the constant change in elasmobranch populations from the younger to the older indicates quite clearly how things are shifting concerning the natural supply of these species. This can impact their behaviour towards the corrective policies (Bunce et al., 2008; Jabado, 2014; Haque & Spaet, 2021). In the current study, several fishers were certain that some species (e.g., wedgefish, sawfish) have been uncommon/rare throughout their fishing career, and that there is no way to prevent the decline or the bycatch events. As a result, some fishers had the view that regulations may not help to conserve such species. Such mindsets can be challenging when attempting to convince fishers to adhere to specific regulations to limit catch. This emphasises the need for education, including evidence and relatable examples of the positive effects of conservation actions on species survival, and on fishers’ livelihoods; which can help change these views and mindsets. Inclusion of fishers' perceptions and understanding of conservation measures can be used to develop more effective conservation regimes for fisheries management (Maynou et al., 2018; Fauconnet et al., 2019; Liao et al., 2019).

The capacity and willingness of fishers to abide by laws and regulations are cardinal for management regimes to be effective. Nevertheless, this study reveals that legal frameworks governing fishing activities and protected species were, in many cases, unknown or not well-accepted by fishers, resulting in non-compliance. This dearth of knowledge is likely caused by limited interactions with fisheries officers, a lack of implementation of existing laws, undemocratic law development processes, increasing corruption and the fear of livelihood loss. Local managers from BFDC and employees of the local government were also either unaware of the fisheries or disinterested due to lack of resources/incentives in promoting elasmobranch protection beyond setting up signboards at some sites (Haque, pers. comm. January 2019). Another important aspect is the oversimplification of the national law, which does not consider the complexities of fisheries. For example, several species are prohibited from being caught and traded, with little provision for awareness generation or facilitating fishers' adherence to the regulations, either logistically or technically (e.g. bycatch mitigation strategies). A more detailed and holistic approach is needed for effective conservation and compliance. Additionally, incentives for fishers would help secure compliance and effectiveness of the law in protecting threatened species. For such interventions, it is essential to understand the fishers' situations, perceptions and capacity to comply.

Fishers showed mixed reactions towards participating in elasmobranch conservation actions, depending on several socio-ecological aspects (e.g. financial capacity for good practice at sea, poverty, access to information, effective livelihoods). Although education programs organised by several local and international NGOs exist, they were unable to reach the fishers at the scale required due to a lack of resources, the sheer number of fishers in all coastal regions, and the short-term nature of such projects.

A substantial number of fishers were willing to participate in bycatch mitigation methods and were aware of the reasons behind population depletion. However, as fishers face lost incomes, unpaid debts (Haque et al., 2020) and corruption, it is also likely that these factors will cause illegal activities and enhanced levels of non-compliance (Jaiteh et al., 2017). Prosocial attitude is critical for the long-term management of common property resources like fisheries. Socioeconomic characteristics influence fishers' prosocial actions, as a result, management regimes need to understand fishers' socio-economic backgrounds (Rojas et al., 2021). For example, providing ineffective alternative livelihoods/compensations for hilsa seasonal catch ban to mitigate fishing mortality generated conflicts in Bangladesh (Islam et al., 2017). Similarly, recent sporadic implementation of the umbrella bans on shark catch has instigated alternative ways of landing and selling the catch in coastal Bangladesh and conflicts amongst fishers and government fishery officials, but failed in mitigating capture of elasmobranch species (Haque, unpubl. data, 2022). For both cases, this was because these actions were largely devoid of in-depth understanding of fishers' socio-economic conditions. Similar bans on shark catch remained futile in Myanmar and non-compliance was an issue in the absence of acceptance by the fishers (Begum et al., 2020; Collins et al., 2021). Ensuring fishers' participation in data collection has been effective in the Bay of Bengal as it builds trusted relationships and active participation (e.g., reporting Critically Endangered sawfish catch in Haque et al., 2020), which can lead to ownership of the actions and marine resources (Haque et al., 2020). Monitoring measures are also essential in this regard (Price et al., 2016) to ensure mitigating any further illegal activates. There are several other factors which enhance fishers' compliance with laws. For instance, fishers follow laws when they understand them, feel that the laws serve their interests, and have relationships with management authorities that are based on trust (Hønneland, 1999; Hauck, 2008). Nonetheless, participating meaningfully and representing the fisher communities in the fisheries decision-making process has hardly been considered to date in Bangladesh.

The decline in elasmobranch populations and the difficult financial and economic situation of most fishers is succinctly captured in the following quote of a bycatch fisher from Alipur interviewed in January 2018: "*In the early days (the 1970s - 90s), we caught sharks and rays abundantly. Now they have declined due to heavy fishing pressures. We have no other alternatives for our livelihoods than fishing. Although we do not target them, an extra income from sharks and rays is always helpful. We do not own boats or nets. We have debts from the boat owners, and more catches are better for us. But the recent attempts from the government officials to stop the catch at the landing sites will not help anyone... not the sharks or fishers. They have to understand our problems and help us if they are expecting real change. Otherwise, there will be some corruption from both ends.*"- (translated from Bangla). This reflects the multifaceted problems that need to be addressed in order to improve fisheries management in Bangladesh and other/similar developing countries. Building on the evidences from this study, openness of fishers for inclusive, future management scenarios, a democratic conservation strategy could be an effective way forward (Table 3.3).

Table 3.3. Challenges regarding elasmobranch fisheries management in Bangladesh with recommendations to address those challenges using fishers' knowledge

	Challenges	Recommendations
1	The fishers found that populations have already declined, and presumably to critical limits for several species of high demand.	Using fishers' knowledge to inform • Prioritizing conservation of most threatened species (Haque et al., 2021c); • Engaging fishers (Islam et al., 2018) to help enforce the setting of sustainable fishing limits and quotas. • Ensuring fishers'' participation in using modified gears and managing bottom and mid-water trawl fisheries is essential for mitigating wasteful fisheries practices.
2	Heavy fishing pressure occurs in critical habitats in shallow water coastal areas.	Using fishers' knowledge to inform spatial management, including protection of critical habitats (Moore, 2018) to provide refuge for threatened species, e.g. shallow water south-central regions are crucial for Rhinopristiformes rays; the

		Sundarbans are important for giant freshwater rays and sawfishes.
3	Given that thousands of fishers in Bangladesh utilize unlicensed vessels and do not use logbooks and or record catches (Haque unpubl. data), monitoring of catch is challenging.	Promoting and facilitating incentive-based monitoring and bycatch mitigation (Booth et al., 2020). • This could be achieved in collaboration with Bangladesh Fisheries Development Corporation (BFDC). • Initiate research into bycatch mitigation techniques to inform this work.
4	Fishers coming from impoverished social strata	Increasing market efficiency of other sustainable catch (e.g. Hilsa) and creating alternative livelihood opportunities, thereby decreasing pressure on elasmobranchs (Haque unpubl. data).
5	Management approaches are a challenge in itself due to the limited capacity of institutions in Bangladesh (Bladon et al. 2015); and an absence of inclusive management regimes, resulting in apparent non-compliance.	Institutional capacity building and approaches for co-designing actions to manage such complex fisheries and enabling transboundary approaches to conservation.
6	Lack of awareness (e.g. of legislation)	Ensuring fishers can access relevant information and practical facilitation/support for following regulations with the help of local governance, Department of Forest and Department of Fisheries.
7	Lack of relatable examples of conservation measures reflecting the benefits of both fish and fishers	Sustainable approaches to fisheries management based on fishers' participation, rather than top-down umbrella bans on catch and trade. Creating and sharing relatable examples of positive conservation outcome for fishers and their livelihoods.
8	Lack of research- Effective fisheries management requires reliable and regionally accurate population assessments and socio-ecological understanding (Haque et al., 2021a, b,c,d).	Further biological research will be critical to determine the size and seasonal catch reflecting species long-term sustainability. Further research to address critical questions raised by this study, such as- • how to incorporate fishers in local governance meaningfully? • how to generate experimental and/or qualitative evidence to identify the most cost-effective and efficient pathways to support local governance at a larger scale?

- how complex elasmobranch management regimes can be structured in a way that enables long-term adaptive and species/group specific solutions?

3.4.3. Future Directions: Preserving Fish and Fishers

Political interest in, and conservation initiatives for, elasmobranchs are new for Bangladesh and need to be supported with geographically appropriate scientific and socio-economic evidence (White et al., 2017), which will take time. A precautionary approach, whereby management regimes are planned before a species is depleted would be ideal but currently lacking (Haque et al., 2021b). This study highlights the value of local fishers' knowledge, observations, perceptions and participation to support conservation through corroborating results from concurrent scientific fieldwork; identifying and addressing knowledge gaps and priority areas; and supporting and guiding the development of management measures. We recommend a three-pronged approach to enhance fishers' engagement in this work and potentially transform the elasmobranch fishery situation in Bangladesh.

3.4.3.1. Input from fishers to ensure management interventions for exploited elasmobranchs in Bangladesh are species/taxa specific

In response to target and bycaught practices, management interventions for exploited elasmobranchs in Bangladesh need to be species/taxa specific. For example, for guitarfishes (CR, CITES II), low catch allocations or total bans (depending on the species' biological resilience against existing fishing pressures) on target catch and retention may be appropriate. Given that post-release mortality is low for some giant guitarfishes (Fennessy, 1994; Ellis et al., 2017), these can be successful endeavours. On the other hand, for sawfish (CR, CITES I), a complete ban on catch and trade with live release protocols (Haque et al., 2020) can be a suitable intervention. For hammerhead sharks and other big carcharhinids, controlling the catch of several age classes towards protecting reproductive adults may be appropriate. Managing all life stages with interventions embedded in evidence is also crucial in this regard (Haque et al., 2021c). However, these will all depend on the availability of technical and social means to control such fishing mortalities. Moreover, due to the extensive spatial extent of many species caught in Bangladeshi fisheries (e.g. hammerhead sharks, whale sharks, devil rays), regional management interventions are necessary to achieve biologically meaningful outcomes. Keeping species-specific realities in mind, we recommend a holistic approach for effective conservation (Booth et al., 2019) to start with, comprising traceable short and long-term management goals (Table 3.3).

3.4.3.2. Meaningful participation of fishers in co-designing, and engaging in, management actions for governing fishery resources

Fishers' meaningful participation in co-designing and engaging in management actions for governing fishery resources is cardinal. It will improve governance by decentralising decision making and endorsing local governance (Dawson et al., 2021), creating trust and improving sustainability. The current study found growing distance and distrust between fishers and fishery policymakers/managers where state governance supersedes customary institutions (e.g., cooperatives) in policymaking (see section 3.3.6, Figure 3.4). It has been profusely reported that local communities play a prominent role, such as when they have significant influence over decision-making or when local institutions control part of governance, producing excellent outcomes for well-being and conservation. Externally managed initiatives, on the other hand, that involve strategies to influence local habits and override traditional institutions tend to produce relatively ineffective conservation while also causing adverse social effects (Dawson et al., 2021). Equitable conservation, which empowers and supports local communities' environmental responsibility, is the key avenue to sustainable long-term biodiversity conservation, mainly when backed by law and policy. Conservation can become more effective through an increased focus on governance type and quality and fostering solutions that reinforce the role, capacity, and rights of communities (inclusion of fishers in this process is graphically represented in Figure 3.4).

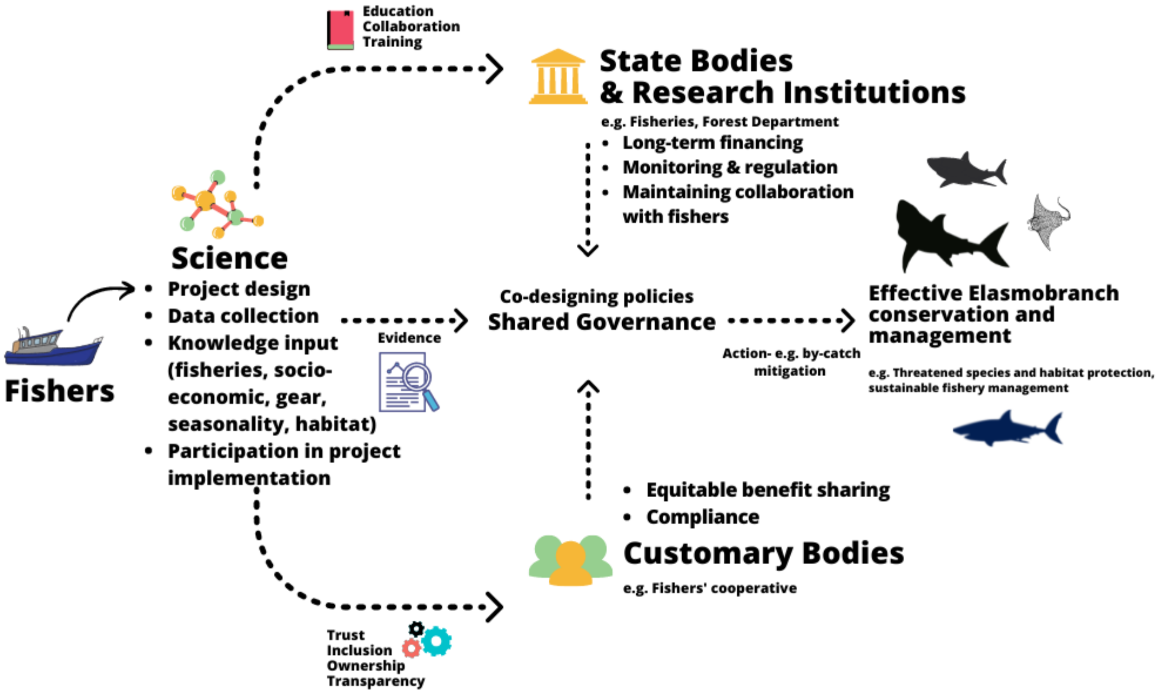

Figure 3.4. Model for fisher's meaningful inclusion and collaboration for science/research, local governance and filed implementation of conservation actions towards species protection.

3.4.3.3. Provision of education, training, facilitation and incentives

Endorsing local governance, providing adequate and long-term education, training, technical facilities and incentives are crucial for fishers to adhere to management actions and regulations. The current study found low to medium identification capacity amongst fishers for morphologically similar species, difficult for untrained personnel (Haque et al., 2021d). Education and training in species identification linked with existing knowledge (ability to identify specific groups and taxa, (see section 3.3.3) will contribute towards species/taxa-specific regulation compliance. An assessment of true improvement in identification ability following trainings can aid in determining the efficacy of such trainings. A substantial number of fishers were willing to adapt to bycatch mitigation if they could be adequately supported in this. Training on safety and live release for bycaught species and best practices at sea are essential. For target elasmobranch fishers, facilitating smooth progress towards an alternative sustainable fishery (e.g., hilsa) and engaging in mainstream financial mechanisms can reduce pressure on elasmobranchs. Ensuring adequate long-term finances supporting gear modification, loss of income concerning live release programmes and catch limits, rewards/incentives, and punitive measures for positive and negative behaviour, respectively, are all important factors to facilitate progress.

We have highlighted the importance of local knowledge in filling crucial data gaps and conservation decision-making in a data-poor region. This study has wider application, especially for other fishery data-poor regions where elasmobranch populations lack the past understanding. In the absence of baseline studies, fisher's knowledge provides an unconventional yet highly valuable basis for assessing fishery status, population trends and for conducting further quantitative assessments. While it is clear from this and other recent studies (Haque et al., 2020; Haque et al., 2021a, 2021b, 2021c, 2021d; Haque & Spaet, 2021) that Bangladesh needs to prioritise elasmobranch conservation and sustainable fisheries management, the approach needs to be holistic and inclusive. Fishers need to be included in co-designing management actions and participating in governance. Such actions may include identifying the most threatened species, critical fishing areas, incentives and facilitation required by the fishers to adhere to good fishing practices at sea and devising strategies for reducing elasmobranch mortality by both legal and social interventions. It is crucial to acknowledge that Bangladeshi fishers belong to the most impoverished communities and reside in the country's least developed areas. As a result, while they face real struggles to provide food and education to their families, they do not have the economic freedom to reduce their impact on the ecosystem to safeguard the future generations of elasmobranchs. We emphasise that approaches to managing elasmobranch fisheries must account for these real-life problems and incorporate appropriate and economically viable incentives and livelihood alternatives to both enable and ensure compliance. This model can potentially be used to change the top-down management of elasmobranch fisheries globally.

We call for further research on specific issues (e.g. taxa specific understanding of threats, mortalities, the biological potential to withstand fisheries pressure, bycatch mitigation strategies, culturally appropriate and accepted alternative livelihoods, incremental approach of management) for geographically appropriate and bespoke actions that also contribute to improving the conservation and management of elasmobranchs in a global context.

CHAPTER FOUR: Trade

4. Trade in Threatened Elasmobranchs in the Bay of Bengal, Bangladesh

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Fins and meat– drying on a thatched roof ©Bengal Elasmo Lab

Abstract

Trade in elasmobranch products is a circum-global practice negatively impacting their populations. Although Asia is at the centre of the shark fin trade, countries like Bangladesh remain data-poor regarding trade dynamics. A limited understanding of trade currently precludes Bangladesh from enforcing regulations effectively and taking timely conservation actions. To address this knowledge gap, we characterized elasmobranch trade by identifying stakeholders involved in national and international trade, routes used, trade hubs, and ports in Bangladesh. We found that Bangladesh has a long-standing history of producing and trading products from vulnerable and protected elasmobranchs nationally and internationally. The study revealed that except when marine fishing was prohibited (from June to July and all of October), traders collected sharks and rays and their products daily throughout the fishing season. They did, however, reveal that even during prohibition months, smaller vessels continued to collect shark and ray bycatch. The study found that trade dynamics varied among research locations depending on aspects such as volumes landed, processing centres' availability, and traders' ability to trade locally or export. Whole-bodied sharks and rays were either auctioned whole or sold by weight. Direct shipments to Thailand, China, Hong Kong, India, the USA, and Vietnam were stated by traders. Most exports were destined for China, but from 2013/ 2014, all exports of shark and ray-related goods were coordinated through Myanmar. Most of the trade remains unreported, violating the Wildlife (Conservation and Security) Act, 2012, and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) mandates. We identified the southeastern region as a trade hub with a syndicate of traders annually exporting elasmobranch products predominantly to China via Myanmar. High-quality fins and dried meat drive international trade, including products from Critically Endangered sawfish (Pristidae), guitarfishes (Glaucostegidae, Rhinobatidae), wedgefishes (Rhinidae), hammerhead sharks (Sphyrnidae), and large requiem sharks (Carcharhinidae). Also prevalent is a substantial national demand for elasmobranchs for consumption and traditional medicinal uses. The influence of Bangladesh's fin and meat trade on vulnerable shark and ray populations is unknown because it has operated for decades with no regulation or reporting regarding sharks and rays. The global trade in shark and ray products is still primarily undocumented, with the actual trade being between 86% and 335% larger than the declared trade. Only a small portion of global trade data is published, while the vast bulk of trade goes undocumented. International databases also reveal the shortcomings of Bangladesh's catch and trade accounting system for sharks and rays. The findings demonstrate how Bangladesh's national and international shark and ray trade occupies a complex and specialized market niche for both traditional product usage and consumer consumption.

4.1. Introduction

Sharks and rays (hereafter referred to as elasmobranchs) are amongst the most threatened marine fishes (Chin et al., 2012; Dulvy et al., 2014; Kyne et al., 2020). Unmanaged fisheries and trade have resulted in declines of their populations worldwide (Dulvy et al., 2016; Kyne et al., 2020). As keystone species (Bornatowski et al., 2014), elasmobranchs are crucial marine ecological elements structuring food webs and regulating predator-prey behaviour as apex predators (Dulvy et al., 2017; Roff et al., 2016; Heithaus et al., 2008). Trophic downgrading (Estes et al., 2011) by depleting these species may result in altered ecosystem functioning through meso-predatory species release (Stevens et al., 2000; Heithaus et al., 2012; Grubbs et al., 2015), shifting of food web dynamics (Wallach et al., 2015) and thus unsettling the ecological balance.

Elasmobranch fisheries and trade industries date back centuries (Dent & Clarke, 2015). Increasing demands for shark fins and meat across Asia, Europe and South America (Eriksson & Clarke, 2015; Okes & Sant, 2019) have resulted in a vast illegal global market annually valued at an estimated US$ 1 billion (declared only) (Dent & Clarke, 2015). Between 2000 - 2016, the fin industry alone valued an average of US$ 294 million per year (Okes & Sant, 2019). Although the most traded products are fins and meat, a range of products including fresh, frozen and dried meat, cartilages, jaws, liver oil, skin, and teeth are traded to satisfy a range of versatile needs (Clarke, 2004a; Clarke, 2004b; Hareide et al., 2007; Vannuccini, 1999; Haque et al., 2018). To meet these demands, annually, an estimated 63 - 273 million sharks are caught globally (Worm et al., 2013), of which 26 –73 million sharks contribute to the fin industry (Dulvy et al., 2014). The shark fin trade centre is in Asia, with the biggest fin markets in China, Japan, Hong Kong, Singapore, and Korea (Vannuccini, 1999; Okes & Sant, 2019). Hong Kong imports products from at least 85 countries, including other Asian countries (Clarke et al., 2006b; Hareide et al., 2007; Anon, 2012); however, many countries remain understudied and data-poor regarding trade dynamics and elasmobranch fisheries, including the Bay of Bengal region (Fischer et al., 2012).

The Bay of Bengal, a part of which falls within Bangladesh's sovereign seas, is the world's largest basin and a unique ecosystem (Amaral et al., 2017). It is home to an array of evolutionarily distinct species, including elasmobranchs. Numerous artisanal and industrial fisheries operate in coastal and offshore waters (DoF, 2016; Shamsuzzaman et al., 2017), capturing elasmobranchs as bycatch, as well as through targeted fishing (Haque et al., 2018; Kumar et al., 2019). All parts of an elasmobranch, especially fins and meat but also skin, cartilage and intestines, are processed to meet local and international demands (Haque et al., 2018). In 2010, the Bay of Bengal Large Marine Ecosystem (BOBLME) Sharks Working

Group identified Bangladesh as "very data-poor" in terms of trade data and monitoring (Fischer et al., 2012). As a result, Bangladesh could officially not be identified as a significant shark product exporter (Dent & Clarke, 2015).

Elasmobranch fisheries within the Bay of Bengal, Bangladesh, are also data-poor (Fischer et al., 2012, Haque et al., 2020) with inconsistent international as well as national datasets on aspects relating to illegal trade, supply chains and composition of traded species. This has resulted in a severe underestimation of elasmobranch trade for this region and delayed conservation actions. Available literature focusing on trade and national fisheries specific to Bangladesh is ambiguous, scarce, and patchy. The national accounting system for marine fish categorises all Bangladeshi species of elasmobranchs within a single category (DoF, 2018) and does not account for any coastal landings. Although existing studies on elasmobranchs touch upon existing trade (Hoq et al., 2011; Hoq et al., 2014; Roy et al., 2012; Roy et al., 2014; Roy et al., 2015; Hasan et al., 2017), they do not characterise its extent, the species composition, existing trade hubs, or trade routes, furthermore, they over-simplify the dynamics of countrywide trade and stakeholders/actors (Hoq et al., 2011; Hasan et al., 2017), making recommendations for necessary interventions difficult.

The absence of an empirical understanding of trade and market dynamics hinders Bangladesh's obligations towards implementing the Wildlife (Conservation and Security) Act, 2012 (WCSA, 2012) and CITES (Convention on International Trade in Endangered Species of Wild Fauna and Flora) mandates. Bangladesh ratified the convention in November 1981. As a signatory of CITES, Bangladesh has the international commitment to regulating the trade in at least 17 elasmobranchs species. In addition, the WCSA, 2012 protects 29 species of elasmobranchs (Haque et al., 2018) in Bangladesh's territorial waters. Yet, conservation actions and management policies, for them to be effective, need accurate species-specific catch and trade data (Jabado et al., 2015; White et al., 2017; O'Bryhim et al., 2017; Cardeñosa et al., 2019) and market understanding (McNamara et al., 2016) involving different actors and mechanisms (Oyanedel et al., 2021). This data gap has restricted the quantitative and qualitative understanding of the market character, actors' involvement, product flow, and management needs of the elasmobranch trade in Bangladesh (Dent & Clarke, 2015).

To evaluate trade dynamics of shark and ray (families: Rhinidae, Rhinobatidae and Glaucostegidae) products in Bangladesh, here, we analysed trade data from existing datasets and conducted field surveys and interviews with shark traders at landing sites and shark processing centres. We identified (1) The trade chain of elasmobranch products originating from the region and investigated its extent and dynamics; (2) Target species and products, as well as their values within landings and the trade; and (3) Unreported trade. We also evaluated existing regulations in the context of global trade to conserve elasmobranchs in Bangladesh. The study's overarching objective is to present information that will substantially improve our understanding of the complex elasmobranch trade dynamics in Bangladesh with important global implications which will inform immediate conservation prerequisites for the Bay of Bengal.

4.2. Material and Methods

4.2.1. Study sites

The current study was conducted between 14 October 2016 and 30 January 2020 at four landing sites - the Bangladesh Fisheries Development Corporation (BFDC) landing site in Cox's Bazar, Firingi Bazar in Chattogram, Bazar ghat in Teknaf and the beach on St. Martin's Island, ten adjacent markets and twelve elasmobranch processing centres in Chattogram City, Cox's Bazar Sadar, Teknaf Upazila and St. Martin's Island in the south-eastern region of Bangladesh (Figure 4.1). The selected landing sites are the most important ones in south-east Bangladesh by volume of fish landed. Landing sites in Chattogram City and Cox's Bazar are governed by the BFDC. Landing sites in Teknaf and St. Martin's Island are either privately operated or independent with a comparatively lesser volume of landed elasmobranch specimens. Teknaf forms an integral part of the country's main trade route of elasmobranch products to Myanmar (Haque et al., 2018).

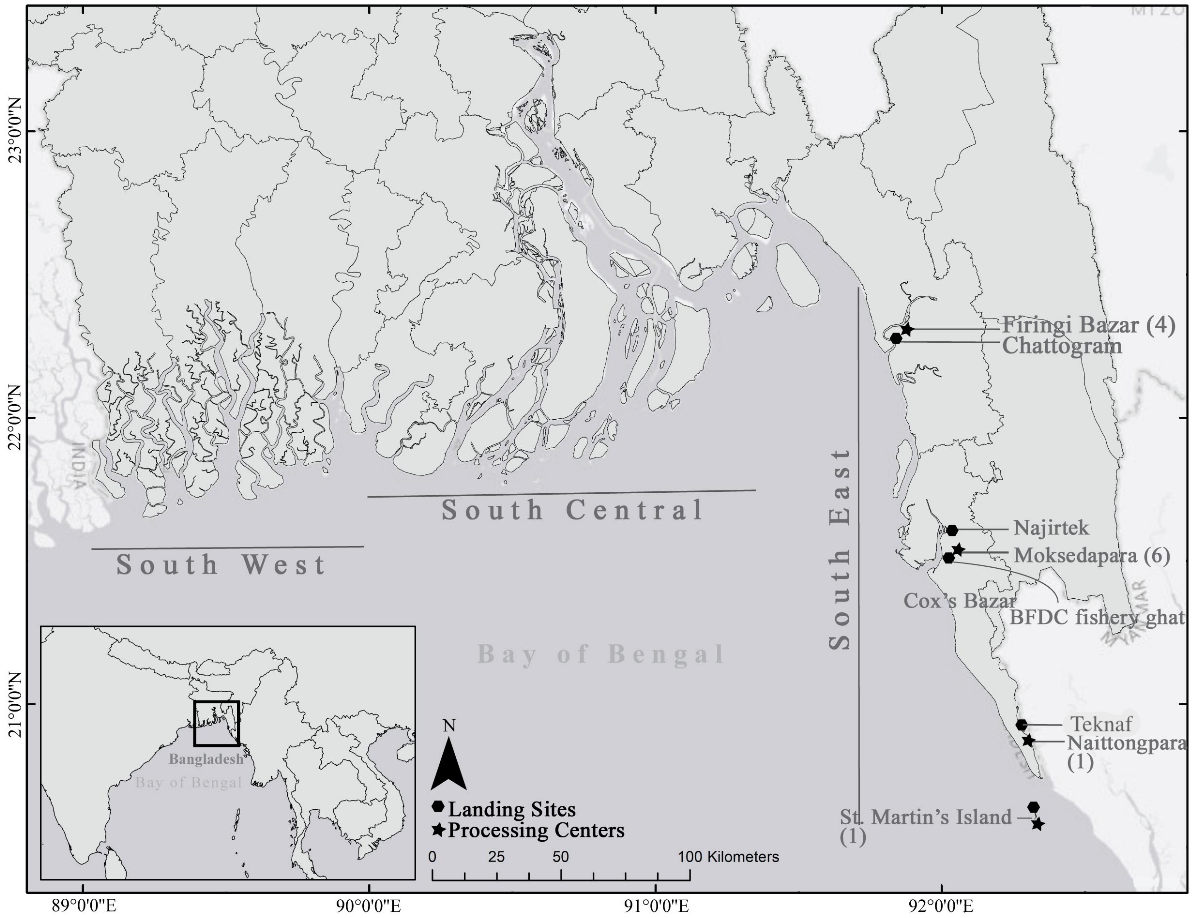

Figure 4.1. Landing sites and elasmobranch processing centres along the south-eastern coastline of Bangladesh. Numbers in the parentheses indicate the number of local processing centres. The inset map shows the location of Bangladesh in the Bay of Bengal. The map was created using ArcGIS 10.3.

4.2.2. Literature review and trade data analysis

Google Scholar and the ISI Web of Science databases were searched using the keywords Bangladesh* Shark trade, Bangladesh* Elasmobranch trade or Bangladesh* Chondrichthyan trade for 1990 – 2019. In addition, reports on trade and trade products were acquired through the Bay of Bengal Large Marine Ecosystem Project website (BOBLME), Bangladesh Fisheries Research Institute (BFRI), Bangladesh Fisheries Development Corporation (BFDC) and the Department of Fisheries (DoF), under the administrative control of the Ministry of Fisheries and Livestock. Trade data from the United Nations International Trade Statistics Database (UN COMTRADE) were analysed for the period 1990-2019 for both exports, import and re-export of shark product within Bangladesh. All reporter countries were checked for both export and import data on any commodity having the keywords' shark', and 'shark fin' and Bangladesh listed as a partner. The commodity codes that were used for these searches are listed in Table S4.1. Additionally, catch data from the Sea Around US website (http://www.seaaroundus.org) was searched for the period 1960 to 2016 and analysed based on the value of elasmobranchs. The CITES trade database (https://trade.cites.org) was searched for any trade records of elasmobranchs imported and exported from Bangladesh between 1975 to 2019. In addition, an online search for companies based in Bangladesh offering shark and shark products was conducted.

4.2.3. Surveys at shark processing centres and markets

Between 14 October 2016 and 30 January 2020, a total of 398 surveys were conducted in south-eastern Bangladesh at 12 major shark processing centres (n=186), 4 landing sites (n=186), 8 local fish markets (n=16) and 2 retail dried fish markets (n=10). Informal landing sites were not included in the study because they were geographically scattered and only operated irregularly. Surveys at elasmobranchs processing centres were aimed to document the preparation and availability of products. During each visit, all available elasmobranch products were photographed, counted and weighed. Collected data were analysed to classify conventional and unconventional products for both national and international markets and to assess the capacity of each processing centres' annual trade in elasmobranch products. Elasmobranch product preparation processes were recorded on film to document the processing techniques. The availability of whole-bodied elasmobranchs and elasmobranch products at markets open to domestic consumers was recorded by identifying and photographing all available elasmobranch specimens and body parts to understand the species-specific national demand for elasmobranchs.

Furthermore, whenever possible, information regarding trade destinations, logistics and timelines for national and international trade were acquired from processing centre staff. Processing centre workers were questioned regarding product sources, prices, buyers as well as domestic or international consumers. Data from trade log-books was recorded when available. This data was corroborated with data collected through interviews with traders (see section 4.2.4) to reconstruct the trade chain and routes for each product type, buying and selling price and to classify the stakeholders involved in elasmobranch trade in Bangladesh.

4.2.4. Interviews with individuals involved in elasmobranch trade

Between 14 October 2016 and 03 May 2018, 65 interviews with Bangladeshi nationals actively involved in the elasmobranch trading business and 2 interviews with retired traders were conducted. Thirty-six interviews were semi-structured, and 31 were unstructured (Table S4.2 a, b, c, Table S4.3). In 2016 and 2017 two qualitative interviews with the experienced traders were taken before desiging this study. This helped to design the questionnaire. The rest of the interviews were conducted after that. Interviewees were either identified randomly or through snowball sampling (Atkinson & Flint, 2001; Etikan et al., 2016). The former president of the Shark Fishers' and Traders' Welfare Association (SFTWA), Cox's Bazar was identified as the first interviewee and a key informant. Subsequently some of the additional significant traders were identified by him (n=8). The rest of the traders were identified randomly at processing centres and fishery markets. Liver oil factory owners and fish feed workers were identified during visits at liver oil factories in Cox's Bazar and fish feed factories in Dhaka. Stakeholder-specific semi-structured questionnaires were designed for traders (n=57) and fish feed workers (n=10) partially based on Jabado et al., 2015.

All interviews were conducted in the south-eastern (n= 57) and central (n=10) region of Bangladesh at five locations, St. Martin's Island (n=7), Teknaf (n=6), Cox's Bazar (n=34), Chattogram (n=10), and Dhaka (n=10) (Table S4.3). All interviewees were of Bangladesh nationality. Except for one trader who originated from Myanmar but had been trading in Bangladesh for over 30 years. Females are not directly associated with the elasmobranch trade in Bangladesh (although many females were involved in the drying process of small elasombranchs), hence all interviewees were males. Traders were classified in five different groups based on their role in the Bangladesh elasmobranch trade, i.e. exclusive elasmobranch traders (n=25, hereafter referred to as 'exclusive traders' who only trade elasmobranch products both nationally and predominantly internationally), liver oil factory owners (n=4), fish feed owners/workers (n=10) and dry fish retailers (n=27).

Questionnaires for traders (Table S4.1a) were designed to cover five thematic areas:

1. Products and processing
2. Supply chain structure
3. Most valuable/target species
4. Product prices
5. The legal framework governing trade activities
6. Compliance and perspective towards the trading business and the conservation of traded species

Based on the acquired information, international and domestic market chains, trade routes and destinations of different elasmobranch products were documented and mapped.

Ethical approval

This study was conducted with the ethical approval by the Ethical review committee of the Faculty of Biological Sciences, University of Dhaka (reference number- 59/Biol.scs.). Free Prior and Informed Consent (FPIC) standards were maintained. The data was protected and saved in a manner that it can not be traced back to individuals and no personal information was used or saved within the data. Before each interview, verbal permission to conduct the interview and use the data for scientific purposes was obtained from each interviewee. Research questions, purpose of the interviews, and data usage were explained to the interviewees prior to each interview. The anonymity of interviewees was guaranteed to avoid biases. Furthermore, the interviews were not restricted to set durations of time nor were interviewees given any directions or instructions. The duration of interviews ranged from 1.5 - 4 hours.

4.2.5. Assessment of unreported catch and trade

Interview data was corroborated with processing centre survey data (see section 4.2.3) to estimate the annual range of traded elasmobranch products (in tonnes) in the international trade for the period 1990 to 2016. We also calculated the average amount of annual elasmobranch landings in the south-eastern region by multiplying the amount of dried products (in kg) by 3.5 (as in most cases, at least 3-4 kg of wet meat/fin is needed to produce 1 kg of dried meat/fin). Aggregated amounts of national trade could not be reconstructed due to dispersed market channels and numerous vendors and retail traders with different trading capacities. The results were compared with national statistics and available reconstructed fisheries data (1990-2016, Pauly & Zeller, 2020).

4.2.6. Combining different data-sets and uncertainty

We gathered information using various techniques due to the limited national accounting system for capture, landing, and trade on elasmobranchs. We integrated them to create a narrative on the current trade and under- and non-reporting of traded products. The shark processing center survey results were utilized to estimate unrecorded trade in elasmobranch products and compare with the information from national statistics and interview data (see section 4.2.4). The interviews revealed each trader's yearly trading capacity on elasmobranch items. To confirm the monthly product processing capacity, we also conducted surveys of the processing facilities owned by the same traders we interviewed. The unreported trade was then evaluated by comparing them to the national data.

These results, however, can have inherent uncertainty and potential bias. For instance, it was assumed that all the years between 2000 and 2016 had the same traded amount and that the traders were disclosing precise ranges of what they traded throughout time. Not all processing centres were surveyed monthly, and not all months were surveyed to unveil month-wise trade. There was also a chance of double counting the products in the processing centres if they were not sold before the next survey. To guarantee that traders communicate reliable information, we have established trust and allocated more time to be present for the traders to ask questions and provide any further information in the study location. By verifying the results with the staff at the processing centre, we eliminated duplicate counting on each survey day for the processing centre surveys. In a week-long survey of processing centres, we only counted once unless fresh items were being processed. However, if we missed counting any goods or did not observe them during our survey hours, this also brings uncertainty to the results. Therefore, rather than averaging them to determine yearly trade, we have given the precise quantity of items counted each month.

Finally, comparing various data sets with various collection efforts and methodologies can be challenging, particularly when contrasted with reconstruction data because the assessment processes are dissimilar. To offer the best results, we have compared the traded amounts to establish a baseline from which a more in-depth study can be done, albeit for a data-poor scenario where monitoring is restricted.

4.3. Results

4.3.1. Trade data analysis

Available published literature provided limited knowledge on the trade in elasmobranchs in Bangladesh. 12 journal articles mentioned ‘trade’; however, did not characterise it further (Table 4.1). Instead, they mainly focused on elasmobranch landings from artisanal fisheries. Elasmobranch catch data was reported under one single group called 'sharks, rays and skates' by DoF in Bangladesh. Data on elasmobranch landings in the south-west and south-central regions was unavailable. DoF and BOBLME reports reviewed in this study, mostly presented conservative catch and landing results, whereas the reporting on trade was sporadic and non-existent in some cases. The BFDC only reported catch and landing data on commercially important fish species (e.g. *Tenualosa ilisha* hilsa, *Scomber sp*. mackerel etc.) and under the category ‘mixed fish’, which includes elasmobranchs. Landing and trade data in these reports were not reported separately. Data from Sea Around Us demonstrated higher elasmobranch landings compared to national data (DoF, 2018) (Table 4.1). CITES Trade Database records showed imports and exports of CITES-listed species from 2017 to

2018 (Figure S4.3).

Moreover, an online search in December 2017 identified 24 companies involved in international export activities of whole sharks, shark fins and other shark-related products. These data demonstrated that available data on elasmobranch trade in Bangladesh were either opportunistically or conveniently collected and presented in various reports without an accurate, holistic view. As a result, for most years, traded species and the amount of traded products were either not reported at all or underestimated.

Table 4.1. Data sources, study location, main findings related to elasmobranch trade, main limitations, data collection periods and references of available literature, international databases and national statistics on elasmobranch trade in Bangladesh. Studies with a primary focus on elasmobranch trade are indicated in bold. SE= Southeast, SC= Southcentral, DoF= Department of Forest, BOBLME=Bay of Bengal Large Marine Ecosystem.

Data source	Study location	Main findings related to elasmobranch trade	Main limitations	Data collection period	Reference
Peer-reviewed literature					
Landing site surveys and analysis of secondary source (e.g. DoF reports) data	National scale (coastal)	1,043 tonnes of elasmobranch landings between 2011 and 2012. 3,675.4 (mean= 204.19) tonnes of shark export from Bangladesh between 1992 and 2010 worth US$24.86 million.	Lack of information on trade routes and stakeholders. Underestimation of the reported trade. High reliance on national reports to estimate traded amounts of sharks and the species composition in the trade. The traded number of sharks is aggregated with fish maw and other fishery products.	July 2011 - June 2012	Hoq et al., 2014
Semi-structured interviews and landing site surveys	Two landing sites in the SE region	Existing trade on 9 shark species. Revenue of US$ 10,655 for the export of one tonne of shark fins from 2012-2013. Lack of official exports between 2010-2012 due to a ban of shark fishing and trade in several countries. Illegal exports during this period.	Over-simplification on countrywide trade dynamics. Failed to report trade between 2010 and 2012.	January-December, 2014	Hasan et al., 2017

DNA analysis of traded elasmobranch products	SE region	Existing trade on 24 elasmobranch species, including CITES listed and nationally protected species. Trade on different products worth US$250,494 between 2012 and 2015 from just one processing centre. Conclusion: Urgent need for monitoring and regulation of elasmobranch trade in Bangladesh.	Results and discussion were limited to elasmobranch diversity in the trade and the possible usage of genetic methods of trade monitoring.	June 2016-June 2017	Haque et al., 2018
Analysis of DoF data	SE region	Between 2009 and 2010 export of a total 955 tonnes of elasmobranch products (with fish maws) worth 1.60 million. Zero trade activities from 2010-2013. Export of dried shark fins, skins, teeth to Myanmar, India, Singapore, Thailand, Hong Kong, China and the USA.	Oversimplification and underestimation of trade data Haque et al. (2018).	July 2003-June 2013	Roy et al., 2014
Reconstruction of fisheries catch data	n/a	Sharks make up 2.0% (1,774 tonnes) of total marine landings.	Lack of information on the amount of shark products traded.	n/a	Ullah et al., 2014
National reports					
Landing site surveys	National scale	On average, 4,588.5 (± 515 SD) tonnes of elasmobranchs landed between 2005 and 2018 (DoF, 2018). 622 tonnes of elasmobranch caught by industrial trawlers, 1,920 tonnes by gill	Limited to the south-eastern region. Aggregate accounts reported under the category 'shark fin/fish maw'.	2005-2018	DoF (2005-2018)

		nets, 205 tonnes by set-bag nets, 1,875 tonnes by long lines and 4,000 tonnes by other gears between 2015 and 2016 (DoF, 2016). 351 tonnes of shark fin exported in 2007, with an average of 96 tonnes between 2004 and 2011 (DoF, 2017). Export of 955 tonnes of shark fins (DoF, 2017) between 2009 and 2010, followed by a significant decline of reported trade from 2010 onwards.			
Review of published literature, workshops with selected traders, fisheries practitioners and policy makers and Landing surveys	National scale	Between 2000 and 2012 elasmobranchs made up 0.67% -1.5% of the total marine catch (BOBLME, 2014). Significant overexploitation of elasmobranchs. Observed decline in catches and specimen size. Identification of the south-eastern region as most important landing area based on number of landed individuals and species (n= 23).	Simplified trade dynamics. Lack of details (e.g. information on stakeholders, amount of shark products traded, vulnerability of traded species).	February - December 2013	BOBLME, 2014, Hoq et al., 2011
International databases					
Sea Around Us	n/a	Continuous increase in elasmobranch catch and value between the 1950s and 2016. On average, 4,936 tonnes of elasmobranchs landed between 1950	Reconstructed data	1950s - 2016	Pauly & Zeller (2020)

		and 2016. Average value of elasmobranchs traded between 1950 and 2016 equalled 21 million US$ per year.			
UN COMTRADE data (Figure A1, A2)	n/a	Negligible trade with Bangladesh from 1990 to 2002 and 2005 to 2007 reported by all countries listed from 2012-2019 China and Hong Kong and in 2018, Oman reported the most frequent import of shark and shark-related products from Bangladesh in bulks. Imports of small amounts (<200 kg) were also reported. India reported import of 70,425 tonnes worth US$ 214,959 in 2015, probably exporting to another country and serving as a conduit. No imports were reported before this period.	Heavily dependent on trade reporter countries.	1990-2019	https://comtrade.un.org/
CITES Trade Database	n/a	Both import and export of CITES-listed species between 2017-2018	Lack of long-term data	1975 - 2019	https://trade.cites.org

4.3.2. Surveys at processing centres and markets

Across all processing centres sharks and guitarfishes were sorted by size [sharks: small (<70 cm), medium (70-150 cm) and large (>150 cm); guitarfishes: small (<70 cm), large (>70 cm)] to separate individuals with large fins from individuals with small fins. Consignments of dried fins, meat and skin, were prepared for export after sorting. Fins were exported on a kg basis, either as a set of four (1st dorsal, two pectorals and a lower caudal lobe) or individually in bulks. Shark and guitarfish skin and intestines were also exported. We identified two types of traders (1) 'exclusive traders' who operate processing centres and only trade elasmobranchs and (2) opportunistic traders who export elasmobranch products along with fish maw and other fish products. Finned sharks were also bought at occasions if specimens exceeded 200 cm. Yet traders preferred the whole body as substantial income came mainly from the fins. Only sharks <70 cm (no guitarfishes were identified), sourced predominantly from traders in Cox's Bazar, Chattogram and sometimes Teknaf or directly from landing sites were processed and dried (salted and unsalted, depending on the current demand) at retail fishing centres. These were sold to smaller shop holders in tribal areas. The majority of dried fish shops at local markets did not offer elasmobranch products due to religious beliefs. Small-bodied sharks (predominantly *Scoliodon laticaudus*, spadenose sharks; *Rhizoprionodon acutus*, milk sharks; smaller *Carcharhinus sorrah*, spottail sharks and *Sphyrna lewini*, scalloped hammerhead sharks, and pups of other carcharhinid sharks) were dried in bundles and sold to retail dealers. Sometimes small elasmobranchs were also sold fresh to tribal markets. A growing market for fresh elasmobranchs was also observed in the Chattogram hill tracts (CHT).

All vertebrae and on occasion jaws and teeth (unconventional products) were collected by locals from the northern part of the country every three to four months for onward sale to traditional village medicinal practitioners or illegally exported to India via the north-western border. Vertebrae were also observed to be sold to village customers, where they were considered to support bone disease treatment (e.g., arthritis, pain in joints, broken bones). Special demand existed for highly priced sawfish meat (believed to cure cancer) from the coastal communities. Throughout the study period, various elasmobranch products were observed to be either dried or stored in bulks at processing centres (Table 4.2).

Table 4.2. Observation period, classification, number and weight of recorded shark products (fins, meat, skin, vertebrae, jaws, liver, dried intestine, heads of hammerhead sharks, dried small sharks and recording location) observed during the drying process at 12 processing centres in Chattogram, Cox's Bazar, Teknaf and St. Martin's Island between 07 June 2016 and 31 January 2020 during 186 processing centre surveys. To avoid double counting products during consecutive days in the same centre was avoided. F= Firingibazar, A=Asadganj (Chattogram); N=Najirtek, M=Moksedapara, NC=Nuniarchora (Cox's Bazar); NP=Naittongpara (Teknaf); SMI= St. Martin's Island; CB= Cox's Bazar, MP= Mohipur, AP= Alipur and K= Kuakata

Period	*Fins (pieces)*	*Meat (kg)*	*Skin (pieces)*	*Vertebrae (kg)*	*Jaw (pieces)*	*Liver (kg)*	*Intestine Dried (pieces)*	*Heads of hammerhead sharks*	*Dried small sharks < 70cm (kg)*	*Location*
October 2016	500	1000	580	1,000	200	121	50	-	5,000	A, M, N, NC
December 2016	1,735	6,500	591	515	104	600	179	-	-	M, NC
Januar 2017	1,050	2,500	-	500	140	-	-	-	6,500	M, N, NC
February 2017	3,500	3,000	340	650	250	-	350	-	4,500	M, N
April 2017	10,000	5,600	275	850	50	580	245	1,050	1,000	NP, M, SMI
April-May 2017	4,500	2,300	560	1,000	34	1,500	-	530	3,000	NP, M, SMI
September 2017	1,660	5,000	377	650	140	100	32	-	-	MP
November 2017	450	-	-	-	23	-	-	-	4,500	M, NC
January 2018	1,500	6,000	654	400	56	-	67	-	3,700	CB
March 2018	4,000	7,500	90	-	45	-	71	670	6,000	CB
April, 2018	4,300	-	-	-	-	-	-	-	500	CB
September 2018	500	1,200	65	-	-	-	54	-	-	CB

December 2018	350	2,000	10	40	23	-	60	43	2,000	CB
January 2019	1,300	5,000	95	-	48	-	110	75	6,500	CB
March 2019	1,850	6,500	87	-	83	-	47	56	800	CB
October 2019	1,500+	8,000	500	1,000+	300+	-	-	-	10,000	MP, AP, K
November 2019	550	1,000	-	-	-	-	-	-	-	CB
January 2020	6,000+	4,600+	-	550	-	-	100+	-	1,000+	MP, AP, K
January 2020	550	850	150	500	21	-	-	25	560	CB, SMI

Amongst other non-conventional products, elasmobranch livers were stored in large containers and sold to liver factory owners in Cox's Bazar. However, after the study period, only one out of four factories were active. These factories produced liver oil supplied to fish feed and poultry industries based in Dhaka and adjacent areas for additional income of traders. In one instance, about 70 large liver oil containers (200 litres per drum, worth US$ 62,5-75 /large container) were observed to be transported to fish feed and poultry feed factories predominantly located in Dhaka and other parts of the country.

4.3.3. Interviews

Interviewees (traders involved in the elasmobranch trading business) ranged from 25 to 72 yrs of age (mean = 46.24 ± 13.37 SD) and had 5-50 yrs of experience (mean = 21.56 ± 12.09 SD) (Table S4.4).

4.3.3.1. Products and processing

Smaller sharks (<70 cm) were gutted and dried whole while larger sharks (>150) were cleaned, gutted and after removal of the fins cut to pieces, resulting in a range of products, e.g., dried fins, dried meat, skin, cartilages (vertebrae), liver, teeth, jaws and dried intestines. The observed preparation process for guitarfishes was similar, except for snouts and fins being separated from the rest of the body due to the value of fins being comparatively higher than for sharks of the same size. Snouts were sold separately for US$ 2- US$ 3 per kg to local buyers. All traders stated that they preferred salting meat and fins to prevent pest infestation and to increase the weight. After salting, products were dried on the thatched roofs of the processing centres. Traders (n=12) also stated that they sorted products for different buyers (local and international). Liver oil factory workers (n=3) stated that liver oil was stored in processing centres, during the peak season (pre-monsoon and winter, November – May). One of the interviewees stated having standing orders of liver oil from a pharmaceutical company and that he had been regularly delivering liver oil to them. No one from the pharmaceutical company could be reached for an interview.

4.3.3.2. Supply chain structure

All traders stated that they collected elasmobranchs every day during the fishing season apart from the marine fishing ban periods (from June to July and all of October). However, three of them indicated bycatch of elasmobranchs, including target ray catches by smaller boats even during this period. Large landings of elasmobranch, especially sawfish (Pristidae), guitarfish (Glaucostegidae, Rhinobatidea, Rhinidae) (>200 kg) were often purchased directly from fishing vessels while still at sea for direct transport to traders. Various buyer groups were identified at landing sites through observations and subsequent interviews who purchased small and, in some case, medium elasmobranchs, e.g. tribal people, minority religious groups and opportunistic tourists.

Trade dynamics differed amongst study sites regarding volumes landed, the presence of processing centres, and the capacity to domestically trade or export. Whole bodied elasmobranchs were either sold by weight (Cox's Bazar) or auctioned whole (Chattogram). In Teknaf and St. Martin's Island, the trade was comparatively less organized and sometimes negligible; most of the times, landings from these areas were directly sold to traders in Cox's Bazar or Chattogram. The biggest trade hub was in Cox's Bazar. Nine interviewees mentioned direct exports to Bangkok, China, Hong Kong, India, the USA and Vietnam. One trader mentioned trading guitarfishes and wedgefishes in Oman. Most exports were destined for China, yet since 2013/2014, all elasmobranch-related exports have been arranged via Myanmar (Figures 4.2 & 4.3). Elasmobranch exports to China and Hong Kong were blocked between 2012 and 2014 by regulations, which traders could not identify properly. In the last five years, direct trade was also not found in Oman, European countries, or the USA. Traders circumvented this problem by exporting elasmobranch products under the names of fishery products through Myanmar. Two traders mentioned the export of specialized elasmobranch products (rostra of sawfish and shark teeth) through airways in passengers' luggage. Generally, elasmobranch products were exported as 'fish products' through the non-custom port of Teknaf using Letters of Credit (LC), which are issued by banks, guaranteeing the timely transfer of agreed payments.

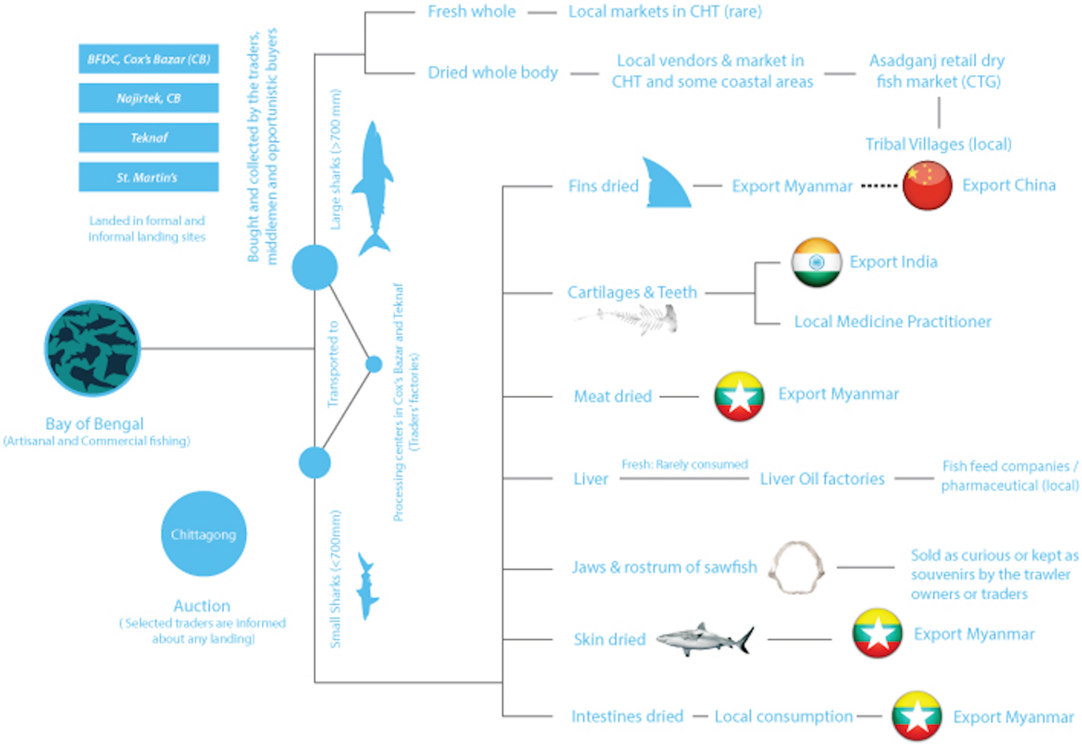

Figure 4.2. Market chain for elasmobranch products processed from whole individuals landed along the south-eastern coast of Bangladesh, which, based on interviews with traders and fishers, were subsequently exported from Teknaf to Myanmar, China and India. Blue boxes indicate the landing sites and the flag indicates the final destination of different products. Most exports were destined for China, yet since 2013/2014, all elasmobranch-related exports have been arranged via Myanmar. Elasmobranch exports to China and Hong Kong were blocked between 2012 and 2014 by regulations, which traders could not identify properly. In the last five years, direct trade was also not found in Oman, European countries, or the USA.

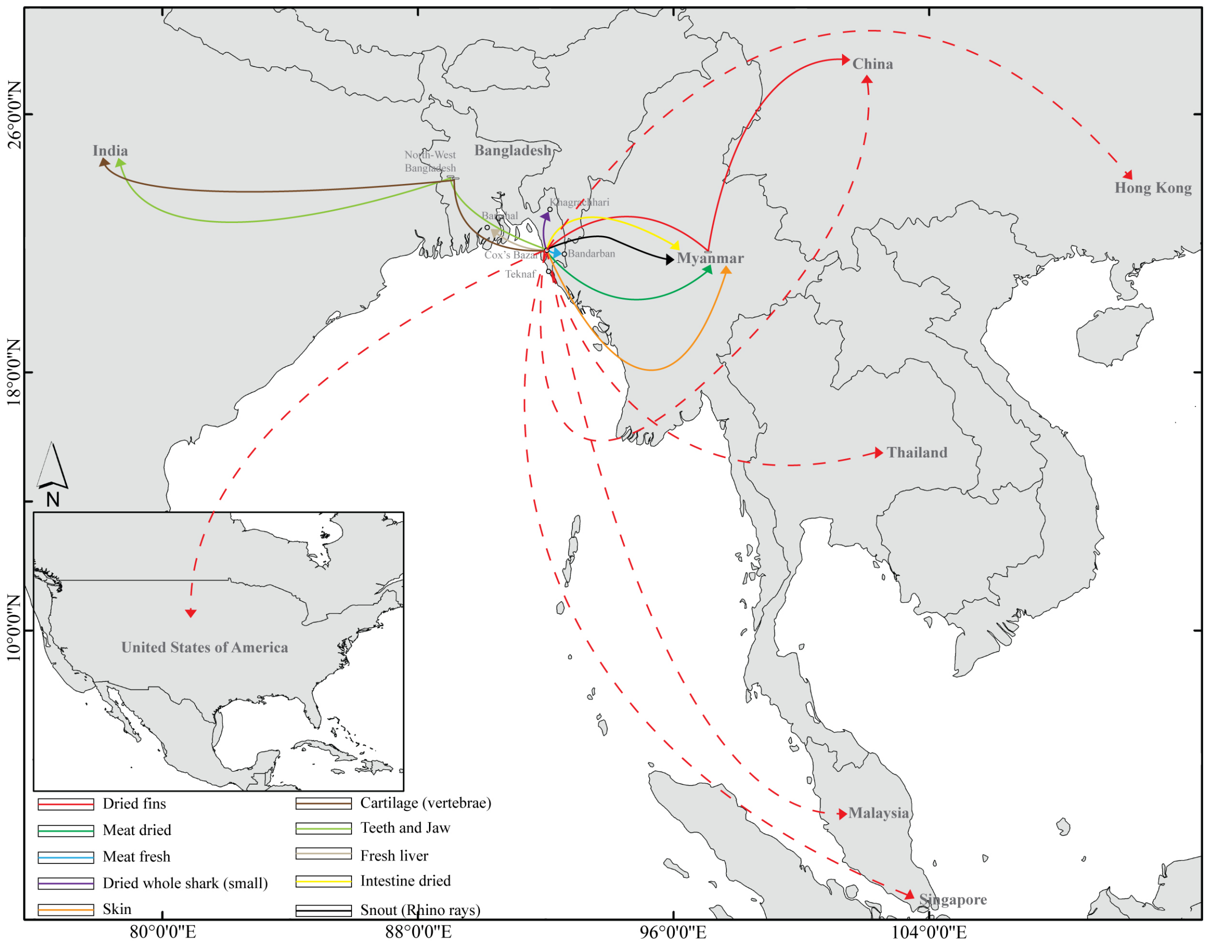

Figure 4.3. Details of market chain to final destination for elasmobranch products from Bangladesh. Solid line indicates existing trade during the study period and the dashed lines indicate previous frequent destinations which were not in place during the study period anymore. Different colours denote different elasmobranch products.

Large sharks and guitarfishes were transported from the southwest and south-central regions to the southeast for further trade and export. The relationship of local traders with overseas buyers was strong, especially with buyers from Myanmar. According to several traders working relationships with buyers from China, Hong Kong, India, Myanmar, the UAE, and the USA existed. Apart from this organized trade, international collectors and general buyers collected different products opportunistically. A recent record of shark vertebrae and teeth found in the USA (Anonymous, pers. Comm. December 2018) and jaws of *Glyphis gangeticus* Ganges shark in Australia (R. Jabado, pers. Comm; March 2020) tracked back to Bangladesh. Furthermore, according to traders, domestic demand for other products (e.g. smaller dried sharks, intestines, jaws, teeth, vertebrae, liver, liver oil, heads) exists (Figure 4.4).

Figure 4.4. Photos of different elasmobranch products taken from the different elasmobranch processing centres in the south-eastern region of Bangladesh. Shark and guitarfish fin (A-C), fresh and dried meat (D-E), dried small sharks and rays ((F-H), skin of guitarfish, sharks and rays (I-K), jaws and vertebrae (L-M), fresh and stored liver and liver oil (N-P), gill plates of Mobula rays (Q-R), sawfish rostrum as a souvenir (S) and intestines (T). The photos were taken between 2017-2020.

4.3.3.3. Target species and value

Overall, targeted shark fisheries were not observed anywhere along the coast; however, targeted ray fisheries were prevalent. The value of whole elasmobranchs and elasmobranch products was taxa or group-specific and dependent on size and availability. Twenty-one interviewees identified spadenose sharks, *Carcharhinus amblyrhynchos*, grey reef sharks, milk sharks, as well as pups of *Carcharhinus limbatus*, blacktip sharks; spottail sharks; *Chiloscyllium* spp., bamboo sharks (<70 cm) and *Rhincodon typus*, whale sharks as the least valued species. Due to their small size or the difficulty of drying the meat due to its high-water content in the case of whale sharks, these species have no export value. The most sought-after species were *Carcharhinus amboinensis*, pigeye sharks, *Carcharhinus leucas*, bull sharks, hammerhead sharks and *Galeocerdo cuvier*, tiger sharks. All traders identified sawfishes (Pristidae), wedgefishes and guitarfishes (Glaucostegidae, Rhinobatidae, Rhinidae) and hammerhead sharks as high-value species.

Traders had knowledge on international price levels and were aware of the usage of different body parts and of fins being the most valuable part (Table 4.3). Prices were typically set by middlemen based on skin and fin quality. Prices for smaller sharks (<70cm), e.g. spadenose sharks, spottail sharks, blacktip sharks and milk sharks, typically ranged from US$1,5 – US$ 2 per kg. Prices for medium-sized sharks (1-1,5m), e.g. pigeye sharks, bull sharks, scalloped hammerhead sharks and tiger sharks ranged from US$ 3- US$ 5,5 per kg (Table 4.4). Prices for sharks >1,5m were determined based on the size of the dorsal and pectoral fins. Prices for rhino rays (e.g., *Glaucostegus* spp. giant guitarfishes, *Rhinobatos* spp. guitarfishes) were generally higher and size-dependent, ranging from US$ 7- US$ 10. Dried fins (>45.5 cm) were sold for a maximum of US$ 350 – US$ 375 per kg. Whereas species belonging to the family Carcharhinidae and Sphyrnidae were sold for US$3-US$4, least-valued species like bamboo sharks were sold at a nominal price (0.6 US$ per kg) upon the availability of a buyer or discarded. Dried fin sets were priced between US$ 8 and US$ 375 depending on fin size (anterior margin; 5 cm to > 66 cm). Export prices for dried meat (1 kg = approximately 3-4 kg fresh meat) ranged from US$ 6 and US$ 10 per kg. Prices of dried products were generally five to six times higher than for fresh sharks. Pieces of shark skin ranged from US$ 6 to US$ 15 per piece. Prices for vertebrae and teeth ranged from US$ 3 and US$ 7 per kg (Table 4.4).

Table 4.3. List of conventional and non-conventional elasmobranch products, their usage and final trade destination based on interview surveys.

Products	Usage	Trade (L: Local/I: International) and destination
Fresh meat	Consumption	L: Kawran Bazar and Jatrabari in Dhaka, Chattagram, other metropolitan cities and all coastal villages
Dried meat	Consumption	L: Coastal villages and tribal villages in Chattagram hill tracts I: Myanmar
Skin	Accessories, Consumption	I: Myanmar, China, Hong Kong, Vietnam, Singapore,
Intestines	Consumption	L: Coastal villages and tribal villages in Chattagram hill tracts
Smaller whole dried rays	Consumption	L: Coastal villages and tribal villages in Chattagram hill tracts I: Myanmar
Gill plates	Consumption (soup)	I: Myanmar, China, Hong Kong, Vietnam, Singapore
Liver	Fish and poultry feed, pharmaceuticals	L: Coastal villages, liver oil in Dhaka
Tail	Souvenirs: rarely used	L: tourists, local landing site workers and village medicinal practitioner

Table 4.4. Prices of different elasmobranch products by size and final destination after being traded.

Product	Size (cm)	Price/kg US$	Price per set of four US$	Destination
Dried fins	5-10	4-8	9-10	Myanmar, China, Hong Kong, Thailand, Malaysia, USA.
	10-15	8-18	12-36	
	16-20	12-18	48	
	21-25	15-42	18-48	
	26-30	17-53	60	
	35-40	30-65		
	45-51	48-118	284	
	51-66 or larger	95-355	308-1182	
Meat dried		6-10		Myanmar

Meat fresh		Bangladesh
Dried whole shark (small)	5-9	Bangladesh
Skin	6-14	Myanmar
Cartilage (vertebrae)	3-10	Bangladesh and India
Teeth and Jaw	4-6	Bangladesh and India
Fresh liver		Bangladesh
Liver oil		Bangladesh
Intestine dried	3	Myanmar
Snout (Rhino rays)		Myanmar
Rostrum (sawfish)	296-710	Bangladesh

4.3.3.4. Regulations: The legal framework governing traders' activities

None of the interviewed traders showed a clear understanding of the existing domestic legislation protecting elasmobranchs (Table 4.5). None of them had ever heard of CITES. None had ever been exposed to any awareness campaigns, received fines from the authorities or faced any other kinds of sanctions for engaging in shark trade. In Bangladesh, elasmobranch and elasmobranch products' trade runs under a general permit for fisheries products' trade, hence elasmobranch-specific permits are not needed. Four percent of interviewed traders stated that since 2014 shark products could no longer be exported on airlines. When informed about the 'protected status' of 29 elasmobranch species in Bangladesh and the legal provisions regulating their trade, most traders expressed a willingness to understand the regulatory framework. They expressed an interest in understanding the reasons behind declining elasmobranch populations. Yet, they had never been consulted by policymakers or other regulatory regimes (Table 4.5).

Table 4.5. Selected questions on elasmobranch fisheries in Bangladesh and responses (including relevant quotes) of exclusive traders (n=25).

	Questions	Answers (in %)			
1	How much was the annual export of dried shark products (dried fins, meat and skin) in the last decade?	0.5- 1 tonnes (32)	25-35 tonnes (28)	>500 tonnes (24)	>100 tonnes (12) and >200 tonnes (4)

3	What was the most successful period in the shark trading business?	Before 2000 (4)	Before 2010 (72)	Before 2012 (12)	1992-2010 (12)
4	When did the trading business start to slow down?	After 1997 (4)	After 2000 (4)	After 2010 (76)	After 2012 (16)
5	Which are the most valuable species?	Species weighing > 20 kg (8)	Size dependent, large species are the most expensive (68)	Rhino rays and sawfish, hammerheads and any bigger shark (24)	Locally called 'bhota' (these represent larger sharks in the family of Carcharhiniformes (4)
6	Which are the least valuable species?	Smaller sharks (> 70 cm) (80)	Spadenose shark (4)	Bamboo sharks, spadenose shark and whale shark (16)	
7	Which is the best season for catching sharks?	Winter and summer (40)	Winter (52)	All seasons except for the monsoon season (8)	
8	Which is the most expensive elasmobranch product?	Dried fins (100)			
9	Are any permits required for shark fisheries and trade?	No (96)	May be for air transport of shark products (4)		
10	Are you aware of the National Wildlife Act, 2012?	No (92)	Yes, but unable to describe its content (8)		
11	Have you been exposed to any campaigns regarding shark conservation or regulations?	No (100)			
Selected quotes					

"When there were trade regulations in the neighbouring countries in the early 2010s, we found a secondary route to continue our trade."
"I used to trade in shark fins, now I trade in other fishes as well, as the number of sharks has gone down."
"I used to have connections with fin buyers from China, Hongkong, UAE, Malaysia. Now I only trade with Myanmar."
"I have traded on 600 tonnes of shark products annually till 2016. Due to a smaller number of sharks caught, now I have changed my shark processing centre to a leather processing centre."

4.3.3.5. Traders' perceptions

According to traders, international trade in elasmobranch products has existed for more than four decades. Elasmobranch trading businesses have been passed down to the second and third generations who now export bulks of elasmobranch products. According to all interviewed traders, the trade in elasmobranchs and their products has decreased since 2010/2011 due to overfishing and regulations by importer countries. Nine out of twelve processing centre owners had the financial capacity, labourer support and processing space to process and export shark products with the capacity of more than 20-25 tonnes of dried meat and 1-2 tonnes of fins annually (Table 4.6). Five traders in Cox's Bazar stated that between 1990 - 2017 annual exports of dried shark fins and dried shark meat ranged from 1-10 tonnes and 25- 200 tonnes respectively with a continuous decreasing trend since 2010. The majority (68%, n=17) of traders within the >50 years of experience group stated that their businesses' highest turnover was achieved between the late 1990s-2010. Traders mostly traded on a licence for exporting fishery products (e.g. fish maw). As a result, most of the international fin and meat trade remains unreported. Few interviewees (11.94 %, n=8) had a general understanding of the biological features and the ecological significance of sharks. All traders emphasized the economic and medicinal benefits of shark-related products. The majority of traders (96%) expressed concern about future conservation measures and their potential impact on their business; 4% (n=1) stated that they might switch to a different business should the trade in elasmobranchs become even less profitable. Yet, the majority of traders (96%) were unwilling to make a 'switch' because they wanted to continue their family business's legacy, although some were concerned about declining shark populations. They expressed a desire to abide by the government's regulations if the government looked after their needs. On the other hand, opportunistic collectors were ignorant with regards to conservation need. They stated that it was impossible to stop bycatch and that elasmobranchs would always be landed in these areas. All traders, however, were alarmed by the persistent decrease of elasmobranch landings.

Table4.6. Traders' capacity to process and export of elasmobranch products (dried fins, dried meat, skins, cartilage, intestines and liver) annually (average) from 1990s to 2017 (reference year 2017) by location.

Location	Dried Fins (tonnes)	Dried Meat (tonnes)	Dried Skin pieces (shark and ray both, 10-20 kg per piece)	Cartilage (kg)	Intestines (kg)	Liver (kg)
Cox's Bazar (6)	1-100	25 -200	2006-2012: 20,000-25,000 2012 to date: 6,000-12,000	1,000	200	3,000-4,000
Teknaf (1)	6	600	2,400-3,000	1,000	200	-
Chattogram (4)	2-4	25-100	-	-	-	-
St. Martin's Island (1)	-	2 (majority rays)	500	-	-	-

4.3.4. Assessment of unreported catch and trade

According to 'exclusive traders' from the south-eastern region between 20 and 622 tonnes of dried shark fins were exported per year from the south-eastern region alone. Total aggregate product traded ranged from 2,108 to 4,905 tonnes per year (between 2000-2016). The highest volume of internationally exported products were dried meat and skin followed by fins. Between 1,210 and 2,050 tonnes of skin and 852-2,202 tonnes of meat per year were exported. Between 8,400 and 19,600 tonnes of elasmobranchs might have been caught per year according to these estimates (Figure 4.5). This estimate is much higher than what is reported in national statistics (86-335%) and data sourced from Sea Around Us (7.6%) (Ullah et al., 2014; Pauly & Zeller, 2020). Additionally, the results show that almost all trade remains unreported.

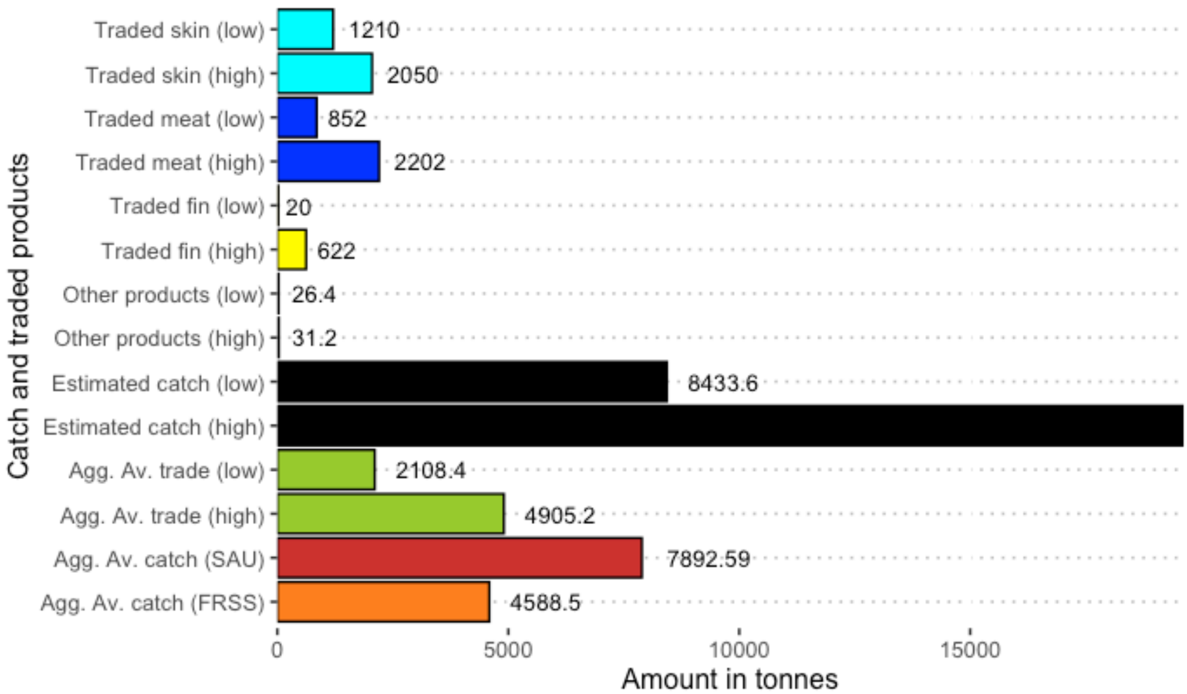

Figure 4.5. Estimated yearly export ranges (lowest and highest value) of traded skin, meat, fins and 'other products' are shown in sky blue, blue, yellow and grey. Black bars show the estimated total catch range between 2000-2016, based on interview data (see section 4.2.4). Green bars show the range of annual aggregate elasmobranch product trade internationally by 'exclusive traders'. Red and orange bars show annual average aggregate catch of elasmobranchs from Bangladeshi waters reported by Sea Around Us (SAU) (Pauly et al., 2020) and the Department of Fisheries (DoF, 2017) respectively.

4.4. Discussion

Bangladesh's artisanal elasmobranch trade has existed for decades with minimal management and an unknown impact on threatened elasmobranch populations. Our study demonstrates that nearly the entire international elasmobranch trade remains unreported, with the actual trade being between 86% to 335% higher than the reported one. We show that Bangladesh's national and international elasmobranch trade fills a complicated and exclusive niche for both consumption and traditional product use. Furthermore, we demonstrate that a high national and international demand for shark products has created a large unsustainable market chain worth hundreds of thousands of dollars annually which drives unsustainable fisheries practices and the motivation for high retention rates of bycaught specimens. The majority of individuals trading elasmobranch products has limited knowledge on the protection status of threatened species and limited access to secondary or alternative livelihoods leading to non-compliance of existing laws. The results and recommendations of our study are fundamental to filling long-standing gaps on trade dynamics from multi-source data. For a resource and data-poor country, this is the first step towards evidence-based management of threatened elasmobranch populations.

4.4.1. Official catch and trade data underrepresent elasmobranchs

A qualitative and quantitative analysis of Bangladesh's reported elasmobranch trade suggests inaccurate accounting and a potentially flawed system. While the Fisheries Statistical Yearbook of Bangladesh, an annual report published by the Department of Fisheries (DoF) under the Ministry of Fisheries and Livestock, reports total fish catch and trade data, the data provided is neither species-specific nor comprehensive (DoF, 2012, 2013, 2014, 2015, 2016, 2017). Landing data is mostly reported from the south-eastern region, primarily from official BFDC landing sites, while unofficial landings from the south-central and south-western regions are not considered. This underestimation of total catch levels is exacerbated by a discard ratio of 4:1 (Kelleher, 2005) and a lack of catch data from industrial vessels (bottom trawlers), which are responsible for 80% of all elasmobranch discards (Ullah et al., 2014, Kumar et al., 2019).

Bangladesh's flawed elasmobranch catch, and trade accounting system is also reflected in international datasets. Only limited trade data is reported internationally and the majority of trade remains unreported. For instance, in the period 2010 - 2018 elasmobranch product exports from Bangladesh were only reported across two years (2012-2013) (1 tonne) and 2016-2017 (0.16 tonne) by DoF. Given that we identified at least four traders who each had the capacity to export as much as 600 tonnes of elasmobranch products annually, these estimates are clearly too conservative. In the marine fishery reconstruction by Ullah et al. (2014), reported marine fish catch and trade was substantially higher than nationally reported catch and trade numbers. Similarly, a comparison of the national DoF landing data with the Sea Around Us data (Pauly & Zeller, 2020) shows disparities suggestive of conservative accounting in Bangladesh. UNComtrade data is patchy and national reports from Bangladesh are virtually non-existent, however, many importer and exporter countries report Bangladesh as a player in elasmobranch trade and several countries (e.g. India, Pakistan, Myanmar, Oman, Thailand, USA) (Figure S4.2) report exports and imports of elasmobranch products from and to Bangladesh, respectively, yet this data is not reflected in national accounts (DoF, 2012, 2013, 2014, 2015, 2016, 2017).

Despite a limited understanding of historical elasmobranch trade in the Bangladesh region, Bangladesh was ranked 19th in the fin trade export by volume by the FAO, with an average export of 95 tonnes of shark fins reported between 2000 to 2011 (Dent & Clarke, 2015). However, export data was available for only eight years (2004-2011). Reporting less than 20 tonnes for most of these years (2004-2011), the FAO data (from FishStatJ) is likely a stark underestimation. Datasets from DoF, CITES and UNComtrade also demonstrated anomalies, such as the export of *Lamna nasus*, porbeagle shark to the USA in 2018, which was documented in CITES trade datasets but did not appear in national fisheries statistics. Although, none of the analysed datasets report consecutive annual elasmobranch trade, such trade occurred between the 1960s-2019 including many CITES-listed species according to interviewed traders.

Bangladesh urgently needs to revisit existing fishery information collection systems and labelling regulations relating to the marketing of fishery products and restructure them to be sensitive to species conservation. Priority steps should include the establishment of formal and well-regulated landing sites at the most significant elasmobranch landing areas, where no formal government accounting system is currently in place. To promote efficacy, on-board monitoring and log-booking should be supported as well as training of landing site officials for identification and monitoring protocols (Table 4.7).

Table 4.7. Problems and priority actions for trade control of elasmobranch products in Bangladesh.

Problems	Recommendations
Fishery data-set loopholes and coarse data resolution	1. Establishing formal landing sites 2. Initiating on-board monitoring programs and collaborative monitoring mechanisms with artisanal fishers 3. Employing trained officials at landing sites and shark processing centres 4. Training and periodic updating of technicians at proposed landing sites and traditional artisanal fishing communities 5. Establishing proper reporting mechanisms for international databases (e.g. CITES)
Illegal trade	1. Awareness building of existing laws and mandates and identification of protected and threatened species. 2. Increasing contingency of law enforcement. 3. Developing and intensifying oversight reporting 4. Increasing the efficiency for suitable practices which in turn can decrease pressure on elasmobranch trade 5. Usage of DNA/genetic (PCR mini barcoding (Haque et al., 2018) tools at the ports to identify illegal consignments for effective monitoring 6. Preventing more traders to enter the market 7. Registering all traders with trade control state bodies and initialising appropriate quota defined in the Non-Detrimental Findings (NDF) in the country

Miscoded and aggregate landing and product trade	1. Designing unambiguous protocols for proper labelling in the case of sharks that are sold as fishery product 2. Ensuring species-specific accounts at landing sites for elasmobranchs 3. Coast-wide standardised monitoring and accounting systems in collaboration with BFD and DoF.
Inefficient legal framework	1. Amending the legal framework based on available data and evidence. 2. Appropriate incentives for law enforcement and implementation agencies 3. Fishing and trading licensing connected to sustainable practices
Insufficient implementation	1. Implementing existing laws at landing sites, trade routes and hubs identified in this study 2. Training on species identification, protected species, trade regulations for local forest and fisheries officers to monitor and manage trade according to the laws
Top-down policies	1. Introducing inclusive policies where the vulnerabilities of stakeholders are considered, and facilitation is provided to mitigate them 2. Establishing a communication linkage between coastal fishing and trading communities and fisheries management bodies.

4.4.2. Elasmobranch trade is driven by national and international demands

The consumption of elasmobranch meat is common in many tropical countries (Kyne et al., 2020; Spaet & Berumen, 2015; Jabado & Spaet, 2017; Moore, 2017), including Bangladesh (mostly by tribal communities). The most sought-after and most valuable species (i.e. hammerhead sharks, pigeye sharks, bull sharks, hammerhead sharks, tiger sharks, sawfishes, wedgefishes and guitarfishes) (Okes & Sent, 2019; Clarke et al., 2007; Jabado et al., 2015; Kyne et al., 2020; Haque et al., 2020) are also the most vulnerable, globally, based on IUCN Red List criteria (IUCN, 2021). Our study showed that, based on interviews with elasmobranch traders, the majority of elasmobranch products were exported to Myanmar between 2014 and 2017 as a conduit to China and Hong Kong. UNComtrade data confirmed trade with several other countries in varying amounts, such as imports of aggregate products from Oman, Thailand and Pakistan. Interview data, however, did not indicate imports or re-exports of dried fins or other products. Information on re-export to Bangladesh is supported by CITES trade datasets, which also confirmed imports of fins predominantly by the USA.

The import and re-export of elasmobranch products, however, could not be corroborated as there are no nationally available datasets. Further studies are needed to unveil this aspect of the trade and to determine whether Bangladesh is a transit point for final destinations, such as the UAE (Jabado et al., 2015). Furthermore, specific research is needed to understand existing markets and the vulnerabilities arising from such diverse market options and actions.

The majority of the elasmobranch processing centres identified in this study had been operating for 40-50 years and were capable of exporting 1 to > 600 tonnes of shark products (mostly fins and meat) to different Asian markets annually. The capacity and scale of these businesses provides a readily available market for bycaught specimens and incentivized fishers for high retention levels. Due to the large variety of products and accessible markets through 'exclusive traders', the elasmobranch trade has become increasingly profitable for all layers of traders and fishers - sometimes more so than the commercially important teleost fishes. While niche-exclusive tribal villages that represent Bangladesh's national market for local elasmobranch consumption could potentially also negatively impact global elasmobranch populations (Cripps et al., 2015), our study found the threats posed by local shark consumption are comparatively low due to a low demand and non-shark meat alternatives (e.g. other dried fish).

Understanding legal and illegal trade routes of protected species is critical for trade control. In this study, mapped trade routes indicate Teknaf as the main port for shark fins, meat, and skin trade, which occurs mainly through waterways but also airports, consistent with 67% of shark fins reportedly imported to Hong Kong by sea and 15% by air (Clarke, 2004a). From Bangladesh, fins and dried meat are destined for Myanmar, while vertebrae and cartilage are destined for India for amulet collections with medicinal value (Hanfee, 1997). In addition to conventional elasmobranch products, skins and intestines are also dried and exported, and used for both consumption and leather production in Bangladesh. Similar practices are prevalent in other areas of world (Jabado et al., 2015; Vannuccini, 1999; Lam, 2009; Wen et al., 2012). Trade route monitoring will be a crucial step for Bangladesh's elasmobranch conservation and population management, both nationally and regionally. Trade hubs, landing sites and fishery product consignments at different ports and destinations need to be monitored in line with national law and CITES mandates, especially in the south-eastern region. Training for local staff of the Department of Forest (the authoritative body to control trade in wildlife under the national act) could enable easy identification protocols for CITES-listed species to be used to increase the accuracy and amount of catch and trade accounting. DNA or genetic tools can also be of great value in this regard (Haque et al., 2018). A regionally coordinated move whereby importer and exporter countries have similar laws would go a long way in conserving elasmobranchs and controlling unsustainable trade.

4.4.3. Need for an improved legal framework

The presence of multiple jurisdictional bodies regulating Bangladeshi wildlife conservation, coupled with a lack of communication and collaboration among them raises jurisdiction conflicts, especially in the face of different priorities. The two most critical regulatory Acts for Bangladeshi wildlife and fish conservation are (1) The Protection and Conservation of Fish Act (PCFA), 1950 and (2) the WCSA, 2012 (Islam et al., 2017; Haque et al., 2018). The PCFA falls under the Department of Fisheries jurisdiction and is framed to provide protection and conservation of inland and marine fishes including 'cartilaginous' fish while the Department of Fisheries has long-standing expedience of managing coastal and marine fisheries through ban periods, gear specifications and compensation mechanisms, it does not have any obligation to CITES, specific fishing regulations for elasmobranchs or any trade management regime for threatened taxa. The WCSA, 2012 falls under the Bangladesh Forest Department, which has the authority to fulfil CITES mandates, however, is only equipped with conservation measures for terrestrial animals and lacks access to coastal waters, fishing vessels or vessel-monitoring regimes. Currently 29 elasmobranch species are protected by the WCSA, 2012, yet several globally threatened species [e.g., *Glaucostegus typus*, giant shovelnose rays (CR); *G. obtusus*, widenose guitarfish (CR); *Rhina ancylostoma*, bowmouth guitarfish (CR)] are not listed. To fulfil Bangladesh's national mandates and international commitments towards halting unsustainable catch and trade, ideally both agencies should amend these acts and manage and monitor elasmobranch fisheries and trade collaboratively. Emphasis should be put on the development of a state-led coast-wide standardized accounting system, including monitoring measures on board, at landing sites, processing centres, and ports used for international trade. For better acceptance and compliance amendments should involve elasmobranch traders as stakeholders (Booth et al., 2019; MacKeracher et al., 2020). There are many examples, particularly from developing countries (Bladon et al., 2016), where existing bans and legislation did not lead to improved species protection due to a lack of enforcement (Spaet & Berumen 2015; Spaet et al. 2016), the absence of quality research (Fischer et al., 2012; Jabado et al., 2015), under-funded weak institutions and lack of awareness (Kuperan et al., 2020). As the majority of traders believe that any mechanisms to control bycatch are inefficient, and that the regional supply of seafood is unlimited, there is a possibility that strict regulations and monitoring (overall ban and abrupt raids and fines) will compel them to either find alternative routes for trade or completely resort to the emerging black market, suggested by traders in China and Hong Kong. For instance, to avoid monitoring, large sharks (> 150 cm) have been landed at a new unofficial landing site in Cox's Bazar since January 2020, (Haque, pers. obs.). The ability to monitor catch is likely to worsen if fishers collect fins and discard carcasses. Traders, however, were keen to know what incentives or government facilitation were in place, providing optimism that behavioural change is possible under the right circumstances. Similarly, while an umbrella-ban on catch and trade can be economically problematic for fishers, understanding and incorporating socio-economic motivations for catch and trade could improve management regimes and compliance (Bergmann et al., 2004; Carlsson, 2005; Castello, 2008; Silvano & Begossi, 2012; Barbosa-Filho et al., 2014; Thyresson et al., 2013; Maynou et al., 2018). While trade regulations shall be cardinal, it will be essential to acknowledge that sudden enforcement of top-down regulatory measures that neglect socio-economic complexities will likely cause more harm than good (Booth et al., 2019; Mason et al., 2020). For example, increasing fishers' social and food security may decrease the pressure on unsustainable trade. Alternatively, placing a priority on sustainable shark fisheries management policies is recommended for meeting shark conservation and fisheries management goals.

4.4.4. Lessons learned to work in data-poor scenarios to improve management

Managing fisheries with limited data requires a context-specific and adaptable strategy. For continuous improvement, it is essential to evaluate management practices often, monitors the results of actions, and modify tactics in response to new data and stakeholder input. Some examples of strategies that may help are-

1. **Participatory approach:** Involve stakeholders in decision-making, including the community and local fishers.
2. **Build trust and a shared goal:** especially in the socio-ecological study, those planned for improving management must exclusively put some time into the project to build trust with the communities. Having a shared goal for mutually beneficial outcomes for the conservation of species and locals' livelihoods is also necessary.
3. **Essential information**: Gather information that is critical for management choices. Encourage fishermen to keep logbooks or participate in low-cost, low-technology, and accessible data-collecting activities, and offer education and assistance to enhance the accuracy and dependability of the data.

4. **Encourage collaboration and knowledge sharing:** Encourage collaboration and knowledge sharing among all interested parties, including researchers, decision-makers, fishermen, and local people.
5. **Investment in capacity-building** and training programs for fishermen, management, and law enforcement officials.
6. **Involve experts:** To aid programs for managing fisheries that lack enough data, collaborate with international organizations, NGOs, and donor organizations.
7. I**mplement preventative measures:** Apply cautious management strategies to preserve resources without precise data.
8. **Increase monitoring:** Increased funds should be allocated to monitoring and surveillance.
9. **Adaptiveness** in every step of the project design and implementation/enforcement

CHAPTER FIVE: Market

5. Mitigating elasmobranch fin trade: A market analysis for made-to-measure interventions

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People and Market– Fish landing site beside Bakkhali river, Cox's Bazar

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Abstract

The unsustainable trade in elasmobranch products, particularly fins, contributes to the decline of elasmobranch populations worldwide. Designing and implementing context-appropriate solutions to mitigate unsustainable trade requires a thorough analysis of markets. Here we assess the market component of the elasmobranch fin trade in the Bay of Bengal, Bangladesh, using a framework designed to analyse wildlife markets. Using a mixed-method approach, we characterized the market to identify the components contributing to unsustainable practices. Bycatch retention levels were high leading to the development of a solid market. Trade on fins was prevalent due to a high price, lack of awareness, actors' limited ability to adhere to regulations, and no strategies and incentives to limit fishing mortality. An imbalanced power and financial structure between actors were revealed, with some actors accessing unequal benefits from the market. Impediments for adopting conservation measures by low-access actors (e.g., fishers) with limited decision-making power or resources were evident. We also identified challenges to enforcement primarily due to limited reporting and issues identifying species and products. Fishers noted several socio-ecological, technical, and enforcement issues (e.g., policing instead of meaningful monitoring, punitive measures without facilitating compliance), that will require adequate time and resources to change practices. Lack of opportunities and information to adhere to regulations and increased enforcement has led to conflicts, non-compliance and unwillingness to report catches. The study has significantly strengthened the current understanding of Bangladesh's complex elasmobranch product market while highlighting critical knowledge gaps that must be addressed to inform and improve management decisions. Based on the findings, we recommend targeted actions to respond to the current market for mitigating elasmobranch product trade and moving towards establishing sustainable and ethical trade. Our work has both regional and global significance, given the role of the Bay of Bengal nations in the worldwide elasmobranch product market.

5.1. Introduction

Unsustainable wildlife trade has been a conservation concern since the 1960s (Milner-Gulland, 2018). Unsustainable wildlife trade (including illegal) negatively impacts threatened and trafficked species (‘t Sas-Rolfes et al., 2019; Bennett et al., 2021). To evaluate wildlife trade, its complexities and potential to drive unsustainable practices, it is important to unpack wildlife markets ('t Sas-Rolfes et al., 2019; Oyanedel et al., 2021a; Challender et al., 2022). Wildlife markets are complex systems that include harvesting resources for consumption or other usages and are influenced by a myriad of factors relating to legal and socio-economic contexts, actors’ relations, access to information and financial mechanisms, among others (Goodall, 2019; Arias et al., 2020; Siriwat & Nijman, 2020; Oyanedel et al., 2021a). Indeed, assessing how and when a specific market might initiate and/or exacerbate unsustainable or illegal wildlife trade is critical for mitigating detrimental effects on harvested species (O'Neill et al., 2018; McNamara et al., 2019). By intervening with tailored, targeted, and scale and context-appropriate actions, unsustainable practices can be addressed and reduced (Purcell et al., 2017; O'Neill et al., 2018).

Several studies have researched how wildlife markets can promote or hinder sustainability (Ling & Milner-Gulland, 2006; McNamara et al., 2016; Oyanedel et al., 2021b). However, most efforts look at isolated components (e.g., supply, demand or actor’s motivations to trade) within the market instead of the complex inter-relationships among different actors and institutions (Oyanedel et al., 2021a). Without a holistic understanding of wildlife markets, potential solutions to mitigate trade can lead to adverse consequences, such as the emergence of black markets, social injustice or market failures (e.g., monopoly, negative environmental externalities-biodiversity loss) (Larrosa et al., 2016; Haque & Spaet, 2021d; Haque et al., 2022). Interdisciplinary understanding of the complex wildlife trade dynamics has been identified as a significant need for practical and effective management strategies in Southeast Asia (Blair et al., 2017). Yet, comprehensive studies of the prevalent wildlife markets in the global south are limited even though these are known to be detrimental to several threatened species (Nijman, 2010; McEvoy et al., 2019) including elasmobranchs (sharks, rays and skates).

Elasmobranch exploitation has grown rapidly in recent decades, particularly to meet the demand for fins and meat (Clarke et al., 2006; Okes & Sant, 2019). Fins and meat of the captured elasmobranchs are frequently redirected along different supply pathways to fulfil demand in expanding global markets (Dent & Clarke, 2015; Okes & Sant, 2019). Between 2000 and 2016, an average of 16,177 mt of shark fins (worth USD294 million per year) were internationally traded to different markets (Okes & Sant, 2019). This has contributed to dramatic declines in elasmobranch populations. Therefore, there is a need for more knowledge regarding how market forces influence elasmobranch catch and trade, particularly in the global south, where many of these trades originate (Okes & Sant, 2019). The lack of these understandings makes it difficult for conservation and management strategies to be apt and particularly applicable to the current and geographically unique markets.

Here we focus on Bangladesh's elasmobranch fin trade, as such we only consider sharks and rhinopristiformes in this study (Haque et al., 2021a). High-value fins (i.e., any commercially exported and viable sized fins) are Bangladesh's most valuable elasmobranch products, exclusively traded in international markets, followed by meat (Haque et al., 2018; Haque & Spaet, 2021d). Fins are mainly exported to Myanmar, then on to destinations in China and other countries (Haque & Spaet, 2021d). Very little trade information is documented due to factors including limited monitoring on-board vessels, at landing sites and in custom ports (Haque & Spaet, 2021d). Fishers do not report species-specific catches and traders do not report on product-specific trade, or species-specific trade (DoF, 2019; Hasan et al., 2017).

In terms of Bangladesh's policy and legislation, there has been an increased level of enforcement of the newly amended national law- the Wildlife (Conservation and Security) Act of 2012, by regulating catch and trade of most elasmobranch species (Haque et al., 2022). Although the law doesn't stipulate a complete ban on all species, fishers stated, it is being interpreted as such by enforcement activities (e.g., random landing site checks, punitive measures, seizing catches) for the majority of elasmobranch species (Haque unpubl. data, 2022). This may be due to limited identification capacity and training or absence of species-specific management measures. However, when 'complete bans' are put in place, these can jeopardise the potential for sustainable shark fisheries (Simpfendorfer & Dulvy, 2017; Collins et al., 2021) and have no effect on shark mortality (Shiffman et al., 2017). In small-scale natural resource use systems, complexities may impede straightforward solutions (Mahon et al., 2008; Waylen et al., 2013). Instead, a collection of evidence-based policy tools, rooted in strong conservation theory and practice, should help managers identify the conditions for which economic or social improvements might encourage compliance and when non-economic incentives (e.g., education, awareness, empowerment) are required (Oyanedel et al., 2020a; Booth et al., 2021).

Here, we use a framework designed by Oyanedel et al. (2021a) to assess wildlife markets (hereafter referred to as 'the framework'; see section 5.2.1) to characterise market dynamics of the high-value fin trade for elasmobranchs within the data-limited fishery of Bangladesh. Using the framework, we examine actor involvement, trading mechanisms, legality, profit-generating mechanisms, the design of wildlife supply chain networks, and the existing competition within the high-value fin markets. Using the evidence/results found, we recommend apt market interventions. Our goal is to provide evidence to the involved actors, conservation community and policymakers to identify the most effective regime for trade management that is inclusive, transparent, sustainable, replicable and scientific.

5.2. Methods

5.2.1. The Framework

The framework identifies a sustainability problem within a wildlife market and uses three analytical levels to characterise the market. The analytical levels are- a) actors' (i.e. individuals, groups or institutions that partake in a wildlife market) access to market benefits and motivations for engaging in the market; b) inter-actor (i.e. interactions and the flow of information, capital and products amongst actors) relationships involved in supply chain structure and competition dynamics; and c) market, including supply-demand dynamics, price determinants and legal versus illegal aspects. The three levels are further described in Table 5.1, Table S5.1 and S5.2 (glossary of the various terms used within the framework). The framework also includes potential interventions (based on published literature) aligned with the market's characteristics to mitigate unsustainable wildlife product use (Table S5.1).

Table 5.1. Analytical levels of the framework for evaluating the market influencing unsustainable wildlife use (Adapted from Oyanedel et al., 2021a). For detailed description see Table S5.1 and for definitions see Table S5.2

Analytical levels	**Dimensions**	**Description/Definition**
Actor level analysis	Access	Legal or informal mechanisms to operate and collect benefits from a market. (e.g., property rights, social relationships, information about catch demand, political power).
	Motivation	Reasons behind an actor behaving or engaging in a market in a particular way. The underlying motivations are the real cause for an actor's behaviour.
Inter-actor	Supply-chain structure	Interactions and the flow of information, capital and products that affect markets' operations and the

level analysis		sustainable use of the product in question (Damania et al. 2005; McNamara et al. 2016; Milner-Gulland, 1993).
	Competition dynamics	The way actors interact, compete and prevent new actors from entering the wildlife market.
Market level analysis	Supply-demand dynamic	If the market is controlled by a supply- or demand-driven process.
	Quantity and price determinants	The variety of factors that influence product quantities provided and required within the market, along with product prices.
	Legal/ illegal interaction	Presence or supply of illegal products and how these products are integrated into the supply chain.

5.2.2. Application of the framework in Bangladesh's high-value fin trade case-study

We have selected the 'high-value fin trade' as our study topic. We selected our scope and scale for actor and inter-actor analyses as *the sale of whole-bodied elasmobranch at landing sites and detached dried fins at processing centres in the southeast region, for the international fin trade markets*. For the market analysis, we assess the high-value fin trade *at the national level (all affiliated coastal regions*). We present three levels of analysis; 'actor', 'inter-actor' and 'market' as presented in the framework. The three levels enable us to evaluate: how actors profit from wildlife markets; the design of wildlife supply chain networks and nature of competition between actors in that market; supply-demand dynamics, quantity and price factors, and the existence and impact of illegal commodities. Based on our findings, we propose tailored solutions from the published literature promoting socio-culturally and economically appropriate interventions for mitigating unsustainable fin trade.

5.2.3. Data

The framework guided the data collection process. A mixed method approach was taken to characterise each of the analytical levels. Data and information from field surveys at elasmobranch landing and processing sites (Figure 5.1), and key-informant interviews (KII, hereafter referred to as "interviews") were used, applying a triangulation design. During the field surveys, leaders in elasmobranch catch and trade within the study sites (Figure 11) were identified and later approached for detailed key informant interviews (KIIs). This entailed simultaneous collection of qualitative and quantitative data, (with similar questions asked), with each type of data then used to verify the other. (Creswell, 2009; Newing, 2010; Bergman, 2011) (Figure 5.2). Quantitative data included the amount (in tonnes) of fin trade, price, and landing volume. Qualitative data included product processing, trade route, trade mechanism, trade hubs identification, actor characterisation using access mechanisms and motivations, and aspects of compliance with trade regulations amongst fishers and traders. Furthermore, information from informal conversations with traders and fishers, documented as field notes, contributed to the study. Relevant literature was reviewed from the published framework (Oyanedel et al., 2021a) and through a rapid literature survey for identifying interventions. Detailed methodologies and data were documented and tabulated (Table S5.3 to S5.7). 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. The human ethical approval was granted by the Ethical review committee of the Faculty of Biological Sciences, University of Dhaka (reference number- 59/Biol.scs.).

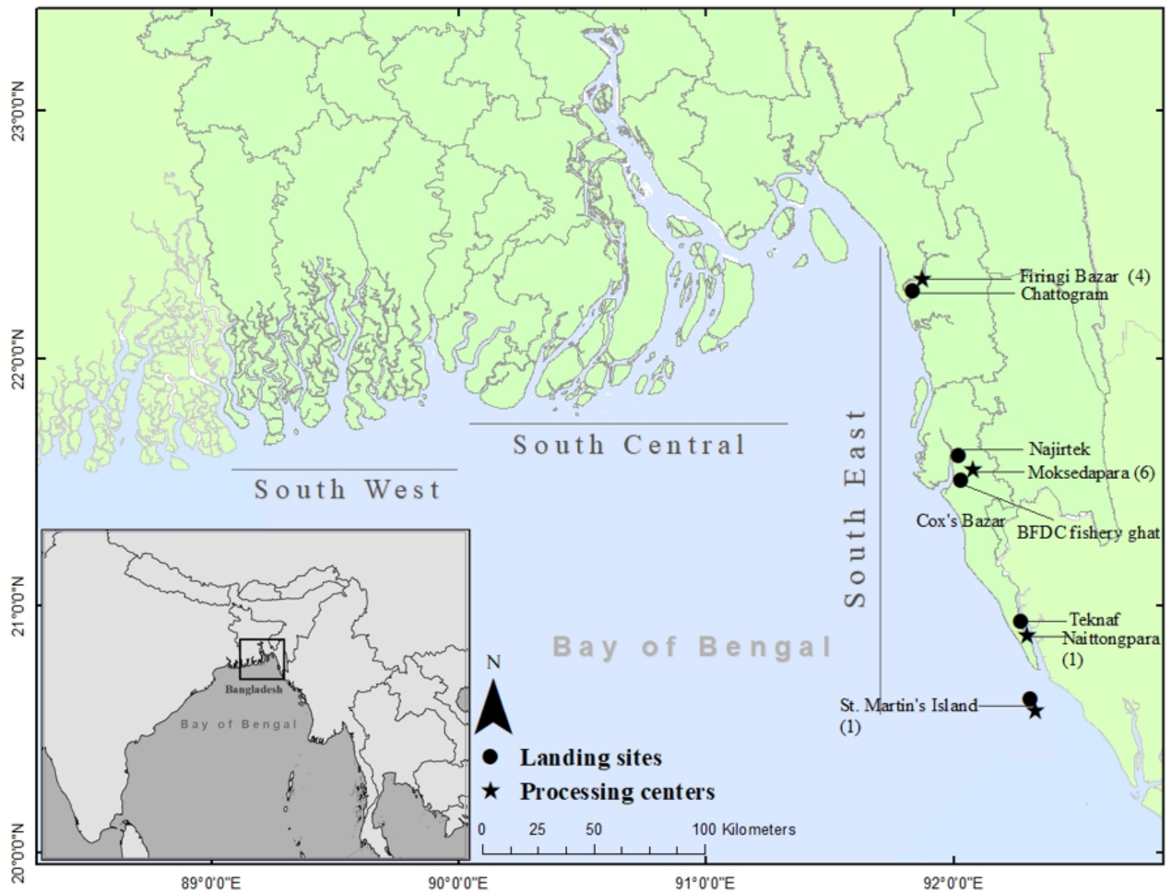


Figure 5.1. Landing sites and elasmobranch processing centres along the south-eastern coastline of Bangladesh. Numbers in the parentheses indicate the number of local processing

centres. The inset map shows the location of Bangladesh in the Bay of Bengal. The map was created using ArcGIS 10.3.

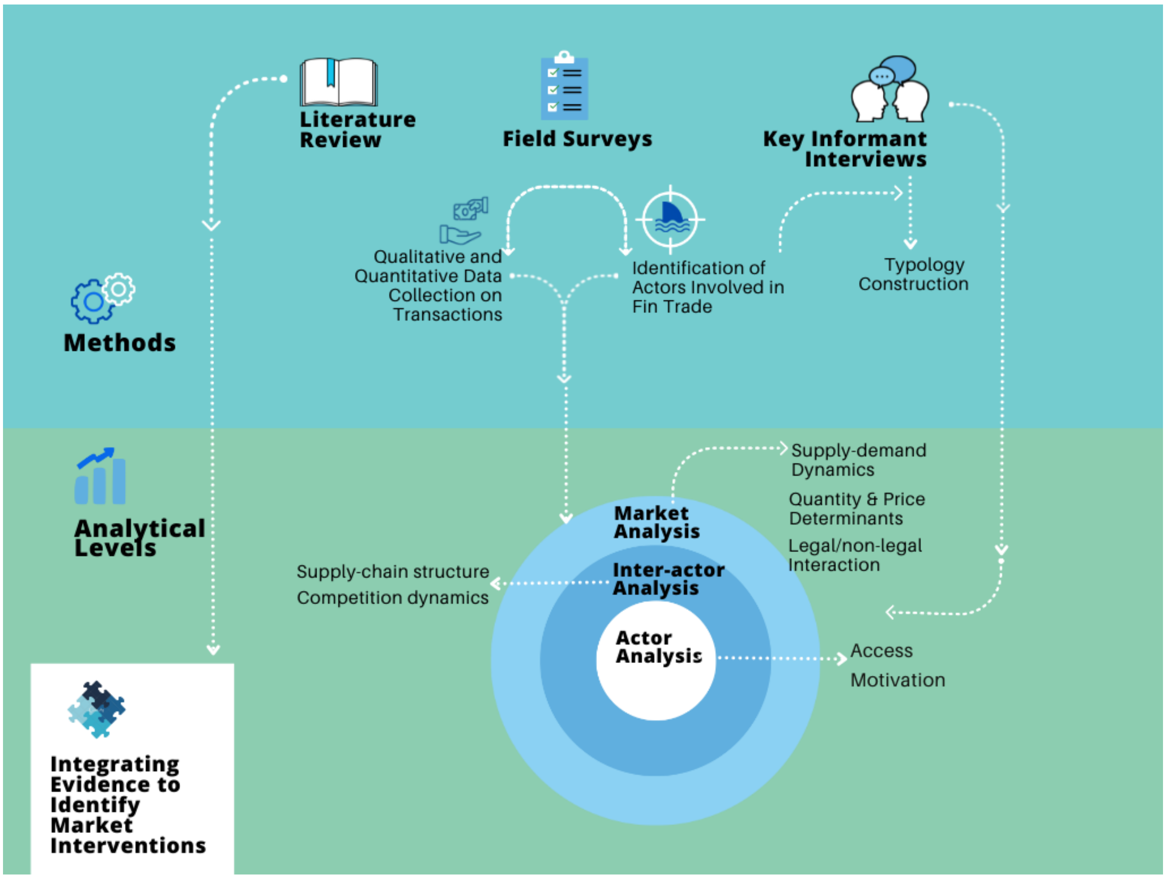


Figure 5.2. Graphical representation of methods used to analyse each dimension within the framework (Oyanedel et al., 2021a) to identify market interventions.

5.2.4. Using the data in each analytical level

5.2.4.1. Actor level analysis

Using field surveys and interviews we identified actors that participate in the market (Table S5.6), and characterised the actors' motivation and access mechanisms used to benefit from the market. The mechanisms of motivation and access can help identify the processes that drive unsustainable use of wildlife products. For instance, an actor's motivation can be instrumental (i.e. actions driven by economic benefits) (Table S5.2). In such a case, negative incentives (penalties, enforcement) or positive incentives (rewards for compliance, alternative or more effective livelihood options) can potentially alter behaviour. Similarly, actors' access can be restricted to information or financial mechanisms. In that case, creating information platforms and access to capital can be provided for sustainable trade (Table S5.1).

We categorised all actors (Table S5.6) into actor-types (Table 5.2) according to commonly shared attributes using the motivation and access dimensions (Table S5.8 and S5.9). A typology construction process was used to create actor-types following Kluge (2000). Typologies refer to the systematic construction of types - which are unique combinations of attributes that influence the relevant outcome. Typologies were constructed by:

i) **Development of relevant analysis dimensions:** three motivation attributes, i.e., instrumental motivations, non-instrumental motivations (normative- motivation that relates to social and personal norms, legitimacy based- motivated to comply with a regulation due to the acceptance and its beneficial outcomes) and mixed motivations, and two access attributes: limited/low access and varied/high access (see glossary in Table S5.2), were used.

ii) **Grouping the cases and analysis of empirical regularities:** the actors were grouped into empirical regularities, ensuring adequate heterogeneity for creating types.

iii) **Analysis of meaningful relationships and type construction:** merging the attributes potentially encompassing unique behaviours of the different actors.

iv) **Characterization of the constructed types:** the constructed actor-types were characterised (Table 5.3).

It was beyond the capacity of the study to interview the end-of-chain vendors (one of whom did not agree to the publication of interview results) and foreign consumers (lack of resources and access to conduct interviews). As a result, the actor types assigned were limited to harvesters, traders, and intermediaries.

Table 5.2. Characterization of the constructed actor-types for high-value fin trade in Bangladesh. For detailed description see Table S5.10.

Actors	**Actor type**	**Characterization**	**Motivation**	**Access**	**Comments**
Harvester	***Type I*** *"Bycatch and opportunistic fishers"*	Catch elasmobranchs as non-discarded by- catch.	Mixed	Limited/ low	Most are on a payroll from boat owners so access to benefits from these catches is low.
	Type II *"Target ray-fisher"*	Target all rays using bottom set non-baited long lines.	Mixed	Varied/ low	The primary mechanism of benefits is the price of rays sold to intermediaries at the landing sites or to the exclusive traders at the processing centers.
	Type III *"Boat owners"*	Those with the financial capacity to operate multiple boats and hire several fishers and through a debt-driven mechanism.	*Instrumental*	Varied/ high	Highest access to any catch from those boats and the power to make decisions, receiving between 50-75% of the profit.
Intermediaries	***Type IV*** *"Permanent landing site middlemen"*	Appointed by exclusive elasmobranch traders at the landing sites or independent middlemen to source the catch and transport it to the processing centers.	*Instrumental*	Varied/ high	Have the permanent access to the benefits but mostly controlled by traders.
	Type V *"Opportunistic landing site middlemen"*	Buy elasmobranchs at landing sites for transport to tribal areas or to the retail fish driers.	*Instrumental*	Limited/ low	Dependent on specific conditions when they buy elasmobranchs and hence, do not have permanent access to the benefits from the fishery.

Traders	***Type VI*** *"Exclusive elasmobranch traders (mainly fins, gill rakers and meat)"*	Operate from main landing sites and in processing centres in the southeast region. These actors are well organized, work within a community.	*Instrumental*	Varied/ high	Have diverse mechanisms for accessing benefits knowledge of demand, ties with boat owners, relationship with national and international buyers, financial capacity to buy bulk products, capital, collusive price-fixing, process and store and infrastructure.
	Type VII *"Opportunistic elasmobranch traders"*	Trade in all fishery products including fish maw (dried swim bladders). Opportunistically trade elasmobranch products, mainly fins and meat.	Mixed	Varied/ high	Access maintained by regularly visiting the landing sites, relationships with intermediaries, landing site workers and international buyers.

Table 5.3. Summary of findings from the application of the framework to high-value elasmobranch fin trade in Bangladesh highlighting potential interventions sought from published evidence. 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.

Level of Analysis	Dimension	Evidence	Illustrative quotations	Possible interventions	References	Uncertainty
Actor	Motivations	Fishers' motivation was instrumental leading to high retention rate and mixed motivation for rare species like the sawfish, guitarfish. Both traders' and intermediaries' motivation were instrumental as well to	Trader: "*End of chain traders earn a lot of money from fin trade and sometimes use vessels of their own to bypass*	-Initiate quota for sustainable stock and better financial arrangements for keeping the profit afloat/certification -Reduce benefits from unsustainable practices and increase market price/incentives for	Oyanedel et al., 2021; Oyanedel et al., 2020b; Haque & Spaet, 2021; Cialdini & Trost, 1998; Ferrier, 2008; Milner-Gulland &	**High/Medium**- a suite of detailed trade studies (Haque et al. 2020a, 2020b; 2021; Haque in review) allowed to evaluate the

	attain the highest value possible and avoid being detected by the law enforcement body.	*port checks, but boat owners earn the most at the landing sites*" Fisher: "*There is no requirement of any reporting the shark catch"*	sustainable products (substitutes) - Performance-based rewards, alternatives or compensation -Punitive measures in combination to other actions -Influence for changing normative behaviour	Clayton, 2002; Shiffman & Hammerschlag, 2016; Van Riel et al., 2015; Sánchez et al., 2020	heterogeneity in motivations of all actors except of international consumers. However, some uncertainty remains as normative/legitimacy-based motivations couldn't be assessed.
Access	Traders are the greatest benefit taking actors in the high-value fin trade. They have diverse access mechanisms (e.g. access to market, financial resources, organisation, knowledge, syndicate participation and price-fixing). Intermediaries have access to all exclusive shark trades depending on where they operate (landing sites or processing centres of	Trader: "*I have connections with international agents and buyers and thus I know about the pricing and demand. None can buy so much of sharks if not financially capable"*	-Access and incentives for a better reporting system at landing sites and on board -Provide market information through information centres at the landing sites/trading hubs -Incentivise low access fishers to organise into cooperatives -Access to better financial mechanisms/ reducing income inequalities	Döring, 2001; Haque & Spaet, 2021; Haque et al., 2022; Wamukota et al., 2014; Oyanedel et al., 2021; Purcell et al., 2017; Amarasinghe et al., 2017; Digal & Placencia, 2017; Wandel &	**Medium /Low-** responses from the interviewees were not directly about the access mechanisms for each component of the analysis. However, they were evaluated from questions asked about their socio-ecological aspects

		different regions). They are the links/middlemen between the exclusive traders and the fishers/boat owners. Fishers are just the minimal price takers from the landing site middlemen or traders.	Trader: *"I keep connection with traders and suppliers from other regions to keep the supply going"*	-Trainings and long-term education regarding legality and capacity building	Smithers; 2000; Patel, 2001	and power hierarchy in the fishing and trading industry.
Inter-actor	Supply chain structure	The supply of elasmobranchs to the market is unreported and unregulated. All high-value fins are exported through a limited number of traders. Intermediaries connects traders with fishers. Currently all products are exported through the SE region. No alternative pathways could be found.		-Licensing, taxation & ensuing revenue requirements -Ensuring direct sale links after distinguishing protected species from unprotected ones	Oyanedel et al., 2021; Sodik, 2009; Finkbeiner et al., 2017	**Low-** Several workshops were conducted and actors were asked to map the supply chain of the products in question.
	Competition dynamics dimension	Highly connected actors trade on high-value fins. Responses were consistent in indicating that the number of traders in the region is somewhat fixed, with highly saturated markets, making the trader component an		-Breaking the disproportionate power of boat-owners and traders -Permit introduction with details of acceptable catch/size/gear limits (for sustainable species through scientific analysis)	Finkbeiner et al., 2017; Haque et al., 2022; Shiffman & Hammerschlag; 2016	**High/ Medium -** Responses from informants were consistent in identifying traders as an oligopoly and fishers' as perfect competition.

		oligopoly (a few actors control the fin trade currently). Fishers seems to have a perfect competition (no barriers for fishers to enter the market).				However, we could not characterise all traders to the fullest as vendors were not characterised within this study in this regard.
Market	Quantity and price determinants	Size, seasonality and recent enforcement affected the supply. Price can fluctuate depending on the quantity landed, with price falling if the landing increases. Fishers also mentioned that, if the landing of hilsa (*Tenualosa ilisha*) increases then the landing of elasmobranchs decreases, though this was not econometrically tested. Supply significantly diminishes during the marine fishery ban period in June- July and October.	Fisher: "*the price is highest for large sized sharks especially sawfish, guitarfish etc.*" Trader: "*price sometimes increases in the religious festivals in Myanmar*" Trader: "*If the landing is too low the price decreases as no trader wants to*	-Increased access to hilsa if bycatch is mitigated and sustainable -Further studies are needed for specific recommendations	e.g., McNamara et al., 2019	**High-** Different datasets were looked at to estimate components of this dimension. It could not be ensured if these data were collected in a standardised way or was biased towards locations and species**.** This analysis could not consider un-reported supply, so there is high uncertainty

		keep small number of sharks for long and the export cost would be too high"			regarding the price and quantity determinant of the unreported supply
Supply-demand dynamic	The market was found to be mostly supply-driven. Most fishers act independent of price signals. However, exception may occur in target ray fishers.	Fishers: "*We can never know what are going to be caught in our nets, we cannot control the catch, nor any bycatch mitigation strategy was shared with us"*	-Reduce fisher's reliance on target fishery /sustainable livelihoods -Bycatch mitigation strategies - Provide more efficient market for sustainable products enabling better livelihood options/income diversification	Kasperskia & Holland, 2012; McNamara et al., 2016; Wright et al., 2016	**Medium /Low -** Both bycatch and target fisheries were identified partaking in this market. All high-value fin yielding species were looked into separately and incorporated in identifying the market dynamics. There is uncertainty in this characterisation of the market as the study could not assess the international

					consumers' or buyer's behaviours.
Legal/ illegal interaction	Legal and illegal high-value fins are indistinguishable in the landing sites, processing centres and can be sold/exported through the same channels. Almost 100% unreported trade has been encountered. Absence of a coherent reporting system motivated actors not to report on high-value fin trade irrespective of protected or unprotected. Emerging corruption is also an issue.	Trader: *"how do we differentiate which shark is protected and which one is not?"* Intermediary: *"we can identify many sharks and rays, but I have never got any training on which one is protected"*	- Strengthening port checking, customs officials, border guards and coast guards (trainings); provide mechanisms to differentiate legal and illegal products (forensic tools) and initiating on-board and landing site monitoring system. -Awareness about the legality issues -Ensuring transparency in enforcement of the law (fighting corruption and bribery) -Improving traceability of the products in the supply chain	Haque & Spaet, 2021; Haque et al. 2021b, c,d; Haque et al., 2022; Shea & To, 2017; Dharmadi et al., 2015; Magnussen et al., 2007; Cardeñosa et al., 2018; Ogden, 2008; Hanich & Tsamenyi, 2009; Hinsley et al., 2016; Roberts & Hinsley, 2020	**Medium /Low -** The amount of trade on only fins from all traded products could not be distinguished to estimate the unreported and illegal traded amount. However, qualitative understanding of these trade was adequately evaluated.

5.2.4.2. Inter-actor level analysis

Interviews were used to analyse how the actors operate within the market, using two dimensions:

i) *Supply-chain structure* - configures how products, information, and capital travels through the entire supply chain.
ii) *Competition dynamics dimension* - evaluates interactions between actors and type of competition. Competition is characterised as a) perfect competition (when several actors participate in a market, no particular actor has any disproportionate power of control on supply or demand), b) oligopoly (when a few powerful actors control the market by reducing competition), c) monopsony (a market circumstance where there is just one buyer) or d) monopoly (when one actor supplies the product in question and has full control of the market) (Table S5.1 and glossary in Table S5.2).

The transactional interaction of elasmobranch products within all actors was modelled and visualizations were created graphically. The overall aim of the graphical representation was to provide an overview of the whole network of actors, focusing on the major actors playing critical roles at the national level by a high number of social ties, transactions made, and thus controlling international trade.

5.2.4.3. Market level analysis

Interviews and literature review were used to conduct market level analysis for three different dimensions:

i) *Overarching market dynamic dimension* - determines if the market is supply-driven (suppliers partake in the market independent of price signals) or demand-driven (suppliers respond to price signals by changing the amount of supply). These factors were analysed using only interviews;
ii) *Quantity dimension* - identifies different factors that influence the quantity and price of the supplied and demanded products. The factors determining price were qualitatively evaluated.
iii) *Legal/illegal interaction dimension* - the occurrence and impact of illegal products and their trade on the market dynamics were analysed.

As consumers and vendors were not included in the study, this brought some uncertainty to the market analysis (assessed and presented in the results). However, following McNamara et al. (2016), the market was defined from the information gathered from suppliers (see section 5.3.3.1).

5.3. Results

We identified 34 different actors (Table S5.6) in different regions involved in the elasmobranch fin trade and found different motivation and access mechanisms (see sections 5.3.1.1 and 5.3.1.2) using interviews and field surveys at processing centres. For instance, traders (high access) exclusively or opportunistically traded on fins and sold to vendors, whereas intermediaries (low access) facilitated the sale from the harvesters (low access fishers) to traders.

5.3.1. Actor level analysis

Using typology construction, we identified seven actor-types (Table 5.2) from all actors (Table S5.6), based on shared attributes (Table S5.9).

5.3.1.1. Motivations

Motivations were aligned differently for low value and high-value species (Table 5.3 & S5.10). Traders were motivated by high monetary reward as fins were more expensive than many other fishery products at the market. For traders, motivation to trade in products was sometimes tied to rarity (e.g., sawfish) but primarily to higher prices depending on fin size (anterior margin) and sometimes species (e.g., hammerhead sharks, guitarfishes). No legitimacy based (motivated to comply with a regulation) or normative (motivated by social and personal norms) motivations to trade in high-value fins, were reported by traders. More detailed interviews revealed a general unwillingness to report such trade to avoid detection from the law enforcement bodies and absence of any reporting mechanism. Unwillingness to report catch was motivated by several reasons (see Table S5.7), including distrust with managers. Recently, several incidents have occurred where punitive measures (e.g., jail time, fines, seizures) were taken to mitigate trade. However, the fishers involved needed more clarity about species protection and the processes of adhering to this regulation, especially as there has yet to be a bycatch mitigation strategy in place. As a result, there was distrust between fishers and managers in some regions. If the fishers trusted the fishery managers enough and believed management would provide help to them, reporting catch or trade would be easier for them. Intermediaries and fishers mentioned they were similarly motivated, although sometimes influenced by normative motivations for sawfish fins and meat, cartilages of sharks and guitarfishes (e.g., personal and social norms of believing in their disease-curing properties). Target ray fishers' motivations were instrumental (motivated by a higher price; however, supply quantities could not be set beforehand). Fishers' instrumental motivations were driven by poverty, lack of social security and adequate livelihoods; however, benefits gained were comparatively lower than traders, as stated by the fishers.

5.3.1.2. Access

According to the fishers, the traders are the most significant economic beneficiaries of the high-value fin trade, and boat-owners are the price takers for whole-bodied specimens at the landing sites (Table 5.3 and S5.7) (with some exceptions, e.g., some fishers get to keep the prices of any bycatch in some region). In contrast, the traders identified the end of chain vendors (not added in this study) as the most significant economic beneficiaries. Traders from south-east (SE) Bangladesh dominate international trade and use various mechanisms to access and maintain benefits from trade (e.g., access to national and international vendors, export routes, information regarding the international market, demand and price, availability of financial resources, and national demand information) (Table S5.7). Traders obtain high catches by employing intermediaries at landing sites and establishing relationships with harvesters (Type III, i.e. boat owners, see Table 5.2). Furthermore, traders are organized, with associations that support greater opportunities for potential collusive price-fixing. However, intermediaries and fishers identified that they had limited access. Intermediaries are primarily controlled by the traders who share some of these access mechanisms. Fishers had limited selling positions and low access to finances or information (sometimes driven by low literacy rates), further constrained by their debt-driven relationships with boat owners (Table S5.7).

5.3.2. Inter-actor level analysis

5.3.2.1. Supply-chain structure

Interview results showed the supply-chain of fins is constrained at the traders' level. At least six traders (33% of interviewees) reported landing elasmobranchs at informal sites to bypass monitoring. Interviewed traders and fishers found trading straightforward, but mentioned that recent acts of enforcement (e.g., sudden seizures) and corruption led to unwillingness to report fin trade to avoid detection. While a high number of fishers and intermediaries partake in the shark trade market, most supply goes through a limited number of traders, especially exports (Table S5.7). This creates a bottleneck that controls the supply chain routes at national and international scales meaning the market is dependent on a limited number of traders. Traders exported high-value fins predominantly to Myanmar via Teknaf (SE region), through ports or sometimes personally-owned fishing vessels. While this is the dominant supply chain, we also identified supply chains created through opportunistic traders and online marketplaces that source products from the same landing sites, intermediaries or traders locally in the SE region (Table S5.7).

Traders from the SE region (TSE) of Bangladesh were found to be the most prominent actors in the elasmobranch trade, maintaining the highest number of transactional connections with other national and international actors. Some of these traders were members of the shark traders' association that has some control over the sale of sharks and rays at the landing site. The landing sites in the SE region are the most prominent, landing high volume catches, including high-value fins and from other regions, and with traders' involvement. Most connections were unilateral from the seller to the buyer; however, traders also have bi-lateral relations, trading elasmobranch products with each other (Figure 5.3).

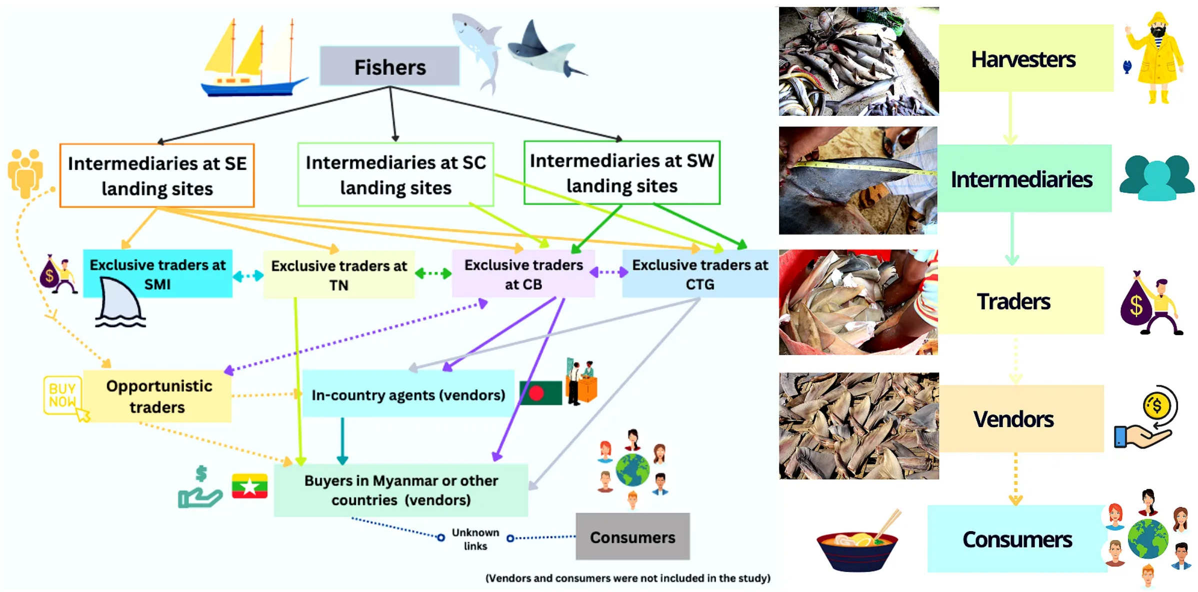


Figure 5.3. Simplified version of the network of actors involved in elasmobranch catch and trade in different levels (this shows only the major supply-chain transactions). The directed lines (arrows) show the direction of supply chain (supplier to receiver of products), bilateral arrows mean that both actors have sold and bought elasmobranchs or products from each other at some point of their business career. The different colours identify the 'exclusive traders' (Type IV) from different geographical areas. Here, SC= south-central, SE= south-

eastern, SW= south-western, SMI= St. Martin's Island, TN= Teknaf, CB= Cox's Bazar and CTG= Chattogram.

5.3.2.2. Competition dynamics dimension

Interviewees described the market structure at the trader level as an oligopoly (Table S5.2). Other key aspects from the interviews that are relevant to competition dynamics indication that traders can prevent new entries to the market through coordination with the shark traders in the SE region using organised social connections with boat owners and intermediaries. However, according to a former chair of the shark traders' association, the market is already saturated, with several traders leaving for other livelihood options (Table S5.7) and they had not stopped new entries. Oligopoly also exists at the intermediaries' level, although there are no high entry barriers for new actors. At the fisher level, the market structure is at perfect competition (Table S5.6). According to the fishers, there are no barriers for fishers to enter the market (however, they need to find the finances for a boat, gears), as no permit is needed for elasmobranch catches, and no quota was being enforced at the time of the research. The interviewed fishers identified a disproportionate power hierarchy amongst the boat owners and fishers due to debt-driven fishing practices (see Haque et al., 2022a) with a number of fisher cooperatives with limited influential market power. Overall it appears that all fishers in the region may catch elasmobranchs as bycatch regardless of their target species. In addition, many fishers target rays, including those with high-value fins such as guitarfishes, with little competition.

5.3.3. Market level analysis

5.3.3.1. Supply-demand dynamic dimension

Traders stated that demand depends on species availability at the market resulting in supply-driven processes dominating overarching market dynamics. Traders indicated some species had higher prices (e.g., guitarfishes, large rays) and were heavily targeted. The traders we interviewed did not have any prior demand set for the fishers in terms of supplying the market with any particular amount for any particular species. However, anecdotal information from informal conversations with traders unveiled a possible high demand period during the religious festivities in Myanmar. Field observations (Table S5.2) suggested fishers supply whatever they catch, independent of demand. Fishers indicated that their behaviour was independent of price signals generated by the market, except for very high-priced species (e.g., sawfish, guitarfishes). For instance, target fishers may respond to the increasing price of elasmobranchs by exerting greater efforts at sea (species-dependent). However, fishers also emphasized that, given the declining catch rate of many target fish species, efforts are increasing which may be a general response to lower catches rather than the higher prices. The target ray fishery has increased over time to diversify fishery practices (e.g., seasonal variation, multi-species fishing practice) according to the fishers. A fisher stated, "*the catch has plummeted to the point that we may not catch any rays in a seven-day expedition, but if luck is on our side, we may catch a good number of rays occasionally. If the catch is low, we stay at sea for longer to make up for the debt we have already taken from the boat owner*." Although increasing efforts, increasing price and declining populations can be independent of each other, it was beyond the capacity of the paper to quantitatively analyse this. The quantity and species caught is also supply-driven, as fishers mentioned, catch cannot be determined *a priori* and no indication of increasing efforts to increase bycatch was found in the interviews.

5.3.3.2. Quantity and price determinants dimension

Interview results demonstrated that prices are set at the landing sites, mostly by intermediaries but directed by traders. One trader stated, "*sometimes fishers would ask for a very high price without knowing the international price signals, however, at the end they sell at a price fixed by the negotiation of the intermediaries, boat owners or sometimes fishers themselves*". However, export prices are set by international buyers and vendors. Most fishers know the overall price per kg for different species, with some pre-selling their catch (e.g. fishers take debts from boat owners and thus the catch mostly belongs to the debt giver).

Interviews indicated that the prices of high-value fins are dependent on their size followed by species (Table S5.7). According to the intermediaries, prices can fluctuate depending on the quantity landed. For example, prices sometimes fall if the landing increases. Although if the landing amount is negligible, this may also result in prices falling. However, for large-sized fins prices always remained high. One trader mentioned that "*if the landing is too low no one wants to buy as it would not cover the cost of drying, contacting a buyer to transport it and as a result the price falls; whereas if the landing is high for desired species the price then can be increased through an auction*". Fishers also mentioned that if the landing of the highly targeted and high value species hilsa (*Tenualosa ilisha*) increases then the landing of elasmobranchs decreases, though this was not econometrically tested. Supply significantly diminishes during the marine fishery ban period in June, July and October (Table S5.7), however, preservation of high-value fins enables supply to be maintained throughout. The literature review showed that although fishers got lower prices for the whole body of sharks, if the fin size was large enough, then price increased. For fins the high price is reflected in both the buying price (up to US$350 per kg depending on the size) attained in the landing sites and the selling price (up to US$1,182 for a set of four fins >50 cm) in international markets (Hasan et al., 2017; Haque et al., 2021b; Haque & Spaet, 2021). For instance, fins of guitarfishes were the most expensive, with selling prices ranging from US$4.73–18.92 (fin 15.24 cm) per kg and US$ 8.28–23.65 (fin 20–26 cm) per kg (Haque et al. 2021b). The price increased significantly between buying at the landing sites to exporting the fins (Hoq et al., 2011; Hasan et al., 2017; Haque & Spaet, 2021) for example: a large shark (>300kg) can be bought at the landing site at US$3.75 whereas the set of fins may be exported for US$350 and meat for US$6-10 per kg.

5.3.3.3. Legal/illegal interaction dimension

Traders accurately asserted that no permit or license is currently required for elasmobranch trade (correct at the time of this study, in October 2021). However, traders traded under the license and paid tax for general fishing products to justify international export. Several traders also reported employing fishing vessels for this trade to avoid customs-related regulations (Table S5.7). The literature review (Table S5.4) and field observations demonstrated that legal and illegal products are all traded together (Figure 5.4). The confusion arose as some species were legal to trade nationally but illegal when traded internationally (the Convention on International Trade in Endangered Species of Wild Fauna and Flora, CITES species) at the time of the study. Fishing and trading on threatened (by the International Union for Conservation of Nature- IUCN Red List of threatened species) and CITES-listed species but not protected by national law were not illegal until October 2021, after which the law was amended. The legality of species-specific elasmobranch catches and trade was unclear to fishers and traders (evident from interviews and literature, Table S5.4 & S5.7). A leader in traders' community stated, "*we do not know which species are prohibited to catch and which are not. I am assuming all cannot be protected and If so we have not been trained about it*".

The proportion of unreported and illegal trade could not be quantified due to a lack of segregated data for both protected and unprotected species in the fin trade found in literature or national accounting system. Traders reported not providing information to any Government accounting system on high-value fin trade between the 1960s to date. Interviewed fishery officials suggested that non-reporting may remain in the absence of advanced monitoring mechanisms and within an umbrella ban (Table S5.7).

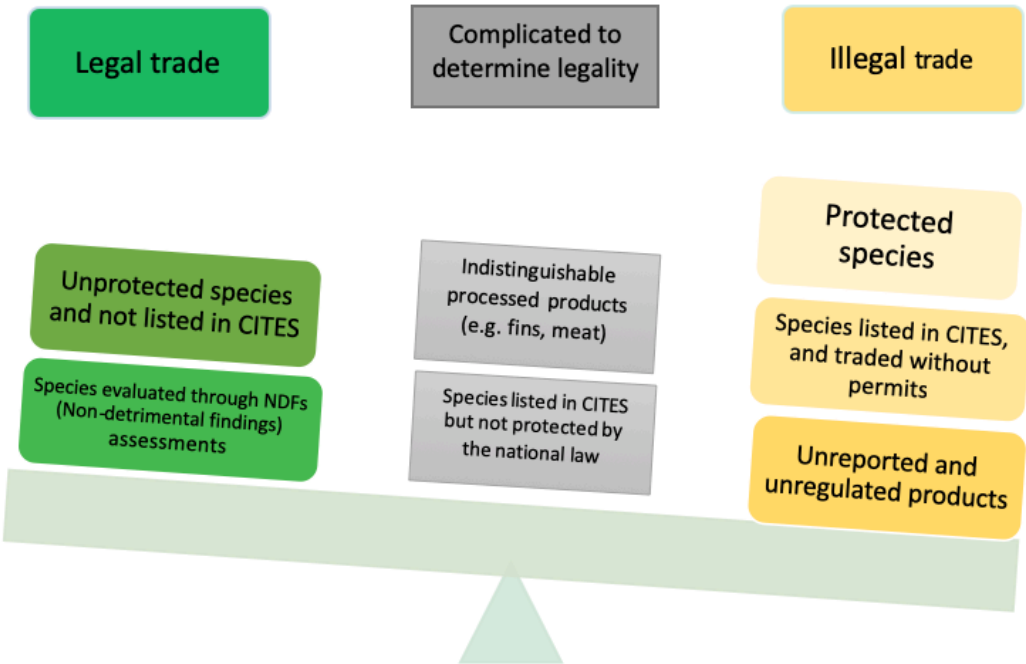


Figure 5.4. Legality dimensions of the elasmobranch trade in Bangladesh. Here, the green boxes define the activities relating to trade on species in question as legal (e.g., species not protected, not listed in CITES or if listed in CITES, then non-detrimental findings (NDFs) allow export (NDF is a species-specific science-based evaluation that determines whether or not a potential export is harmful to the species' preservation)). The grey boxes define where distinguishing legality becomes challenging (e.g., when the specimen is de-finned and processed, and there is no expert or forensic tool to identify if it is a protected species or not or species which are listed in CITES or CMS; however, no NDF is performed or not protected by the national law). As there is ambiguous clarity regarding existing regulations, especially how to adhere to them amongst fishers and traders, the legality issues are contested. The yellow boxes indicate illegal activities (e.g., trade on protected species, CITES-listed species without proper permits, or unreported and unregulated catch and trade).

5.4. Integrating evidence to identify market interventions

We identified actors partaking in the fin trade and observed complex elasmobranch market dynamics and intricacies in our study (e.g., a supply-driven market where traders are the most dominant actors, complex trade mechanisms, organized actors' network, limited access of harvesters, persistent legality issues). Actors adjust to changing market conditions based on their access to finances, influence, or social relationships (e.g., potential stock-piling, changing landing locations and trade routes, selling from the boat without landing at formal landing sites in response to increased enforcement; increasing efforts in response to declining catch by target ray fishers). Different actors had different access and motivations and thus requirements to adhere to long-term measures to enhance elasmobranch capture and trade reporting and mitigate unsustainable trade. For instance, low access fishers need positive incentives and financial mechanisms to change behaviours, generate and maintain adequate and sustainable livelihoods, and bycatch mitigation strategies to mitigate catch. In contrast, traders might require opportunities and facilities to change business models towards more sustainable practices. Negative incentives are also needed to disincentivize actors to trade unsustainably, but this needs an implementation phase so that time is given for an opportunity to change practices. Our findings show that the high-value fin market is supply-driven, implying that supply-side measures are more likely to succeed to mitigate unsustainable trade on elasmobranch fins. We propose supply-side interventions (based on published evidence) that lead to potential increased adaptive benefits for all actors. These interventions were prepared at each analytical level are summarized in Table 3 and Figure 5.5 and discussed below (section 5.5.1).

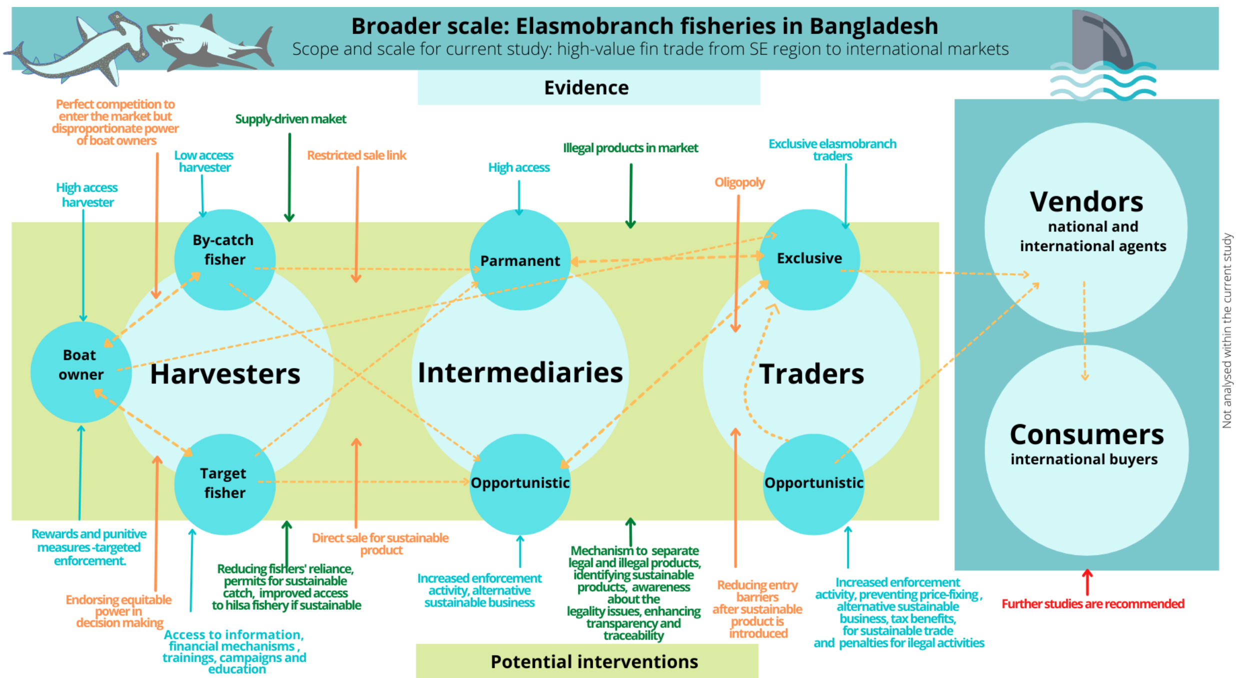


Figure 5.5. Intervention map for reducing unsustainable trade in high-value fins within Bangladeshi elasmobranch fishery. Here, the blue circles indicate actors within the Bangladeshi elasmobranch fishery and trade, and the orange lines indicate their interactions.

The green box shows the market encompassing all actors and interactions. The evidence section shows the key characteristics of each analytical level (actor, inter-actor and market) in different colours, and the potential intervention section shows the recommended interventions relating to each market characteristic and corresponding to the characteristics of the evidence section in the same colour.

5.5. Discussion

5.5.1. Proposed interventions to improve elasmobranch market sustainability

5.5.1.1. Actor level interventions

The small-scale fishers in Bangladesh are amongst the most geographically, socially, and economically vulnerable communities (Islam et al., 2014). Thus, the capacity to implement management actions is limited by a lack of ability and subsequent willingness to absorb short-term expenses (Carbonetti et al., 2014; Brown et al., 2015), creating barriers to compliance (McClenachan et al., 2012). Local management, therefore, needs to be positively incentivized to offset the cost of enforcement (Bulte et al., 2003; Child, 2012; Biggs et al., 2013; Di Minin et al., 2014; Cooney et al., 2015; Haque et al., 2022). Implementing improved allocation of benefits from sustainable stock, developing species/taxon-specific harvestable quotas depending on biological sustainability (Squires et al., 1998), and more robust financial arrangements to keep fishers' profits afloat may improve compliance with regulations.

Furthermore, enabling long-term investments is essential (Hilborn & Parrish, 2005) to increase fishers' capacity to fish sustainably. Long-term investments can aid in generating alternative fisheries products (e.g., seaweed, oysters) (Hossain et al., 2013; Sarkar et al., 2016; Islam et al., 2017) and provide training and education for best practices at sea. Investments can also be used to provide technical facilities to mitigate bycatch (Osuka et al., 2021) and a balanced market where fishers can sell responsibly obtained catch at a higher price. Fishers' ability to comply is also hampered by limited access to market information (e.g., price, demand). This may be improved through alternative platforms that shorten the supply chain, communication (e.g., information/knowledge centres, dedicated fishery officers) and market access (Gaonkar & Viswanadham, 2007; González-Mon et al., 2019).

It is imperative to remember that information or training alone does not equate to adopting sustainable behaviour of fishers; hence long-term commitment through education is needed

(Digal & Placencia, 2017; Wandel & Smithers, 2000). Many fishers may have been pressured into non-compliance as they worked for boat owners and have over-reliance on traders to sell their catch, limiting their ability to undertake pro-conservation behaviour. Increasing access to equitable governance and regulatory decision-making through organized customary bodies can be critical for fishers in reducing their reliance on other actors (Haque et al., 2022). Enhanced access may promote compliance by strengthening fishers' agency (Oyanedel et al., 2020a, b), improving their ability to derive benefits (Ribot, 1998; Ribot & Peluso, 2003) from sustainable fishing and shift that to the most vulnerable in the system (Haque et al., 2022).

Traders have more access mechanisms than those used by fishers to benefit from the system. Therefore, traders need specific interventions; however, several interventions proposed for fishers are also applicable for traders. For traders, targeted law enforcement and prevention of over-access to the fishery benefits would help promote sustainability (Haque et al., 2022). A limited number of traders had disproportionate market control, with the financial capacity and international ties to trade in high-value fins. Such control can exacerbate the problems if trader motivations are not aligned with long-term sustainable management (Oyanedel et al., 2021a). In Bangladesh it was evident that circumventing wildlife trade restrictions is typically described as high-profit, and low-risk (Haque & Spaet, 2021d), like many other regions (Goncalves et al., 2012; Wyatt & Cao, 2015). To enhance trade control mechanisms, trader behavioural change is needed (Wallen & Daut, 2018) together with the implementation of an effective monitoring and reporting mechanism, with both positive and negative incentives. Positive incentives, such as rewards or tax benefits, for sustainable trade and negative incentives, such as penalties, could also be introduced to promote trade mitigation. Promoting certification for legal products may be of help (Newing, 2010; Jouffray et al., 2019). Although 'legal products' need to be carefully defined.

The combination of solutions needs to be co-designed with the actors meaningfully involved, and tested, implemented and appropriately adapted in order to maximise the chance of successful implementation (Haque & Spaet, 2021d; Haque et al., 2022). Otherwise, just the prohibition of elasmobranch species captures and trade may be insufficient.

5.5.1.2. Supply-chain interventions

Within inter-actor level interventions, short and well-monitored supply chains can be beneficial by encouraging direct means of sustainable trade benefitting fishers. Supply chains can be shortened by issuing permits with strict regulations on open access to resources (Purcell et al., 2017; Ribot, 1998). Authorised permits such as fishing licences with log-book records for both target species and catch quotas to trade in fishery products will help monitoring. Rigorous annual checks of permit use may help support legal trade. Improving supply chain monitoring has significant global implications, despite the complex characteristics of the elasmobranch trade. In the absence of catch monitoring regimes, monitoring these markets may be the greatest option for understanding global shark exploitation levels and species pressures (e.g., Clarke et al., 2006; Clarke, 2008; Shea & To, 2017). For instance, Clarke et al. (2006) reported that quantitative stock assessments are typically hindered by the lack of comprehensive, specie's-specific catch data, both locally and globally. In such cases, trade studies can reveal insights into exploitation that landing site monitoring cannot.

5.5.1.3. Resolving legality issues

Actors were unclear on the legality due to limited meaningful awareness campaigns and consultation (Haque et al., 2021b, c). Limited clarity regarding species protection status did not impact trade from the traders' perspective as they trade on all species. However, it was problematic from the monitoring and enforcement angle (e.g., seizures). Challenges in distinguishing protected elasmobranch species at landing sites exacerbate the issue, with identification being problematic for untrained people, especially for products (e.g., meat) without genetic analysis. Consequently, all fins are packaged together for export and registered in the traders' register books as 'fins' or 'fishery product' and 'fishery products/ fins and fish maw' (DoF, 2019) in the national accounting system. It is crucial to ensure that protected species (illegal) are distinguished from un-protected species (legal) when they are landed whole and when the fins are removed at the processing centres, ports, and markets. One solution is to introduce forensic tools at checkpoints (Ogden, 2008; Cardeñosa et al., 2018). Relevant officials can achieve species identification skills by training, information centres, or installing advanced tools on-board and at landing sites, such as digital monitoring and genetic tools (Shivji et al., 2005; Clarke et al., 2006; Chapman et al., 2009). Improved monitoring with a price premium for legal products may encourage sustainability (Roheim et al., 2011; Sánchez et al., 2020).

Some corruption is evident, although there are no organized crime networks for fin trade in Bangladesh. Generally, for high-value species, illegal trafficking is frequently assisted by organized networks, high levels of corruption (Wyler & Sheikh, 2013) and significant global revenue. Corruption among government officials responsible for enforcing legislation is a significant factor in enabling illegal trade (Bennett, 2015; Smith et al., 2015; Brown, 2017) and precursor to conflict between actors and managers. Efficient governance is necessary, within which corruption is alleviated through increased transparency and accountability from policymakers and enforcers, and a relationship of trust is built. Only punitive measures without enabling actors to adhere to law or promoting sustainable catches, have increased conflict and scepticism on the part of traders and fishers regarding the effectiveness of laws and motives of fishery managers. This has also exacerbated traders' fear of detection and subsequently reduced willingness to report catch and trade (Haque et al., 2022a). Traders are adapting to this situation by changing elasmobranch landing and sale locations (Haque unpubl. data, 2022) which is a common tactic (e.g., Milner-Gulland & Clayton, 2002) to by-pass enforcement activities.

In many nations, including Bangladesh, legal enforcement occurs at the market end of the trade chain; for instance, customs agencies or port authorities are usually in charge of goods management along the supply chain for international trade. These authorities tend to have minimal expertise in wildlife management (Bennett, 2011). It is crucial to train the proper authorities throughout the supply chain in illegal trade monitoring (Haque & Spaet, 2021). Recently, greater focus has been placed on law-making and CITES requirements at higher levels (e.g., policymakers, custom authorities) to deal with illegal trade in Bangladesh (Haque unpubl. data, 2022). However, this does not solve the problem of reducing the supply of the product. While law-making and regulations are required, it is essential to mitigate supplies and monitor at a more local level, intervening with actor-specific market solutions.

5.5.2. Prioritisation and application in the wider context

We recognize that it will be challenging to accomplish all the recommended interventions within Bangladesh's existing socio-ecological, institutional, and political context. The capacity to manage legal suppliers and regulate illegal ones highly depends on the management system, including its efficacy and available resources. Intervening in systems with institutional frameworks that require improvements, such as Bangladesh's, is challenging, and the realities of the situation must be considered throughout. We suggest setting realistic, time-bound priorities that can be met, even if these are not the perfect solutions on paper. This does not obviate the need for long-term, more ambitious and impactful solutions; instead, achievable short-term gains should also be prioritized, paving the way for long-term solutions. More specifically, we propose a *'lag phase'* approach in the application of current legislation for fishers and traders to adjust their practises before stringent measures are enacted to avoid criminalizing fishers using traditional methods. That way, actors' capacity to adhere to such a law can be assessed during this *lag phase* (including seeking feedback from the actors, barrier assessments, and incentives needed), and this information can help facilitate effective compliance in the long term. This can also help build a trusted relationship between actors and managers. Failing to do so may result in the ineffectiveness of the law and continued overfishing. In the short-term, access to more sustainable alternative fishery products to fins, local institutional capacity building for co-designed policies, interim incentives for adopting best practices at sea and educational training can be provided. Finding common goals for synergistic outcomes toward sustainable and ethical trade through the organized and meaningful participation of fishers in decision-making can be achieved in the longer term (Haque et al., 2022a). For instance, the existing rules and payments for ecosystem services (PES) (Mohammed & Wahab, 2013; Wahab et al., 2013; Bladon et al., 2016; Islam et al., 2016) could be improved and made incorporated to compliment the management of elasmobranch capture in Bangladesh while avoiding imposing too many regulations on the same actors. Here we do not recommend more stringent regulations but more appropriate regulations co-designed and co-managed with the actors involved.

Such nuanced and empirical understanding regarding markets and actors to inform policies at the local and regional levels has significant implications for addressing global unsustainable trade issues. Achieving global priorities (e.g., Sustainable Development Goals-SGDs, the Convention on Biological Diversity- CBD, the CITES mandates) without local, national and regional commitments and capacity is unrealistic. A highly efficient management regime that maintains a well-balanced and well-monitored market with sustainable trade needs knowledge, transparency and thorough planning with time-bound goals. This methodology can be implemented flexibly in characterizing the elasmobranch fin and meat trade to inform and guide global attention in prioritizing local and regional needs.

5.5.3. Future directions and limitations

It is necessary for researchers and managers to consider the interconnectedness of different fisheries operating in the same area (e.g., spatial overlaps, cumulative threats, different supply chains) prior to proposing interventions to avoid competing or conflicting actions. The price fluctuations of target species may also impact the demand and catch of the bycaught elasmobranchs. A cross-elasticity analysis (which quantifies the responsiveness in quantity demanded of one product when the price changes of another related product) can be used to evaluate the impacts (McNamara et al., 2019).

Furthermore, the same actors may participate in more than one type of fishery and trade (e.g., seasonal fishers, fish trades) making them either beneficiaries or cost-payers of the several management actions with different goals/projects. Therefore, it may help to find a common goal serving synergistic outcomes of several fishery related problems in the relevant region. As a result, the methodology might be more beneficial with another layer of analysis (e.g., *feasibility*) that assesses the influences of such fisheries and actors participating in multiple practices, motivations, and their impact on the sustainability problem while designing solutions. ***The feasibility layer*** can also evaluate the – i) *acceptability* (by the actors), ii) *achievability* (by the mangers), iii) *appropriateness* (in the social, geographic and cultural context of the fishery), iv) *viability* (resources availability to implement and political will/national agenda), and v) *congruity* (harmonization with other existing management actions for resource-effective solutions) of the proposed actions which have been collated from published literature, the research of which may not have been conducted in the same region or fishery. For instance, a fishery harvesting the maximum sustainable yield for one commercial species can still have significant bycatch (e.g., hilsa fishery in Bangladesh, Haque et al., 2021a). To truly identify a sustainable alternative fishery product (as suggested in this study in Table 5.3), it is cardinal to evaluate the true impact of that product/fishery on elasmobranchs.

In the Bangladeshi elasmobranch fishery, there is evidence of emerging underground trade in response to enforcement. To halt such activities a profound grasp of the system is needed, requiring future in-depth research (e.g., social and economic cost of legislations on actors involved, application methods of science-based legislative and social actions at scale, consumer demand). Making trade illegal and enabling sustainable trade are two techniques adopted to preserve and protect threatened species (Bennett et al., 2021). It was beyond the scope of this study to determine the effectiveness of a no-trade policy or permitting species-specific legal trade in conserving the Bay of Bengal's elasmobranch populations. Further research is needed to understand the species' biological resilience towards sustainable catch and trade so as to recommend a species-specific trade ban or catchable quota. Our study was unable to analyse the access and motives of international consumers; nonetheless, there were signs that the potential increased demand may be matched by supplying from stored/stockpiled products. It is important to remember that consumer preferences, the availability of suitable alternatives, and the available wealth may all impact the supply of a certain product (Bennett et al., 2021). For a thorough picture of the supply-chain structure, more research is needed on the consumer and vendors.

The absence of an on-ground monitoring mechanism made it challenging to understand the true motivations of the actors' partaking in the unreported and illegal trade, as a result the uncertainly remains somewhat high. Only when an appropriate monitoring regime is in place and facilitation is given to actors to adhere to it, then we will be able to evaluate the true motivations for non-compliance towards the reporting regulations. Improving national scale data collection through monitoring and utilising different methods to analyse each analytical level will help improve the value and effectiveness of the framework in the future.

5.6. Conclusion

Our study used the Oyanedel et al. (2021a) framework to guide data collection from three data sources and applied these to characterise the high-value elasmobranch fin market operating within Bangladesh for national and international trade. Our research has become even more relevant since Bangladesh's national legislation was amended in October 2021 to protect most elasmobranch species, with strict regulations on their capture and trading. Bangladesh has pledged to safeguard elasmobranchs by legal measures and adopting a national action plan. There is now a timely opportunity to disseminate our recommendations to help with the effective implementation of the new legislation. Our work has both regional and global significance because of the major role of global south countries in elasmobranch trade. Our findings provide important insights into the local origin of traded elasmobranch products. The interventions we recommend have the potential to help mitigate and manage elasmobranch product trade if implemented. Therefore, global conservation priorities must be tailored for local and regional contexts, and resources should be directed to tackle local and regional needs.

CHAPTER SIX: Area of Exposure

6. Area of exposure- 3D mapping of Critically Endangered shark and ray overlap with fisheries in the Bay of Bengal

Fishers in science– fishers of Bangladesh ©SOSF/Oliver Deppert

Abstract

Overfishing has devastated shark and ray populations worldwide. Efforts to address this issue are hindered partly due to a lack of understanding of fishing patterns in key areas like the Bay of Bengal. Bangladesh has a dearth of data on the spatially explicit interaction between fisheries and sharks and rays, limiting effective management. Using a novel assessment technique to highlight the most appropriate spatial and temporal management units for fisheries interacting with sharks and rays, we analyzed socio-ecological and species distribution data and identified areas where Critically Endangered sharks and rays are at risk from fishing activities. This study is the first to map these species' spatially detailed fishing footprints and risk assessments in Bangladeshi artisanal fisheries. Our findings show that most southwestern and south-central shallow waters are exposed to cumulative fishing pressure. Different fisheries operate at varying depths and locations, with artisanal gillnet fishing posing the greatest threat by using comparatively larger fishing areas. However, analysis of the 3D spatial operation of other gear types reveals that species of conservation concern are exposed to various gear types. While some refuge for deep-dwelling species exists, several of them are exposed to shallow waters while using them as nursery grounds at a juvenile or pregnant stage. Overall, there is a significant overlap between species ranges, critical habitats, and the footprint of artisanal fisheries. Spatially explicit maps, incorporating local socio-ecological knowledge, were created to address conservation and management challenges by area-based management actions in data-limited situations. This approach allows for mapping numerous fishing vessels and gathering more attribute data than traditional tracking methods by including fishing techniques, fishing depth, seasonality, gear use, and potential species interaction. We propose adaptive area-based management, which includes proactive measures to reduce species interactions with fisheries through improved management practices such as effort control, gear modifications, and incentive-based safe release. Priority should be given to specific coastal locations, high-risk species, and fisheries to promote multi-taxa conservation.

6.1. Introduction

The Bay of Bengal region of the Indian Ocean is critical for both biodiversity and fisheries worldwide. It encompasses crucial habitats, including breeding and feeding sites for various marine organisms, including Chondrichthyans (sharks, rays, and chimaeras – henceforth referred to as 'sharks and rays'). Sharks and rays play an important role in the Bay of Bengal marine ecosystem, underpinning the provision of essential ecosystem services, including sustaining the species beneath them in the food chain and acting as an indicator of the ocean's health. At the same time, this region is an important area for artisanal and commercial fishing, impacting shark and ray populations through unsustainable catch volumes (Dulvy et al., 2021; Sherman et al., 2022c). Overfishing is a significant threat in this region, with a reported decline in catches for commercial species (Ullah et al., 2014), including sharks and rays (Haque et al., 2021a; Haque et al., 2022).

Sustainable, evidence-based fisheries management is crucial for conserving sharks and rays regionally and globally, especially in the face of global overfishing (Dulvy et al., 2021). Effective management requires assessing the status and trends of the natural resources (e.g., sharks) and the drivers of threats, emphasizing the intricacies of the entire ecological system (Folke et al., 2005). This is necessary to determine which management strategies (e.g., specific area management, effort control) and where (e.g., spatiotemporal location) would lead to desired outcomes (Jones et al., 2011). Due to the paucity of species-specific and spatially explicit fisheries data, risk assessments (i.e., the risks of fishing in space and time) for sharks and rays are often qualitative rather than quantitative. Furthermore, estimating spatial fishing exposure is also difficult, particularly where no vessel monitoring system (VMS) is in place due to the high number of fishing vessels in operation (e.g., Bangladesh within the Bay of Bengal).

Risk assessments are beneficial to effectively manage data-limited stocks because they are adaptable (e.g., to data scarcity, regions, broad taxa, gear types, and habitats). Risk can be described as the likelihood of species extinction or depletion to a critical limit (biological resilience perspective) (IUCN, 2021) or the possibility that a particular fisheries management target was not met (management perspective) (Hobday et al., 2011). Risk assessments are frequently used to inform adaptive policy, including managing marine fauna (Hobday et al., 2007; Brown et al., 2013; Roberson et al., 2021).

Risk can also be estimated by identifying the 'area of exposure,' meaning areas with the highest potential of catch simply as the spatiotemporal distribution overlaps species' known range with the fishery, which can provide an understanding of the areas which are mainly exploited (e.g., susceptibility or exposure components of risk assessment in Hobday et al., 2007). These areas require immediate management measures. Identifying high-risk areas is crucial, especially now, to fulfill the targets of the Global Biodiversity Framework, agreed upon at the 2022 United Nations biodiversity summit, Conference of the Parties (CoP15). One of the twenty-three objectives of the agreement, known as 30x30, is to safeguard at least 30% of the planet's land and water by 2030.

Although formal marine protected areas and other effective area-based conservation measures (OECMs) have been the foundation of spatial conservation for decades, identifying areas with the highest effectiveness and ecological connectivity for species conservation is crucial. Ecological connectedness is frequently emphasized as a crucial component in constructing robust MPAs because it regulates the movement of individuals throughout spatially fragmented habitats. Connectivity is a vital biological mechanism in marine environments supporting population persistence and recovery through the distribution of marine life across populations, groups, and ecosystems. When designing an effective MPA, where the whole is greater than the sum of its parts, connectivity—the degree to which spatially distinct populations, communities, ecosystems, or habitats are linked by the transfer of genes, organisms, nutrients, and energy—is thought to be a crucial ecological criterion (Botsford et al., 2009; Balbar & Metaxas, 2019). We must explore how science and policy can identify these connected areas for species to thrive and how to manage a well-connected marine area.

For these protections to be most effectively applied, it is critical to identify areas most at risk for species of conservation concern. However, while there are several studies on the impacts of fisheries on teleosts (e.g., Fatema et al., 2022), data and studies on the spatiotemporal distribution of active fisheries and their fishery-specific interaction with sharks and rays are absent in Bangladesh, limiting the potential of fishery-specific spatial management.

Here, we developed a novel assessment technique highlighting the most appropriate spatial and temporal management units for fisheries interacting with sharks and rays. We present the risk to threatened sharks and rays across different gears and taxa by identifying the 'areas of exposure' in Bangladeshi waters. We completed assessments by (1) gathering primary data for fisheries footprint mapping, (2) mapping species distributions both vertically and horizontally, and (3) combining the three-dimensional (3D) fisheries footprint and species distributions to determine the 3D overlap.

6.2. Materials and methods

6.2.1. Study region and fisheries

The coastline of Bangladesh is 710 km and comprises three major regions: the Ganges tidal plain in the west, which includes the Sundarbans Reserve Forest (SRF); the Meghna deltaic plain in the southcentral region, and the Chittagong coastal plain in the east (Barua, 1991; Quader, 2010; Brammer, 2014; Brammer, 2017). Bangladeshi coastal and marine fisheries are primarily multi-species and multi-gear (Haque et al., 2022; Ullah et al., 2014) and operate over the whole coast. The fisheries cover diverse fishing methods and work over various habitats and water depths. Despite this heterogeneity, the fisheries have historically been classified into two main categories: artisanal and industrial (see details of fishery types in supporting information five App. 5.1). The artisanal fishery is further divided into informal sub-fisheries based on the gear used (i.e., gillnet fishing, set-bag nets, longline, hooks, and trammel nets (DoF, 2016; Haque et al., 2022), and captures 80% of the shark and ray Bangladesh (Ullah et al., 2014).

6.2.2. Data and data analysis

6.2.2.1. Interviews, fishery classification and participatory fishery footprint mapping

Interviews- Between January 2019 and February 2022, 1150 semi-structured (Table S5.2.6.1, Figure 6.1) interviews were conducted with Bangladeshi fishers that catch sharks and rays (target, desirable secondary catch, and/or unintentional catch). A total of 988 interviews (86% of all interviews conducted) were selected and used for fishery classification, and 162 (14%) interviews were eliminated as these were either localised describing secondary fishing practices or interviews were incomplete. A semi-structured questionnaire was prepared for fishers to evaluate: (1) fishing practises, (2) details of gear used and operational techniques, (3) spatial range of fishing operation, (4) bathymetric range of fishing operation, and (5) average numbers of sharks and rays caught per fishing trip. The questionnaire was based partly on Haque et al. (2021b, c; 2022a). The semi-structured questionnaire included prepared questions (supporting information five App. 5.3A) to compare responses and unplanned questions. The latter allowed the exploration of issues significant to individual responders on an informal level, which aided in qualitatively characterising the fisheries system (e.g., fishing techniques and gear deployment tactics). Interviews were conducted in ten fishing areas including villages, fish landing sites and shark processing centres in three coastal regions of Bangladesh- south-eastern (n= 342, 30%), south-central (n= 599, 52%) and south-western (n= 208, 18%).

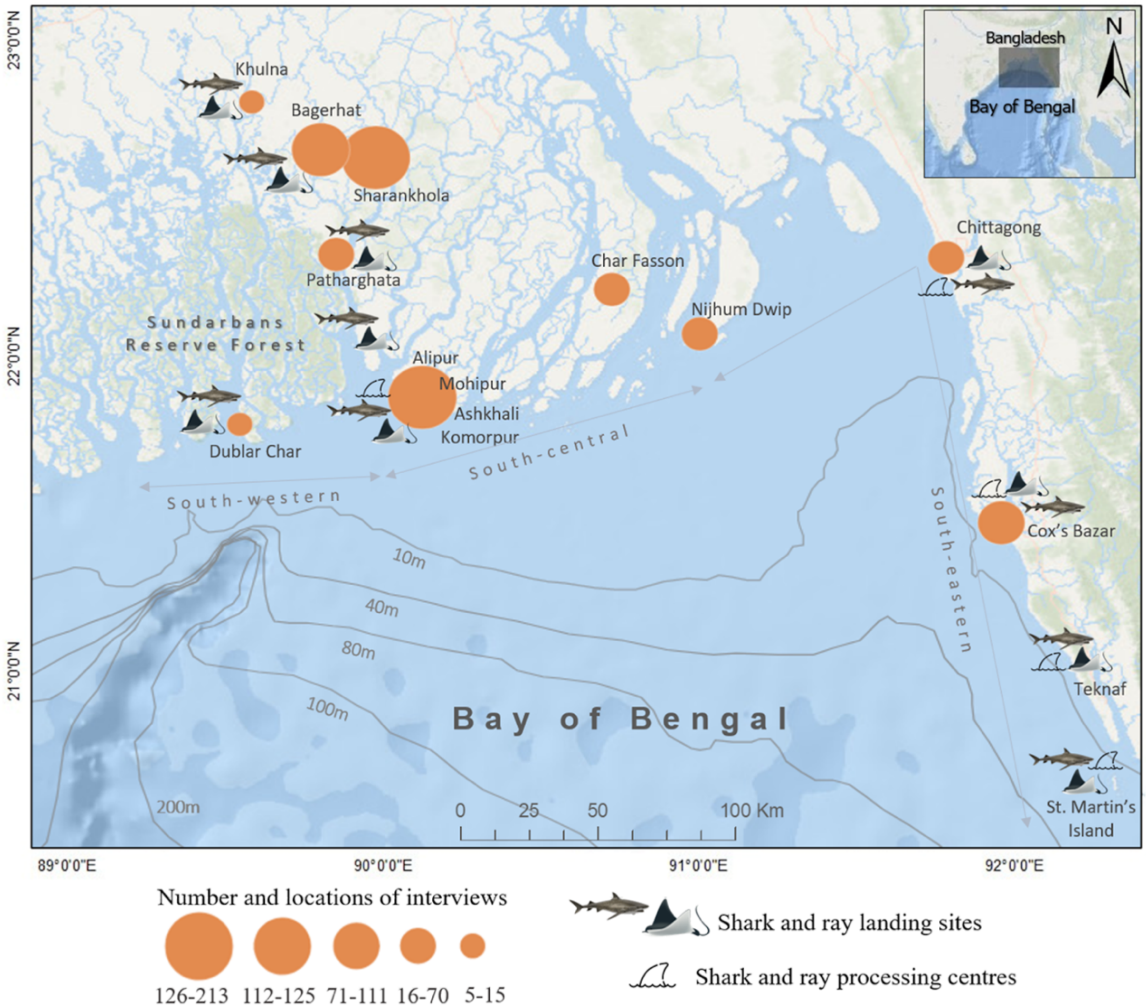


Figure 6.1. Map of the study region indicating shark and ray processing centres, landing sites, and survey locations indicating survey sites along the coast of Bangladesh—Bangladesh within the Bay of Bengal region (inset). The size of the orange bubbles indicates the number of interview participants. The isobaths show the depth ranges within the Bay of Bengal. The map was created using QGIS version 3.22.

Ethical approval- This study was conducted with the ethical approval by the Ethical review committee of the Faculty of Biological Sciences, University of Dhaka (reference number-59/Biol.scs., 172/Biol.scs, 173/Biol.scs) for three research projects conducted with the support of Dhaka University, Bangladesh Fisheries Research Institute, and other funders. Before each interview, verbal permission to conduct the interview and use the data for scientific purposes was obtained from each interviewee. Research questions, the purpose of the interviews, and data usage were explained to the interviewees prior to each interview. The anonymity of interviewees was guaranteed to avoid biases. Furthermore, the interviews were not restricted to set durations, nor were interviewees given directions or instructions.

Fishery classification- Interview responses were used to categorise and characterise sub-fisheries within artisanal fishery practices, then validated using a fishers' workshop and published literature (e.g., DoF, 2019; Fanning et al., 2019; Haque et al., 2021 a, b, c, d; Haque et al., 2022a). The majority of selected interviews (n= 971, 98.3%) were artisanal, while the remaining (n= 17, 1.72%) were industrial (Table S5.2.6.1).

Participatory mapping- To map the spatial footprint of fisheries, all fishers were given a grid map (10km X 10km) with landmarks (e.g., coastal villages, coastal islands, landing sites, ports, river mouths, fish markets, fishing locations) and depth range at sea (isobaths) (supporting information five App. 5.3B). Fishers were first asked to describe the fishing location verbally (e.g., how far from the landmark they travelled- either the distance in km or time of travel in hours, the direction to which they travelled, fishing location names, and the depth at which they fish). Then the fishers were asked to identify the location in the grid map. Biases were minimized by considering a variety of variables, including depth, location, direction, travel time, target species, and publicly accessible fishing location data, to pinpoint these sites as precisely as possible within the 10X10 km grids and each fishing point's impact radius was the average net or trawl length; thus, the nets' length and motion were considered. Additionally, a focus group discussion comprising 21 experienced participants was conducted to validate the spatial and bathymetric range of fishing operations gathered from individual interviews. Previously conducted and published interview results (interview number= 814; in Haque et al., 2021b, c, d; Haque et al., 2022 a) were also used.

Fishery footprint- Heatmaps were created to show the most exploited fishing locations for each sub-fishery level (fisheries' spatial footprint) using the point fishing locations identified by the fishers (details in supporting information five- App. 5.4). A heatmap is a valuable visualisation tool for displaying the density or frequency of events (here, catch locations/fishing footprint) along with the extent of spatial influence around each data point. As a result, we can see how the concentration of event occurrences is distributed spatially using a heatmap. Here, the heatmaps were created using the KDE method, which stands for Kernel Density Estimation. KDE uses a Probability Density Function (PDF) to estimate a point value (see supporting information SIV). Heat mapping was used to determine fishing density within a particular search bandwidth or radius. A search bandwidth or radius of 30 km was set weighted by the individual net length. The bandwidth is derived from a quantitative understanding that each gear type has an average length and may exploit a specific area of water in a fishing site using an array of gears.

6.2.2.2. Species selection and species-specific data including distribution ranges

A total of 19 Critically Endangered (CR) sharks and rays were selected (Table 6.1) for the assessment. IUCN Red List website (www.iucnredlist.org) was used to collect information on each depth range, water column position (i.e., demersal, pelagic, bathyal), and habitat requirements (e.g., mangrove, riverine, reef-associated, deep-sea). When feasible, peer-reviewed literature was used.

Table 6.1. List of Critically Endangered shark and ray species selected for the study with details of their habitats, water column and depth range usage

Family	Species	Common name	Habitat use	Water Column	Depth range (m)
Carcharhinidae	*Carcharhinus hemiodon*	Pondicherry shark	Marine neritic/ inshore on continental and insular shelves	Pelagic	10-150
	Carcharhinus longimanus	Oceanic whitetip shark	Marine oceanic/ Deep sea	Epipelagic	0-1082
	Glyphis gangeticus	Ganges shark	Marine neritic, wetlands (inland)/ tropical rivers in freshwater and estuarine	-	0-50
Sphyrnidae	*Sphyrna lewini*	Scalloped hammerhead shark	Marine neritic, semi-oceanic/ Shallow shelf to deep sea	Pelagic	0-1043
	Sphyrna mokarran	Great hammerhead shark	Marine neritic, semi-oceanic/ coastal	Pelagic	0-300
Dasyatidae	*Maculabatis arabica*	Arabic whipray	Marine neritic/ shallow inshore and shelf waters on	Benthic	0-37

			muddy bottoms		
	Maculabatis bineeshi	Short-tail whipray	Marine intertidal/ inshore waters from the surface to bottom	Benthic	0-100
Gymnuridae	*Gymnura tentaculata*	Tentacled butterfly ray	Marine neritic/ close inshore	Benthic (need more information)	0-87
Pristidae	*Pristis pristis*	Largetooth sawfish	Marine intertidal, wetlands (inland)/ juveniles occupying freshwater and estuarine habitats, and adults occurring in both estuarine and coastal waters	Benthic	0-60
	Pristis zijsron	Longcomb sawfish	Marine intertidal/ Young are born in nearshore nurseries including estuaries and mangrove creeks that are also used by juveniles	Demersal	0-100
Rhinidae	*Rhina ancylostoma*	Bowmouth guitarfish	Marine neritic/ close inshore to continental shelf/ coral reefs	Demersal/ occurs close to the seabed	0-70
	Rhynchobatus laevis	Smoothnose wedgefish	Marine neritic/ close inshore/ continental shelf and has a preference for shallow bays and river mouths	Demersal/ Benthic	0-60
	Rhynchobatus australiae	Bottlenose wedgefish	Marine neritic/ inshore/ continental shelf/ coral reefs	Demersal/ Benthic	0-60

Glaucostegidae	*Glaucostegus typus*	Giant shovelnose ray	Marine intertidal	Benthic (need more information)	0-100
	Glaucostegus granulatus	Granulated guitarfish	Marine intertidal	Benthic (need more information)	0-120
	Glaucostegus obtusus	Widenose guitarfish	Marine neritic/ inshore	Benthic (need more information)	0-60
	Glaucostegus thouin	Thouin ray	Marine neritic/ inshore	Benthic (need more information)	0-60
Rhinobatidae	*Rhinobatos annandalei*	Annandale's guitarfish	Marine neritic/ inner continental shelf	Demersal	5-73
	Rhinobatos lionotus	Smoothback guitarfish	Marine neritic/ inner continental shelf	Demersal	0-73

6.2.2.3. Potential 3D overlaps between the fishery footprint and species' known range

The ocean is a three-dimensional environment, and therefore the estimation of potential interactions between a given species and fishery should consider both overlapping horizontal areas and vertical depth overlap.

Horizontal overlap relates to how much a species's known distribution and the fishery distribution overlap on a two-dimensional plane. More horizontal overlap means greater exposure since a fishery cannot affect a stock without at least some overlap with the stock's distribution (Patrick et al., 2010). However, if there is no overlap in depth, there would be no exposure despite the horizontal overlap.

Depth overlap is based on the species' ecological behaviour as an adult and favoured habitats and bathymetric ranges (depth range in the water column relative to gear position). This vertical relates to where the stock is in reference to the fishing gear in the water column (e.g., demersal, benthic, or pelagic). To estimate the degree of vertical overlap between fishing gear and a species, information on the depth at which gear is deployed (for example, the depth range of hooks for an unbaited longline fishery) and the depth occurrence of the species was used (Patrick et al., 2010; Furlong-Estrada et al., 2017; Hobday et al., 2011). This considers the possibility that a species would encounter the fishing gear when deployed (Hobday et al., 2007).

Species distributional ranges were downloaded from the IUCN Red List website (www.iucnredlist.org) as shapefiles and depth ranges were extracted from Red List Assessments. Socio-ecological data was used in mapping the fishery footprints and provided data on the extent and depths of the fisheries occurring within the Bangladesh Exclusive Economic Zone (EEZ). Bathymetric data were obtained from the GEBCO 2022 Gridded Bathymetry Data (GEBCO Compilation Group, 2022).

In order to work across vector and raster data formats, we generated a hexagonal grid across the extent of the Bangladesh EEZ, within which we could summarise the input datasets and calculate the three-dimensional overlap. Each cell within the hexagonal grid has an area of 866025.4 m2 or 1,000 m across. We generated the mean depth from the bathymetric raster data for each cell and filtered for the cells with a depth of less than 0, as these correspond to underwater cells.

We assigned 0 or 1 to every grid cell for each species and fishery according to whether the particular species or fishery was absent or present. We then estimated the vertical extent of the species or fishery in each grid cell using the available depth ranges and bathymetric data. We converted these into volumes by multiplying by the area of the grid cell. To calculate the total volume of each species and fishery, we summed the volumes of all present grid cells (Figure 6.2).

We calculated the vertical (depth) overlap between the respective depth ranges for every combination of species and fishery. For each grid cell where both the species and fishery were present, we assigned the depth overlap constrained by the mean bathymetric depth of the cell. We then calculated the volume of overlap in the cell between the species and fishery by multiplying the horizontal area of the cell and the depth overlap. With these volumes, we can express the potential for interaction between a species and a fishery as a proportion of the species volume that overlaps with a given fishery.

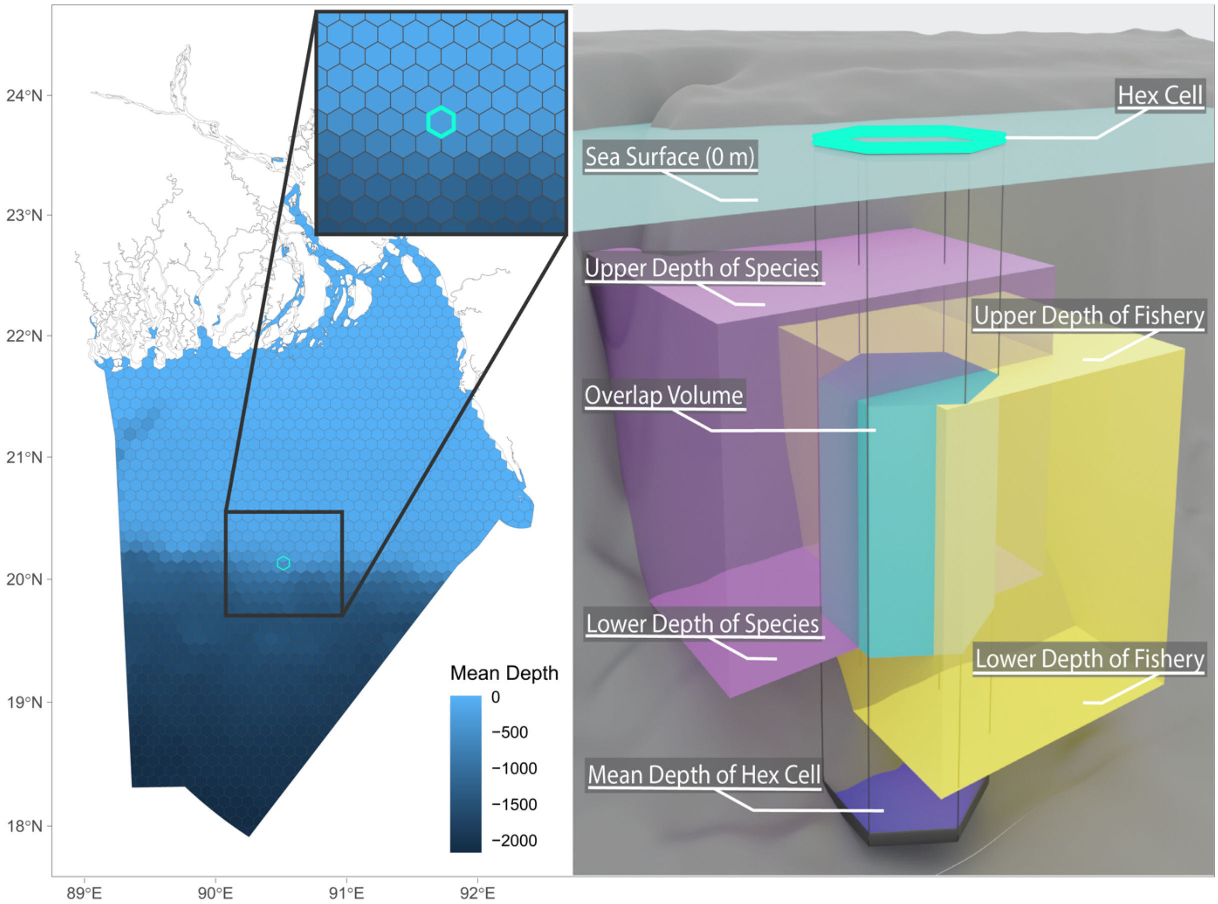


Figure 6.2. Graphical representation of the method used to calculate the 3D overlap between the species distributional range and fishery footprint.

To determine if the total number of overlapping cells varied with different sub-fishery types, we fit generalized linear models (GLM) with Quasi-Poisson distribution due to overdispersion of the data (R Core team, 2020). The model fit was checked by comparing the model with a null model (without any predictors) using the *summ()* function in the *jtools* package (Long, 2020).

6.3. Results

6.3.1. Interviews: fishery classification and characterisation

Artisanal fisheries were divided into seven sub-fisheries based on their fishing tactics, depth usage and species targeted: (1) small-mesh, (2) medium-mesh and (3) large-mesh gillnets (SGN, MGN, LGN), (4) set-bag nets (SBN), (5) prawn-trawl nets (PTN), and longlines (6) baited (BLL), and (7) unbaited (ULL). Gillnet fisheries were divided by mesh size to small

(SGN; ≤ 12.5 cm mesh size), medium (MGN; 12.51- 20 cm), and large (LGN; >20.1 cm). (Full gear details available in Table 6.2 & S5.2.6.2). Gillnets and modified gillnets (SGN, MGN, and LGN combined) were the most frequent gear (75.2%), followed by PTN (8%), BLL and ULL (7.6%) and SBN (6.78%) by interviewed fishers. Floating nets were deployed by 38% of fishers, submerged gear by 37.5%, and trawl nets by 10% of fishers. The rest of the fishers used multiple gear types. Sub-fisheries operated in different, but overlapping, fishing grounds and exploited different parts of the water columns (e.g., SGN fished at all levels in the water column, whereas PTN and ULL fished only at benthic levels). About 14% of fishers concentrated fishing operations in upper surface or pelagic water, 17% in demersal water, 36% in benthic water, and 13% in combined pelagic and demersal water columns. The rest of the fishers exploited different combinations of water columns (Table S5.2.6.1 & Figure S5.2.6.1). Sub-fisheries had different but overlapping fishing seasons, depending on the availability of the target species. For instance, BLL had the longest season, operating for 5-10 months with an annual average 9.5 months. Gillnets also had long fishing seasons of 3-9 months (annual average 8-8.5 months). SBN and PTN fisheries operated for an average of 7 months and ULL had the shortest season with 5 months of fishing. However, some fishing vessels fish throughout the entire fishing season but change gears according to the seasonal target species.

Fisheries targeted a range of species. Most fishers (67%) targeted hilsa (*Tenualosa ilisha*) but landed sharks and rays as unintentional catch, while 3.5% targeted sharks and rays. The rest (29%) targeted a suite of different teleost species (e.g., *Harpadon nehereus*, Sciaenidae, Ariidae) and invertebrates (e.g., shrimp). These fisheries captured varied numbers of sharks and rays per trip ranging from 1 up to 4,000 individuals per trip, though SGN and ULL averaged ~68 sharks and rays per trip (further details in Table 6.2 and Table S5.2.6.2).

6.3.2. Fishing footprint

We examined the magnitude and location of the artisanal fishing activity (3D fishing footprint), seasonality, and fishing efforts (annual fishing months and days) (Table 6.2). When compared to other fishery types, drift, floating, and submerged gillnets had by far the highest average effort and the largest footprint within the Bay. For instance, small-mesh gillnets (SGN) had the largest footprint, with an average yearly fishing time of 182 days (54-270 days). It exploited an 80028.54 km^2 area (horizontal fishing footprint), which is more than half the size of entire Bangladesh and 2538.38 km^3 (3D) exploited water volume. These values represent 39% and 49% of the total area and volume exploited by all sub-fisheries, respectively (Figure S5.2.6.2). Around 70% of the SGN fishery was concentrated in the southcentral and southwestern regions (Figure 6.3). Next was the medium-mesh gillnets (MGN), 16% less area use than the SGN. The southcentral and southwestern areas held most of the MGN fisheries (50%), followed by the southeastern region with 36%. The rest of the interviewees fished in multiple regions (Table 6.2). In comparison to the SGN fishery, the unbaited longline (ULL), set-bag net (SBN), and prawn trawl net (PTN) fisheries had relatively small fishing footprints (Figure 6.3). Although there is a significant concentration of these fisheries in the southcentral and southwestern areas, they have a coast-wide presence. However, BLL and PTN had limited presence in the southeastern region. SBN had the highest presence near the Sundarbans and in Teknaf peninsula, near the Naaf river and St. Martin's Island.

The sub-fisheries used intersecting yet different depth ranges within the coastal and marine waters (Figure S5.2.6.1) (e.g., on average SGN fished at 52 m, MGN fished at 81 m, LGN fished at 98 m, and PTN fished at 10.5 m). About 62% of the SGN fishers fished between 2 and 50 m, and the average depth was 52 m (for 100% of the fishers). About 56% of MGN fishers fished between 9.2 and 80 m depth, 80% of SBN fishers fished between 3.5 and 20 m depth, 73% of PTN fishers fished between 2 and 10 m depth, 97% of ULL fishers fished between 6.5 and 20 m depth and about 60% BLL fishers fished between 5 and 40 m depth (Figure 6.3 & S5.2.6.1). The cumulative fishing exposure is greatest in shallow water coastal zones and strongly correlates with species distributional ranges (Figure 6.3).

Table 6.2. Characteristics of artisanal fishery types (sub-fishery) including number of respondents in each sub-fishery, perceived number of sharks and rays caught in each trip, total number of vessels in operation, fishing efforts in annual days of operation. net description and depth at which they operate. A detailed classification characteristic including fishing footprints is tabulated in the Supporting Information Table S5.2.6.2.

Sub-fishery type	Number of sharks caught per trip	Total number of vessels in operation	Annual fishing duration (months/ days)	Depth range of fishing (m)	Net length (m)	Net width (m)	Mesh size (cm)	Fishing footprint		
								Number of cells	Area (km^2)	Volume (km^3)
Small mesh gill net (SGN) n=644, 65%	Sharks-1-4000 (mean 72)	37,190	3-9 months (mean 8)/ 54-270+ days (mean 182)	1.98- >100 (mean 51)	9.14- 10,000 (mean 3330)	0.92- 46 (mean 19.1)	1.27-12.065 (mean 8.92)	92409	80028.54	2538.38
Medium mesh gill net (MGN) n=90, 9%	Sharks- 1-800 (mean 62)		4- 9 months (mean 8.5)/ 54-324 days (mean 187)	9.2- 304 (mean 77.5)	3- 9138 (mean 3552)	9.2- 61 (mean 34.65)	12.7- 22 (mean 14.5)	53366	46216.31	1684.62
Large mesh gill net (LGN) n=9, 1 %	Sharks- 2-222 (mean 76)		6- 9 months (mean 8.40/ 140-216 days (mean 172)	14- 183 (mean 80)	41.4- 5000 (mean 2204.4)	5.52- 41.4 (mean 19.7)	15.24-38.1 (mean 23.82)	16865	14605.51	603.38
Set-bag net (SBN) n= 67, 6.8%	Sharks- 1-4000 (mean 355)-	20,750	3-9 months (mean 7)/ 96-297 days (mean 159)	3.5- 53 (mean14.5)	10.12- 1500 (mean 110.82)	1.84-69 (mean 16.2)	0.1-15.24 (mean 5.7)	19992	17313.58	95.41
Prawn trawl net (PTN) n= 80, 8%	Sharks- 1-50 (mean 7)	SC region (200-300)	4-9 months (mean 7)/ 48-360 days (mean 164)	2- 46 (mean 10.5)	Net length- 32-9660 (mean 807); Trawl hour- 4-5 hrs; Trawl distance- 15-20 km	2.5-9.2 (mean 4.7)	2.2-2.4 (mean 2.3)	17634	15271.5	81.67
Baited longlines (BLL) n= 40, 4%	Sharks- 1-60 (mean 12); Rays- 2-70 (mean 17)	3,225	5-10 months (mean 9.5)/ 110-252 (mean 173)	5-107 (mean 34)	Hook number- 500-16000 (mean 7445); Line length- 276-40000 m (mean 12283)	Hook line depth- 0.3-21 (mean 2)	NA	15086	13064.9	102.35

Un-baited longline (ULL) n= 35, 3.5%	Shark- 2-5 (mean 4); Rays- 10-200 (mean 64)	5 months/ 90-150 days; Seasonal (Winter to Pre-summer- November-March)	6.5-76 (mean- 11.6)	Hook number- 6000-40000 (mean 25103); Line length- 2000- 10000 (mean 5029)	Hook line depth- 0.15-1 (mean 0.34)	NA	20954	18146.7	52.99

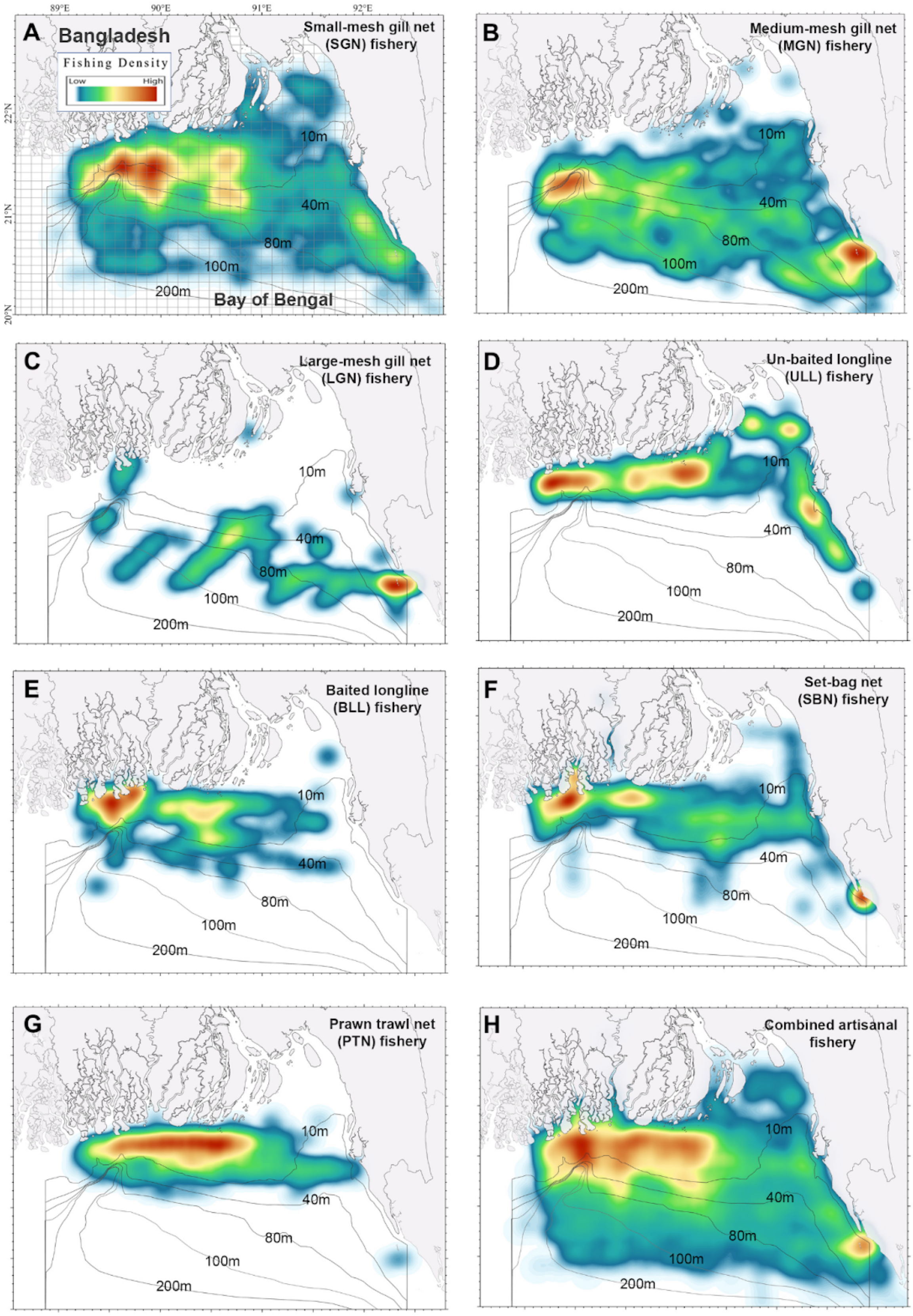


Figure 6.3. Heatmaps showing spatial distribution of fishing footprint of different sub-

fisheries in the study region within the Bay of Bengal, Bangladesh– (A) small-mesh gillnets, (B) medium-mesh gillnets, (C) large-mesh gillnets, (D) unbaited longines**, (E)** baited longlines, (F) set-bag nets, (G) prawn trawl nets and (H) all sub-fisheries combined.

6.3.3. Area of exposure

Different species occupy varying areas and volumes of water inside Bangladesh's EEZ (ranging from 57 to 126,423 cells). *Carcharhinus hemiodon*, for example, has the smallest distribution at 49.4 km2, while *Carcharhinus longimanus* has the greatest covering 109,485.5 **km**^{2} (Table S5.2.6.3). *C. hemiodon* utilized just 0.04 km^3 of water volume (3D space), while *C. longimanus* used 49,765.7 km^3 of water. Whereas *Gymnura tentaculata, Glyphis gangeticus*, and *Rhinobatos annandalei* have restricted distribution ranges in Bangladeshi waters (all less than >22,000 km^2), the rest of the selected species have medium to large distribution ranges.

We found 3D overlap of Critically Endangered sharks and rays with fisheries ranging from no overlap (0%) to complete overlap (100%) (Figure 6.4; Table S5.2.6.4). For instance, *G. gangeticus* had the lowest overlap with ULL (9%) and BLL (10%) fishery to its total range within coastal and marine waters. The highest overlap for this species was with SGN (85%) fishery followed by MGN (42%), LGN (18%), SBN (16%) and PTN (13%) (Figure 6.5). The sub-fisheries exposed different species to varying degrees (Figure 6.6). Shallow water species with smaller ranges (e.g., guitarfishes) had greater overlap with almost all sub-fisheries, while wide-ranging species had relatively smaller overlap, understandably.

The cumulative risk of species exposure to different artisanal sub-fisheries was highest between latitude 21°N and 22°N within the marine and coastal waters (Figure 6.7 & S5.2.6.3), especially within the shallow water southwest (near Sundarbans) and southcentral region. Cumulative fishing pressure on different species also varied depending on space and depth usage by both species and the fishery. For instance, *C. longimanus, Sphyrna mokarran* and *Sphyrna lewini*, by virtue of being large range species, using both shallow and deeper waters, are exposed in the shallower waters, especially near Sundarbans followed by the southcentral region and some parts of the southeastern region but, has refuge in deeper waters (Figure 6.7). However, shallow water and small range species such as *G. gangeticus,* giant guitarfishes, sawfishes and *Maculabatis bineeshi* are extremely exposed for most parts of their ranges without any refuge, especially to bottom-set nets. On the other hand, *Carcharhinus hemiodon* and *Gymnura tentaculata* have not been mapped within Bangladeshi waters due to a lack of presence data and thus showed almost no overlap with any artisanal fisheries.

Results from a quasi-Poisson regression model showed that mean overlap areas for different sub-fisheries are significantly different from each other. We fitted a quasi-Poisson model to predict the number of overlapping cells with different sub-fisheries. The model's intercept, corresponding to fishery = BLL, is at 9.40 (95% CI [9.09, 9.68], $t(126) = 62.46$, $p < .001$). BLL sub-fishery had smaller mean overlapping areas than MGN. The effect of sub-fishery MGN is statistically significant and positive (beta = 1.04, 95% CI [0.70, 1.39], $t(126) = 5.91$, $p < .001$). The effect of sub-fishery SGN is also statistically significant and positive (beta = 1.50, 95% CI [1.18, 1.84], $t(126) = 9.01$, $p < .001$). Although it is also smaller than other shallow water sub-fisheries (PTN, SBN, ULL), the results were statistically non-significant (Table S5.2.6.5).

Although the horizontal overlap was substantial for certain species, the 3D overlap was comparably smaller, indicating some refuge for the species at various depths due to the low depth overlap between the fishery and the species. *C. longimanus*, for example, showed 72% and 40% horizontal overlap with SGN and MGN, respectively, but 3D overlaps (horizontal and depth) were lower at just 5% and 3.22% for SGN and MGN, respectively. Furthermore, *C. hemiodon* had no 3D overlap with any other fishery except SGN and SBN. While *Pristis pristis* had no 3D overlap with the LGN fishery, it was highly exposed to all shallow water fisheries such as ULL, PTN and SBN (>30%) and fully exposed to SGN (100%). *Sphyrna mokarran* and *S. lewini* both have <1% 3D overlaps with shallow water fisheries (PTN, SBN, and ULL) (Table S.5.2.6.4).

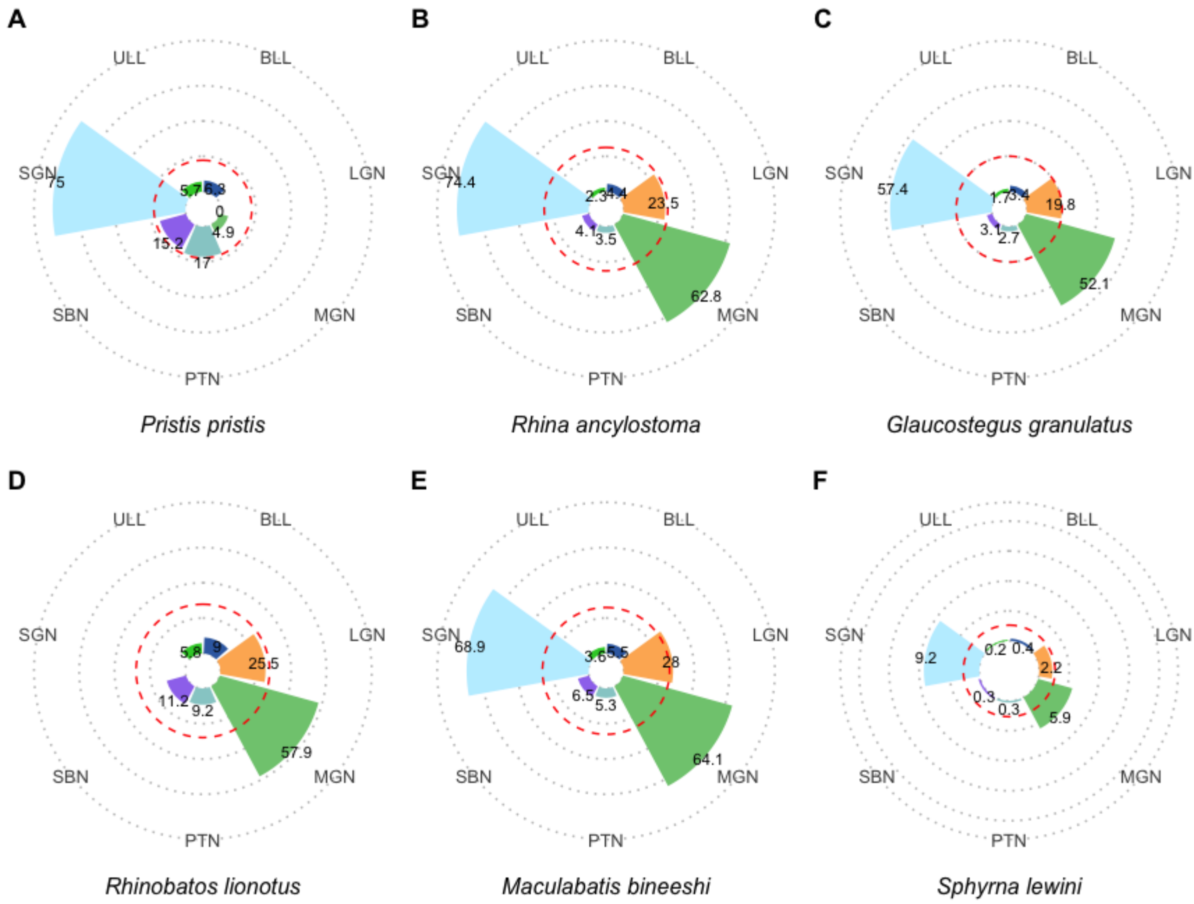


Figure 6.4. Circular bar-plot comparing the percentage of 3D overlap of selected examples of shark and ray species for different sub-fisheries (here, ULL= unbaited longines, SGN= small-mesh gillnets, MGN= medium-mesh gillnets, LGN= large-mesh gillnets, SBN=set-bag nets, PTN= prawn trawl nets, BLL= baited longlines). Here, the red-dashed line denotes the average overlap for all fisheries for the respective species.

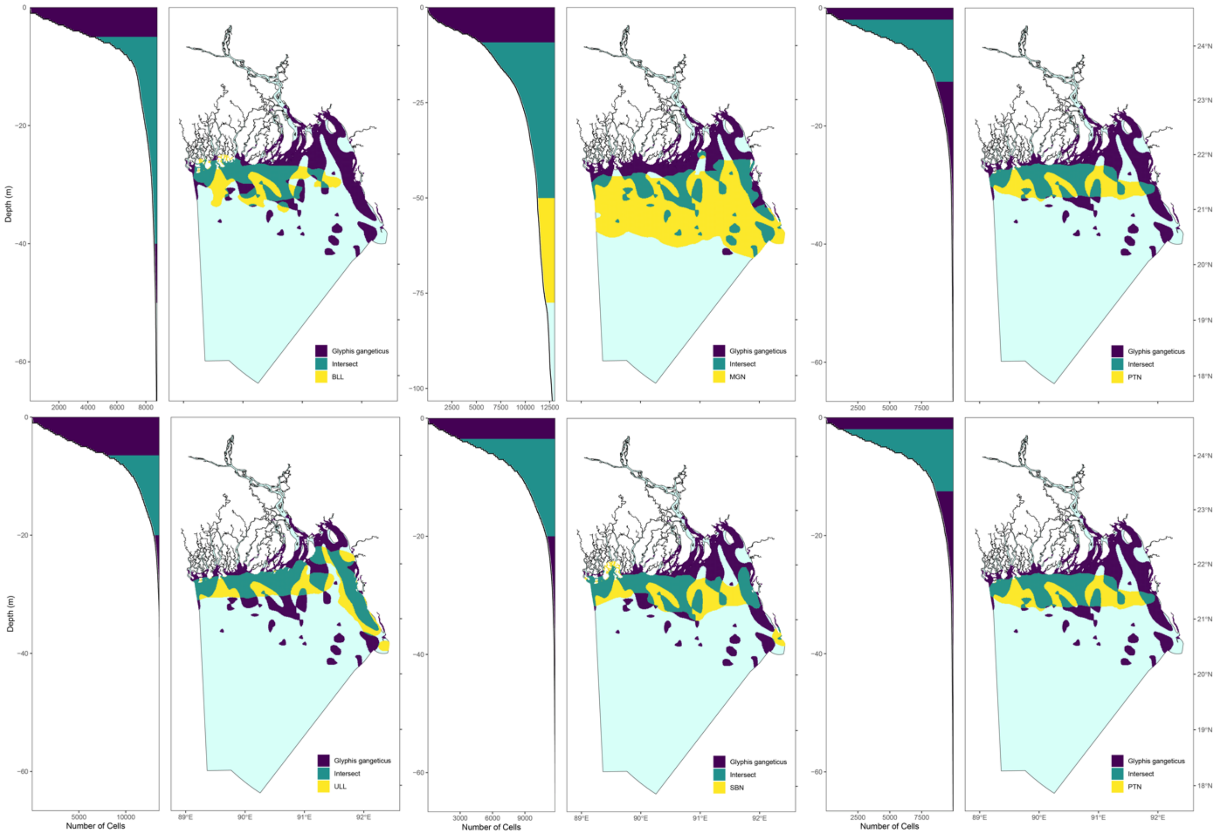


Figure 6.5. Overlap of the distribution range of *Glyphis gangeticus* with different sub-fisheries and number of cells overlap at different depths. Here the colour purple shows the range of the species, yellow shows the fishery footprint and the green indicates the overlapping area between the fishery operation and the species range.

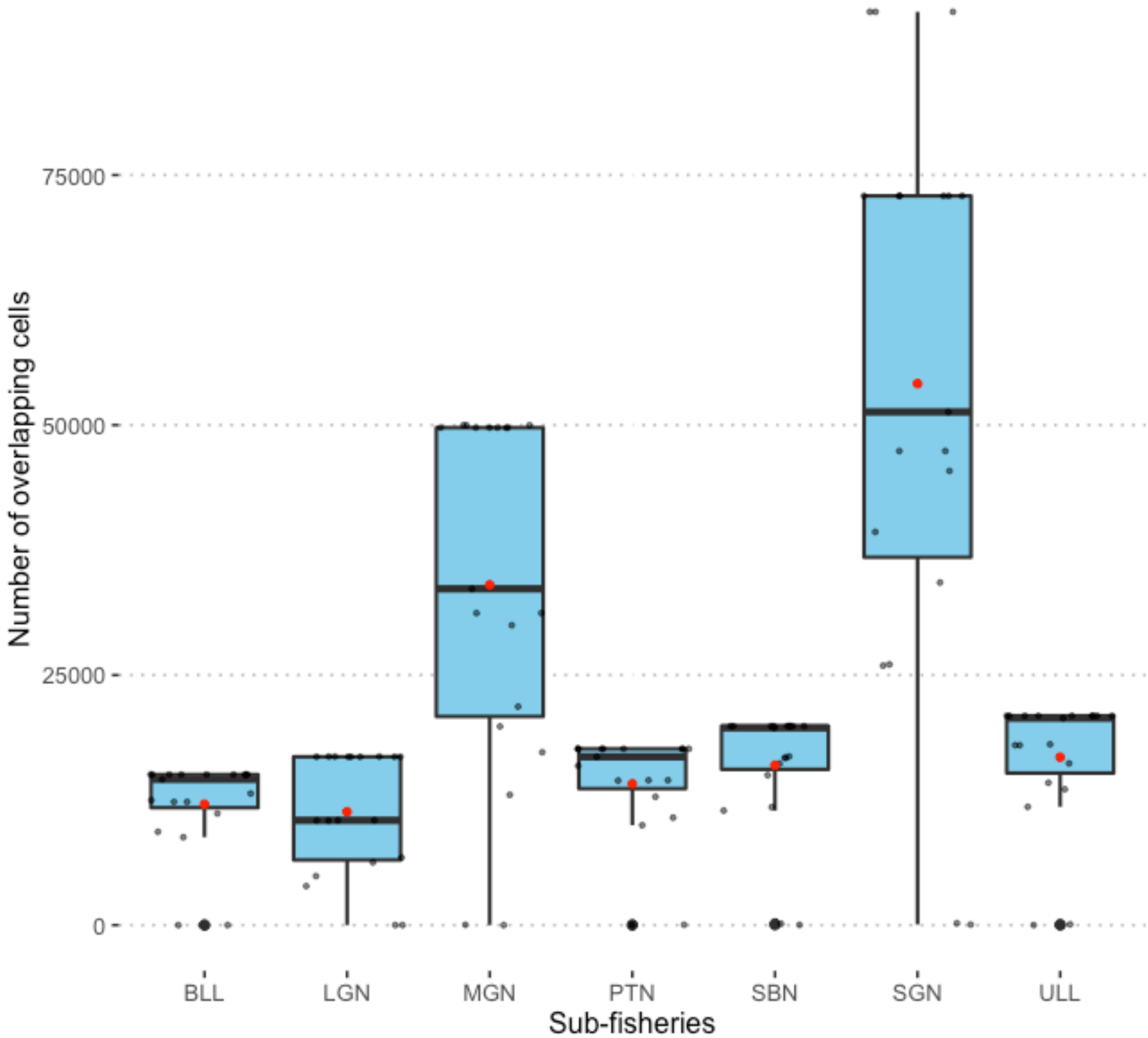


Figure 6.6. Boxplot showing the total number of overlapping cells between the species distributional range and fishery footprint for all selected species (jitter points within the boxplots). The red dots show the average number of overlapping cells.

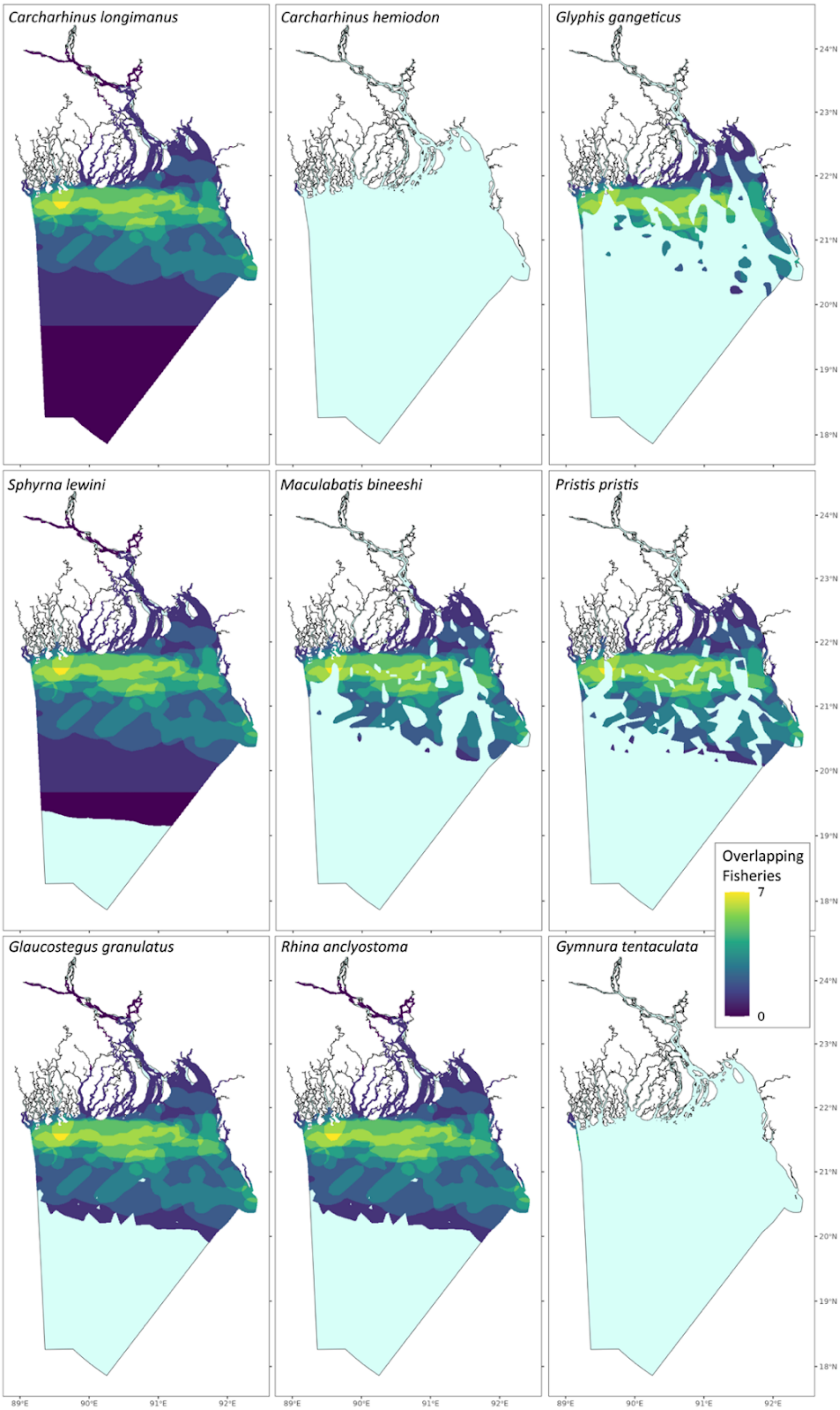


Figure 6.7. Maps showing the cumulative horizontal fishing pressure from all sub-fisheries for selected examples of shark and ray species assessed within the study.

6.4. Discussion

We assessed the risks that Bangladesh's seven principal artisanal sub-fisheries pose to Critically Endangered sharks and rays in the Bay of Bengal. This study is the first to map the spatially detailed fishing footprints and risk assessment of these species caught in Bangladeshi artisanal fisheries. All artisanal fishing, especially in shallower waters, poses major cumulative threats to sharks and rays in the Bay of Bengal. We identified potential areas of concern. The overlap of critical habitats of different species with fishing footprints varies, showing the potential for nuanced area-based management. We proposed potential future prioritisation for area-based management in line with the global 30x30 goal (Gurney et. al., 2023) and management approaches applicable in the Bay of Bengal.

6.5.1. Distribution of fisheries footprint

We determined the distinct fishing footprint of the seven artisanal sub-fisheries operating within Bangladesh's Exclusive Economic Zone using individual interviews and a participatory mapping exercise. To accurately assess the effects of fishing, the maps work best when combined with knowledge of seasonality and gear/species combinations. In the absence of fishing vessel tracking and monitoring data, socio-ecological data were beneficial in identifying these spatially detailed maps. In the Bay of Bengal, mapped outputs can significantly improve the availability of evidence for marine spatial planning.

We have attempted to mainstream local ecological knowledge using this readily repeatable method of combining interviews, fishery classification, and participatory mapping to address critical conservation and management questions, such as how to map fisheries. This inclusive, quick, and cost-effective method enables us to map numerous fishing vessels with more attribute data than conventional boat trackers (such as fishing practices, gear use tactics, detailed gear description, target species, and seasonality). The initiative was well-received and fostered relationships with fishers, resulting in good interview coverage for over 1000 Bangladeshi coastal and marine fishers.

The results revealed that medium to large vessels fish in all coastal and marine zones except certain gillnetters that, in some circumstances, operate more than 80 kilometres south of the shore and at depths beyond 40 m. The most significant fishing grounds are near shore, where high cumulative fishing efforts were found. This is possibly due to smaller vessels' range limitations, species distribution, seasonality, seabed and habitat characteristics, and local knowledge and experience in the absence of any high-tech fishing equipment. These areas are influenced by mangrove forests, freshwater influx, coral patches, and seagrass beds in different coastal regions. These ecological aspects make these regions of high importance for providing critical habitats (breeding/nursery grounds) and fish production for a wide range of estuarine, offshore, and marine species, including sharks and rays (Lauria et al., 2018; Razzak et al., 2020; Haque et al., 2021 a).

6.5.2. Area of exposure

By merging the horizontal space and vertical depth occupied by both the fishing and the species, we have employed a unique approach to quantify the overlap between fisheries and species in the three-dimensional space. The technique reduces the likelihood of overestimation, offers more accuracy when computing the overlap in 3D space, and helps to determine whether a species is less at risk due to little vertical and/or horizontal overlap. This can enable us to develop safe gear deployment methods at different depths in a spatially explicit manner and avoid chances of species interactions at different 3D spaces.
Sharks and rays are exposed to various fisheries in areas with high cumulative fishing pressure. For example, *P. pristis*, a euryhaline species, lives in freshwater and estuary environments near Sundarbans, while giant guitarfishes use these areas as breeding/nursing grounds in the shallow water southcentral region (Weigmann, 2016; Haque et al., 2020; Kyne et al., 2021; Haque et al., 2021 a,b,c). Nearshore sand island areas and southeastern beaches provide critical habitats for giant guitarfishes in Bangladesh (Haque et al., 2021 c; Haque, unpubl. data). *S. lewini* pups in shallow water coastal areas (Rigby et al., 2023) and many juvenile and pregnant females caught within artisanal fisheries in winter (Haque et al., 2021 a).

The risk posed by different sub-fisheries depends on factors like gear selectivity, fishing fleet size, and seasonality. Understanding these fisheries is crucial for interpreting the comparative risks for species within these areas of exposure. For example, the study found *G. granulatus* is more exposed to shallow water small-mesh gillnets (SGN) and set-bag nets (SBN) than in unbaited longline (ULL) fishing. However, ULL fishery has greater selectivity for benthic rays, as they are designed to target them. Additionally, the highly diversified and mostly unmonitored nature of gillnet fisheries raises concerns about their impact on these species. The Indian Ocean region has a sizable bottom-set gillnet industry (Jabado et al., 2015 b; Temple et al., 2018) occupying a large area where threatened species are by-caught regularly. This is particularly problematic for the species at risk with small populations (e.g., *Glyphis* spp.), have high intrinsic sensitivity, or are already severely depleted by high bycatch pressure (e.g., Order: Rhinopristiformes). At this moment, provisions for multi-taxa management for different fisheries may be helpful- especially where species-specific data resolution or identification capacity is low (Haque et al., 2022 a).

It is crucial to consider the region's fishery context to interpret the findings. Benthic and inshore elasmobranchs, for instance, are unlikely to interact with surface or pelagic/demersal gears (e.g., drift gillnets) (Roberson et al., 2022) and are therefore expected to be taken less frequently in SGN fisheries. Nevertheless, the species' projected depth and horizontal overlap are significant within Bangladesh's SGN fisheries regions. This is because gillnets may reach the benthic layers if operated in shallow waters (Temple et al., 2019). Furthermore, weights can be added to shallow water gillnets to extend almost to the ocean floor (Haque, pers. obs.). Therefore, depending on the depth at which the SGN fisheries are operating, benthic and inshore species can be at risk; however, they are at low risk from large-mesh gillnets (LGN) fishery.

We found nearshore areas which are being exposed to cumulative fishing pressure. Although some areas are more exposed than others, the identified areas of exposure are well connected as they are based on species' whole distribution ranges, encompassing critical habitats. While managing marine areas, connectivity is crucial to ensure exchanging genes, nutrients, and energy as communities, ecosystems, or habitats are linked. These connectivities maintain critical ecological processes in marine ecosystems that support population resilience. While the mere sightings or seasonal presence of species typically can be used to designate MPAs, connected spaces are critical to identify and evaluate for effective management and species preservation. The identified 3D spaces can be promoted as "managed areas," ensuring the related biological processes are conserved and managed.

6.5.3. Management implications and recommendations

i. Identifying areas for fishery-specific and area-based management

Our results provide valuable insights into identifying areas of interest for fishery-specific and area-based management within Bangladesh's coastal and marine waters. Furthermore, maintaining ecological connectivity between these areas will be crucial to ensure that species and the livelihoods of local communities can thrive.

Recommendation 1*: Prioritize the management of identified connected areas for biodiversity conservation and upholding human rights.*

ii. Addressing concerns in gillnet fisheries

The small-mesh gillnet fishery poses the highest fishing pressure on sharks and rays due to its scale and lack of bycatch mitigation facilities.

Recommendation 2: *Improve management practices in the small-mesh gillnet fishery by implementing effective bycatch mitigation measures and promoting compliance with legal protections.*

iii. Consideration of cumulative fishing pressure and species-specific risks

The SBN and ULL fisheries, although smaller in scale compared to the gillnet fishery, exert high cumulative fishing pressure on shallow-water benthic species, leading to elevated risks. Time-area closures or dynamic closures in high-risk areas can help reduce encounters between threatened species and fishing operations (Gulak et al., 2015; Shiffman & Hammerschlag, 2016 b; Hazen et al., 2018; Smith et al., 2021; Pons et al., 2022). Time-area closures are spatial management techniques in which a high-bycatch risk area is routinely closed to stop fishing activity at specific times (Smith et al., 2021). Time-area restrictions are an effective method for reducing bycatch in fisheries. Dynamic closures, which have borders that change over time and space, are increasingly recognised as having the potential to protect migratory species in shifting environments more effectively than fixed closures.

Recommendation 3*: Implement time-area closures or dynamic closures in areas with high cumulative fishing pressure and significant overlap with threatened species, ensuring the conservation of vulnerable sharks and rays.*

iv. Strengthening monitoring and research efforts

To support effective management and decision-making, there is a need to invest in comprehensive monitoring of fishing fleets, catch data, and the impact on shark and ray populations. Additionally, relevant research should be prioritised to generate pertinent information for policy decisions.

Recommendation 4: *Allocate resources to strengthen monitoring programs for fishing fleets, improve data collection on shark and ray catch, and incentivize research that directly informs policy decisions related to the conservation of these species.*

v. Using the assessment as a management tool

The assessment conducted in this study can serve as a valuable tool for managers and researchers to make informed decisions regarding the conservation of sharks and rays. It provides a spatially explicit measure of the susceptibility of target and nontarget species to overfishing within specific fisheries.

Recommendation 5: *Use the assessment as a tool for developing and promoting sustainable practices at the fishery level, and safeguarding shark and ray populations. The findings should serve as a reference point for further research and action.*

vi. Engaging fishing communities and stakeholders

Results showed these areas are important for fisheries for coastal communities. Given the direct link between fisheries and the food security and livelihoods of millions of fishers (Miah, 2015; Hussain et al., 2017; Hossain et al., 2020), it is crucial to involve affected fishing communities in the development and implementation of mitigation strategies (Gladics et al., 2017; McCluney et al., 2019; Sinan & Bailey, 2020; Haque et al., 2022 a). Collaboration and consultation with stakeholders will help ensure effective management and the long-term sustainability of shark and ray populations.

Recommendation 6: *Consult and involve fishing communities in the design and implementation of mitigation strategies, considering their perspectives, knowledge, and experiences. This collaborative approach will enhance the effectiveness and acceptance of management measures, as well as address the socioeconomic concerns and needs of the fishing communities.*

6.5.4. Limitations

Firstly, the method used to estimate interactions between fisheries and species has limitations because it treats their presence or absence as static and binary. However, both species and fisheries are distributed unequally across time and space. More research is needed to obtain data describing the occurrence probability for species and fisheries over time and space. Additionally, the current method assumes that species and fisheries prefer all depths equally. Voxels could be used instead of grids by vertically dividing the hexagonal cells to improve the method. Combining temporal data would involve analysing specific time intervals. This assessment technique is adaptable and can be iteratively improved as better data on species' habitat use and catchability becomes available. Research efforts should focus on regions where data is lacking and where highly vulnerable areas or species have been identified. Secondly, we used the best data currently available for species' known ranges while acknowledging that the technique is flexible and can incorporate new data as it becomes available to enhance future estimations. For instance, *Carcharhinus hemiodon* and *Gymnura tentaculata* have yet to be mapped within Bangladeshi waters due to a lack of presence data and thus showed almost no overlap with any artisanal fisheries. This can be improved when species presence data is available. Lastly, this study did not analyse risks from industrial-scale fishing- fish trawlers. Results for large-mesh gillnet (LGN) fishery should be interpreted cautiously as the number of LGN fishers interviewed was low.

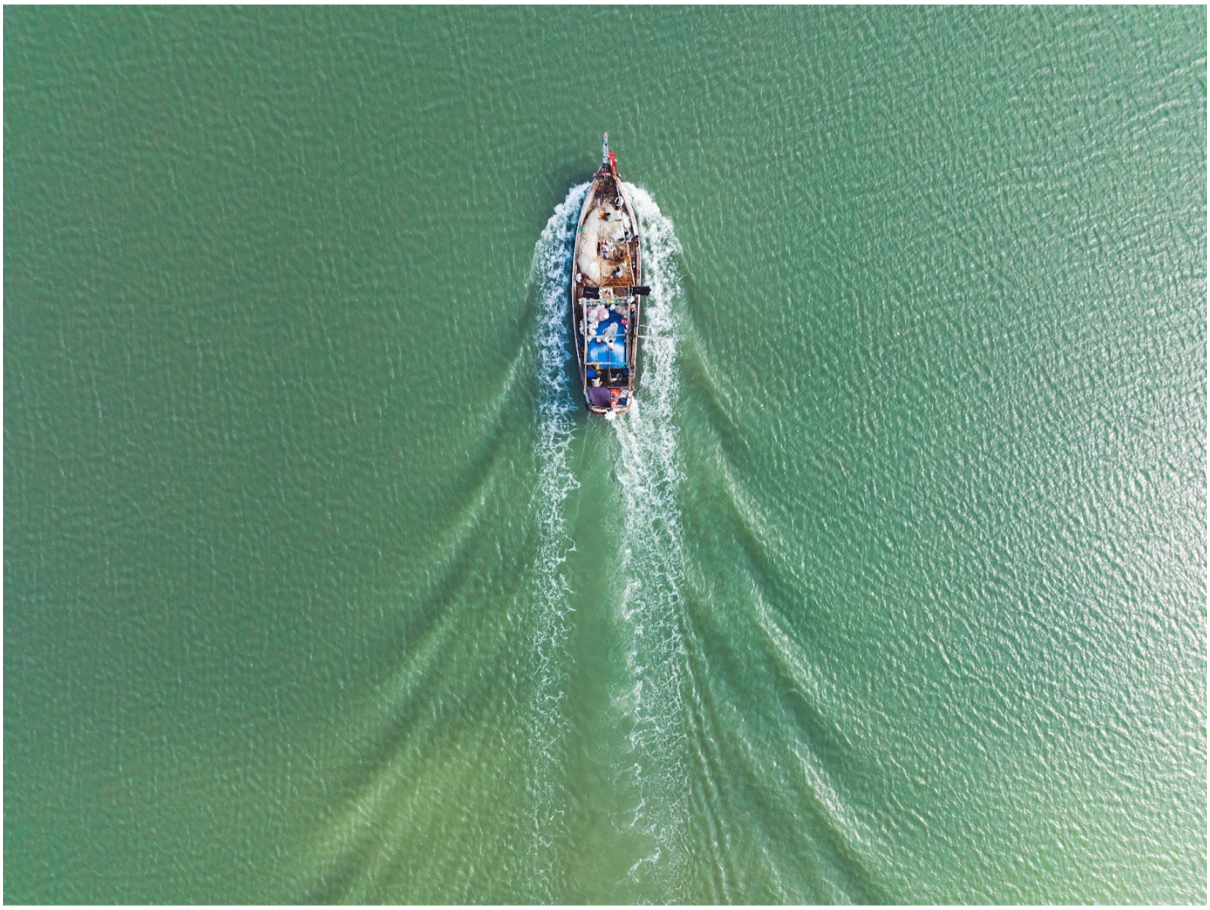
6.5. Conclusion

By implementing these management recommendations, we can take significant steps towards conserving sharks and rays in Bangladesh's coastal and marine waters. It is crucial to recognize the interconnectedness of species, ecosystems, and human well-being in developing comprehensive and effective management strategies. Through collaboration, improved monitoring, and adaptive management, we can ensure the long-term sustainability of shark and ray populations while supporting the livelihoods of local communities and contributing to global environmental conservation goals.

CHAPTER SEVEN- Discussion

7. Fish, Fishers, Science and Policy– plight of the global south for elasmobranch conservation and fishery management

This final chapter is structured into five parts- 1. Summary and context of research aim; 2. Novel contributions; 3. Future directions, 4. Limitations., and finally, 5. Concluding thoughts.



Artisanal fishing vessel and the Sea ©Bengal Elasmo Lab

"The sea, the great unifier, is man's only hope. Now, as never before, the old phrase has a literal meaning: we are all in the same boat."

- Jacques Yves Cousteau
Oceanographer (1910-1997)

7.1. Summary of context and research aim

Elasmobranch populations (hereafter referred to as 'sharks and rays') have decreased by 80% or more in various parts of the world owing to human-dominated actions, such as unsustainable fishing (Schindler et al., 2002; Clarke et al., 2007; Dulvy et al., 2008; Graham et al., 2010; Morgan et al., 2010; Kyne et al., 2020). Information on shark and ray diversity, specific threats to them, habitat usage, capture and bycatch trends, and a historical baseline is limited. This has resulted in the undetected disappearance of several species, including the ganges shark, wedgefish, and sawfish (Haque et al., 2019 a; Jabado et al., 2018; Kyne et al., 2020). Consequently, there is a strong likelihood that numerous species are already threatened without being identified or receiving any management measures (Jabado et al., 2015). In such circumstances, it is essential and urgent to have a much better understanding of shark and ray diversity, fisheries, and threats on a regional and national level for informed conservation decision-making.

Bangladesh, a global-south country, has significant illegal, unreported, and unregulated (IUU) fishing, including underreported commercial catch, bycatch that is discarded, and subsistence catch of sharks and rays (Ullah et al., 2014; Kumar et al., 2019). Therefore, it is evident that the Bay of Bengal's growing industrial, non-industrial, and mechanized fishing fleet is overfishing. In addition, Bangladesh's millions of small-scale fishers rely heavily on marine resources for micronutrients and food security. As a result, the demand for these proteins will continue to grow over the next decade, along with the expansion of fisheries (Mora et al., 2009). Without empirical study and the data required for fishery management decision-making, applying sustainable fisheries methods in the face of such fishing pressure and fishers' vulnerabilities is incredibly challenging.

Sharks and rays have shown a poor record of biological sustainability owing to their biological characteristics (Shivji et al., 2002), which means the chances of rebuilding the stocks once depleted are meagre. However, species' resilience to fishing pressure differs depending on the biological parameters. Hence, different species of sharks and rays will respond differently to the same amount of fishing pressure. Simpfendorfer & Dulvy (2017) suggested moving towards sustainable fishing. Although some shark and ray species have the potential to support sustainable fishing, given that enough science-based management tools are known and set in place (Simpfendorfer & Dulvy, 2017), a balance between biological, economic and social sustainability is challenging to attain. Hence, attaining biological, social, and economic sustainability requires specialized evidence-based actions. However, this region has little research on sharks and rays, including fisheries, as was mentioned in the introductory section. As a result, the data needed to support evidence-based management regimes must be improved. By focusing on the complexities of the complete ecological and socio-economic system, it is necessary to analyze the condition and trends of shark and ray populations.

Taking Bangladeshi shark and ray fisheries as a case study, broadly speaking this doctoral research has:

I. addressed a major information gap by providing new, key data on the state of shark and ray fisheries in the Bay of Bengal in Bangladesh and key drivers of their decline,
II. characterized fisheries, trade and market components to evaluate their impacts on sharks and rays,
III. assessed the spatially explicit ‘ares of exposure’ of Critically Endangered shark and ray species by seven different artisanal fisheries using a risk framework.

7.2. Novel contributions/research summary

Bangladesh was one of the countries with the least scientific study on shark and ray species diversity, fisheries, trade, conservation, and management. As a result, before addressing the main query of risk and sustainability analysis of shark and ray fisheries in Bangladesh, it was necessary to dedicate a sizable amount of my DPhil study to developing a baseline.

In order to achieve the goals of my research, I used a mixed-methods approach (conceptual, socio-economic, and ecological) to gather information on current species landings, fisheries, trade, and threats to sharks and rays throughout the whole coast of Bangladesh. I have also considered adopting a more inclusive management regime in the ecological, economic, social, and political spheres, highlighting potential challenges and recommendations. In order to accomplish my research goals, I critically reviewed recent theories and research on each chapter's theme, as well as gaps in our knowledge of how to handle problems specific to developing nations in the global south.

Chapter outlines of my thesis have been presented in the introductory section (Chapter 1).

7.2.1. Diversity

The nature of landing recording methods may have impeded accurate shark and ray accounts in Bangladesh. Species are grouped together at landings and while accounting, which conceals relative abundance and exploitation status at the species level (DoF, 2017). Assessing diversity was made more difficult by the paucity of exploratory surveys and the scarcity of competent personnel at the landing locations. Due to this, it is highly likely that shark and ray species richness and endemicity have previously been underestimated, raising the possibility that the area may host new, evolutionarily significant species (Naylor et al., 2012).

The diversity of sharks and rays in Bangladesh has traditionally been underestimated. Over 160000 individual elasmobranchs, including 88 species (30 sharks and 58 rays) among 20 families and 35 taxa, were identified throughout the course of our investigation. According to the IUCN Red List of Threatened Species, of these, 54 are considered to be globally 'Threatened', with ten species categorized as Critically Endangered and 22 as Endangered. Most of the specimens investigated were juvenile catches (69–99%). Different species were caught depending on season and gear specificity. Several formerly widespread species were found to be only occasionally landed, suggesting unsustainable fishing and associated population declines. Overall, it was shown that Bangladesh contributed significantly to the harvest of a great diversity of sharks and rays in the Bay of Bengal region.

The findings have significant ramifications both locally and globally, showing that Bangladesh is a global hotspot for shark and ray diversity. The number of shark and ray species found in Bangladeshi waters is greater than that found in other Bay of Bengal and Indian Ocean nations and regions, such as the Arabian Gulf (Moore et al., 2012), Sri Lanka (Moron et al., 1998; De Silva, 2006), Maldives (Anderson & Hafiz, 2002), and Andaman and Nicobar Islands (Tyabji et al., 2020).

Small-bodied sharks and rays have disproportionately greater relative abundances within the catch. This might be explained by the fact that many shark and ray species exploit the mangroves and nutrient-rich inshore waters as breeding habitats (Heupel et al., 2018) within the shallow coastal waters of Bangladesh. Larger-bodied deep-sea, pelagic, and migratory sharks and rays are unlikely to be abundantly captured in the shallow depths where Bangladeshi artisanal fishers primarily fish. However, inshore waters may also serve as breeding habitats for pelagic species (Camhi et al., 2009).

The Bay of Bengal is a hotspot for a number of vulnerable, genetically different, and internationally significant species, according to shark and ray landings and capture studies in the neighbouring nations (Fernando et al., 2019). My research corroborates this, demonstrating that sharks and rays are a crucial part of Bangladesh's marine ecosystem and a substantial component of artisanal fishing, indicating the necessity for catch and landing monitoring. I found that elasmobranchs are being caught using various fishing techniques, including targeted and bycatch fisheries, and landed in unmonitored locations in Bangladesh's Bay of Bengal. This includes species that are both globally threatened and legally protected (e.g., guitarfishes, giant guitarfishes, requiem sharks).

In order to promote and support evidence-based decision-making for elasmobranch conservation and management in the Bay of Bengal, Bangladesh, this chapter provides a crucial first baseline. Furthermore, a series of measures for effective governance and priority research is suggested to prevent the extinction of the most threatened and data-deficient species and to promote sustainable alternatives for other species by cooperatively integrating our knowledge base to enhance understanding of ecology, socioeconomics, conservation, and trade issues. Suggestions include the need for better taxonomic studies, improved elasmobranch stock monitoring, and the most significant degree of protection for vulnerable taxa. It was also noted that elasmobranch stock management and rebuilding require political will, improved national management capabilities, and coordinated regional management strategies.

7.2.2. Fishers and fisheries

This chapter of my thesis, using field studies, revealed that fishers employ a multi-species and multi-gear strategy for fishing within the study area (e.g., submerged or floating gill nets, set bag nets, seine nets, and long lines). The gears were selected based on seasonality and the target species by fishers. In addition to their primary gear, most fishing vessels carried three to five extra hooks to opportunistically catch bigger fish, including sharks. Sharks and rays were targeted in unbaited longline fisheries and taken as bycatch in other] teleost fisheries.

The fishers within this study were not active in targeted shark fisheries, except for one exclusive shark trader in Cox's Bazar, who had a fleet of 7-8 medium to large-sized fishing vessels with modified gill nets. However, targeted ray fishery exists. Fishers reported that each vessel landed between 0.5 and >1000 kg of whole-bodied sharks each day, with some seasonal variation. Bottom longline fisheries deploy 10,000 to

30,000 unbaited 3.8–5 cm hooks per kilometre of the line at a depth between ~5-40m to catch bottom-dwelling rays. Although fisheries target several kinds of rays, guitarfishes and giant rays are the most sought-after. Fishers reported that throughout their careers, they had noticed a sharp decline in variety, individual size, and elasmobranch catch size. The ability of fishers to identify sharks and rays at the species level varied. When apparent features, such as body markings or a distinctive body form, were lacking, identification abilities were inadequate. Shark and ray identification was particularly challenging for morphologically similar species. Hence, species-specific population trend analysis was impractical; however, group-specific (e.g., guitarfishes) population trends were reported.

In terms of legislation, it was apparent that Bangladesh's national Wildlife (Conservation and Security) Act of 2012 was not well-known to fishers. Even those aware of the Act could not detail the legislation. None of the fishers were aware of CITES (the Convention on International Trade in Endangered Species of Wild Fauna and Flora). Several fishers asserted that some sharks might be protected but could not offer specifics on the status of any protection. All fishers claimed that no permissions were needed to trade shark goods.

For management regimes to be effective, the ability and desire of fishers to follow the rules and regulations are essential. However, this study shows that, in many cases, fishers were unaware of or did not understand the legal frameworks controlling fishing operations and protected species, which led to non-compliance. This lack of understanding is likely brought about by infrequent encounters with fisheries inspectors, a failure to enforce current regulations, undemocratic legal development procedures, rising levels of corruption, and the anxiety associated with losing one's livelihood. The simplicity of national legislation, which fails to consider fisheries' complexity, is another crucial factor. For instance, a number of species are protected from being captured and traded. However, there is no support for raising awareness of these restrictions or helping fishers follow them technically or logistically (e.g., bycatch mitigation strategies).

The study shows that in areas lacking data, like Bangladesh, **the expertise of fishers is an invaluable information source that can be used to design management and conservation strategies and to better understand exploited species and historical trends**. The lessons learned from this study emphasize the need for co-designing management regimes for improved sustainability and success and the many advantages of fishers' involvement in conservation. I found that a more thorough and comprehensive strategy is required for successful conservation actions and compliance. Additionally, providing incentives to fishers would help to ensure that the legislation is followed and helps preserve vulnerable species. Understanding the fishers' circumstances, perspectives, and ability to cooperate is crucial for such interventions.

The long-term management of common property resources, such as fisheries, requires a prosocial mentality. I found that many fishers were aware of the causes of population decline and were eager to assist in bycatch reduction techniques. However, it is also possible that these variables will lead to illicit activities and increased levels of non-compliance since fishers are faced with lost wages, unpaid obligations, and corruption (Haque et al., 2020; Jaiteh et al., 2017). The study also found multiple socioeconomic traits influence fishers' prosocial behaviour; therefore, management must be aware of these factors (Rojas et al., 2021).

7.2.3. Trade

I found that sharks and rays were sized-sorted across all processing facilities to distinguish between those with large fins and those with smaller fins for trade purposes. Larger sharks were cleaned, gutted, and then cut into pieces after the fins were removed, producing various items, including dried fins, dry flesh, skin, vertebral cartilage, liver, teeth, and jaws, as well as dried intestines. Sorting was followed by preparing shipments of dried fins, flesh, and skin for export. Similar to sharks of the same size, guitarfish preparation procedures were observed, except that snouts and fins were isolated from the remainder of the body due to the fins' relatively greater value.

The study revealed that except when marine fishing was prohibited (from June to July and all of October), traders collected sharks and rays and their products daily throughout the fishing season. They did, however, reveal that even during prohibition months, smaller vessels continued to collect shark and ray bycatches, including target rays. Large volumes of high-value sawfish (Pristidae) and guitarfish (Glaucostegidae, Rhinobatidea, Rhinidae) were frequently bought from fishing vessels directly to the processing centres while they were still at sea for immediate delivery to traders.

My research found that trade dynamics varied among research locations depending on aspects such as volumes landed, the availability of processing centres, and the ability of trades to trade locally or export. Whole-bodied sharks and rays were either auctioned whole or sold by weight. Direct shipments to Thailand, China, Hong Kong, India, the USA, and Vietnam were stated by traders. Most exports were destined for China, but from 2013/2014, all exports of shark and ray-related goods were coordinated through Myanmar. Between 2012 and 2014, shipments of shark and ray products to China and Hong Kong were prohibited by laws that traders could not identify appropriately. However, traders could circumvent this issue by shipping shark and ray products through Myanmar as general fishery products.

This study found that shark and ray products have been traded internationally for more than 40 years. However, due to overfishing and prohibitions by importer nations, trade has dropped since 2010/2011, or may have been concealed by traders. The yearly exports of dried shark meat and fins varied from 25 to 200 tonnes and 1 to 10 tonnes, respectively, between 1990 and 2017, according to five dealers in Cox's Bazar, with a downward shipment trend since 2010. Although the majority of the species are protected, most people who trade in shark and ray products are unaware of the protected status of endangered species. They have little access to secondary or alternative income sources, making them violate the law.

The influence of Bangladesh's fin and meat trade on vulnerable shark and ray populations is unknown because it has operated for decades with no regulation or reporting regarding sharks and rays. My research shows that the global trade in shark and ray products is still primarily undocumented, with the actual trade being between 86% and 335% larger than the declared trade. Only a small portion of global trade data is published, while the vast bulk of trade goes undocumented. International databases also reveal the shortcomings of Bangladesh's catch and trade accounting system for sharks and rays. My findings demonstrate how Bangladesh's national and international shark and ray trade occupies a complex and specialized market niche for both traditional product usage and consumer consumption.

This research found that legislation is currently the only tool in place for protecting sharks and rays in Bangladesh. Additionally, I found that only punitive measures are being enforced to prohibit the catching and trading of sharks and rays. However, there are numerous instances of existing legislation and bans failing to improve species protection, particularly in developing nations (Bladon, 2016), due to insufficient enforcement (Spaet & Berumen, 2015; Spaet et al., 2016), a lack of high-quality research (Fischer et al., 2012; Jabado et al., 2015), weak institutions with inadequate funding, and a lack of public awareness (Kuperan, 2010). This study also indicated that there is a chance that stringent regulations and monitoring (an overall ban, abrupt raids, and fines) will force traders to either find alternate channels for trade or ultimately turn to the growing black market, as suggested by the behaviour of traders in China and Hong Kong because I found that the majority of traders believe that any mechanisms to control bycatch are ineffective and that the regional supply of seafood is unlimited.

My research found that the current regulations do not take the socioeconomic vulnerabilities of fishers and trades into account to change unsustainable behaviours, a primary cause found for the existing non-compliance. Understanding and embracing socioeconomic drivers of catch and trade should enhance management practices and compliance, even though an all-encompassing ban on catch and trade can be economically detrimental to fishers (Bergmann et al., 2004; Carlsson & Berkes, 2005; Castello, 2008; Silvano & Begossi, 2012; Barbosa-Filho et al., 2016; Thyresson et al., 2013; Maynou et al., 2018). While trade regulations are crucial, it is essential to realize that top-down regulatory measures suddenly implemented and ignoring socioeconomic complexity are likely to do more harm than good (Booth et al., 2019; Mason et al., 2020). For instance, improving fishers' social, economic and nutritional status may alleviate the strain on unsustainable fishing. Based on my findings, I suggest that sustainable shark and ray (as opposed to umbrella bans) fisheries management strategies be given priority to fulfil shark conservation and fisheries management objectives.

International databases show the shortcomings of Bangladesh's catch and trade accounting system for sharks and rays. Only a small portion of global trade data is published, while the vast bulk of trade goes undocumented. The FAO rated Bangladesh 19th in the fin trade export by volume, despite the fact that there is little knowledge about historical shark and ray trade in the Bangladesh region, with an average export of 95 tonnes of shark fins recorded between 2000 and 2011 (Dent & Clarke, 2015). However, there were only eight years of export data available (2004–2011), which is too conservative. The FAO data (from FishStatJ), which reported fewer than 20 tonnes for most of these years (2004-2011), is most likely a gross understatement. Anomalies were also detected in the Department Fisheries of Bangladesh, CITES, and UNComtrade data sets. Therefore, Bangladesh must immediately review its current procedures for collecting fishing data and labelling items used in the marketing of fishery products and reorganize them to consider species protection. Priority actions should include setting up official landing sites with effective regulations in the most prominent shark and ray landing locations where there is currently no formal government accounting system in place. Onboard monitoring and log booking should be enabled to increase effectiveness. Additionally, some relatively simple mechanisms that can be implemented include training landing site officials for identification and monitoring protocols, hiring trained officials at landing sites and shark processing centres, training and routine updating of technicians at proposed landing sites and traditional artisanal fishing communities, and establishing proper reporting mechanisms for international databases (e.g., CITES, FAO).

However, the long-term resource requirements of such a wide range of activities at numerous landing locations and fishing vessels must be taken into consideration. Thus, it is vital to design, test, and deploy alternative, innovative, and affordable methods of monitoring fishing, catch, landing, and trade, for instance, with strategies like Environmental DNA (eDNA). Our capacity to identify the occurrence and distribution of terrestrial and aquatic species has been completely transformed by eDNA technologies. According to recent research, the concentration of eDNA may serve as an efficient, quick measure of biomass and/or abundance for fisheries stock assessments (Rourke et al., 2022). Moreover, several monitoring techniques may be applied, including citizen science, citizen science apps, satellite tagging of species, and combining satellite imaging and remote sensing data (Kourti et al., 2005; Greidanus, 2008; Rourke et al., 2022; Renshaw et al., 2023).

7.2.4. Market

The previous chapters highlight that sharks and rays are caught both as targets and bycatch but predominantly the latter. Fins from both protected and non-protected species are supplied and traded with other sharks and rays and general fishery products (e.g., fish maw). Problems brought on by a lack of reporting, little monitoring, and trouble differentiating products and species were recognised by these studies. Due to a lack of knowledge, skills, and incentives to reduce fishing mortality and the presence of existing markets and financial benefits, bycatch retention levels were found to be high, inevitably resulting in national and/or international trade. Building on these chapters, the market was then considered and studied in more detail using the framework proposed by Oyanedel et al. (2021a). The framework links several market components of the wildlife trade (WT) and collects the numerous factors that affect the dynamics of the wildlife market and was used to analyze socio-economic data. A framework with three levels of analysis was used. First, "actor" assesses the motivations and actions that permit or restrict how actors profit from the wildlife markets. The second layer, "inter-actor," assesses the structure of wildlife supply chains and the competition level between market participants. Last but not least, "market" evaluates supply-demand dynamics, quantity and price aspects, and the presence and consequences of illegal products entering markets. I analyzed the high-value fin trade market for sharks and rays inside Bangladesh's data-limited fisheries using the aforementioned analytical levels. I provide specialized solutions that support economically and socio-culturally sensible measures for reducing unsustainable fin trade based on findings. This technique may be used in data-poor regions with extensive illegal wildlife trafficking, such as Southeast Asia, where market interventions may be successful.

The study revealed that shark fin trade participants were from various geographic locations and had a range of access mechanisms and reasons for participating in the trade. The market's financial structure and the actors' power dynamics were found to be unbalanced, with certain participants receiving undue advantages from the fisheries. For example, fin and meat trade profits were often smaller for fishers than for traders. This hinders actors with little access to resources ('low-access actors') from adopting conservation actions. Conflicts, corruption, non-compliance, and a lack of will to report catch have emerged, as was found by the study.

I found that high monetary benefits attracted traders to trade in shark and ray products. Fishers and intermediaries (i.e., actors facilitating trade on sharks and rays and their products between fishers and traders) reported being equally motivated but occasionally impacted by normative incentives for sawfish fins, meat, and cartilage (e.g., personal and social norms of believing in their disease-curing properties). Due to poverty, a lack of social security, and inadequate livelihoods, target fishers' incentives were instrumental (catch more for a higher price); nonetheless, the advantages achieved were comparably smaller than those of traders.

The benefits of fishing and trading are accessed and maintained by traders in various ways (e.g., access to national and international vendors, export routes, and information). The high-value fin trade primarily benefits merchants, and boat owners set the prices for whole-body specimens at the landing locations. The traders, however, regarded the chain's last vendors as its most significant economic winners. The study found a widespread reluctance to disclose such trade to avoid being discovered by law enforcement authorities. The refusal to disclose catches was also motivated by corruption and mistrust of fisheries and forest officials.

The most geographically, socially, and economically disadvantaged groups in Bangladesh are the small-scale fishers (Islam et al., 2014). Therefore, a lack of competence and subsequent willingness to absorb short-term expenditures limits the ability to adopt management activities, posing obstacles to compliance (Carbonetti et al., 2014; Brown et al., 2015; McClenachan et al., 2012). Therefore, based on the study's findings, I suggest that it is necessary to provide positive incentives for local management to balance the expense of enforcement (Bulte et al., 2003; Child, 2012; Biggs et al., 2013; Di Minin et al., 2014; Cooney et al., 2015; Haque et al., 2022a, 2022b). It may be possible to implement enhanced advantages from sustainable stock allocation, species- or taxon-specific harvestable quotas based on biological sustainability, and more stable financial structures to maintain fishers' earnings and improve compliance with regulations.

The study found that a few traders controlled a disproportionate market and had the resources and connections to deal in expensive fins. It was clear from the study's results that, like in many other places, evading wildlife trade prohibitions is frequently regarded as low-risk in Bangladesh (Haque & Spaet, 2021- Chapter 4 of this thesis). As a result, traditional behavioural change is required to improve trade control measures and implement an efficient monitoring and reporting mechanism with both positive and negative incentives (Wallen & Daut, 2018).

The study found that due to the lack of effective awareness efforts and consultation, actors were unsure about the legality (Haque et al., 2021b, c). The situation is made worse by the difficulty of identifying protected elasmobranch species at landing locations, with identification particularly difficult for untrained individuals and lacking genetic data. Based on the study's findings, I recommend that in the processing facilities, ports, and marketplaces, it is essential to ensure that protected species (illegal to catch and trade) are separated from non-protected species (legal to catch and trade). Putting forensic equipment at checkpoints is one remedy (Ogden, 2008; Cardeñosa et al., 2018).

This research significantly expands knowledge about the Bay of Bengal's shark and ray trade and market. **The findings of this study show that the high-value fin market is supply-driven, implying that supply-side measures are more likely to succeed in mitigating unsustainable trade on shark fins.** Specific management suggestions are made to reduce unsustainable trade (e.g., sustainable catch quotas, improved access to incentives, information and capacity for low-access actors). The methodology may help and enhance the management of sharks and rays in data-poor areas.

7.2.5. Area of exposure

I identified potential areas of exposure to assess the risks of fishing that Bangladesh's seven principal artisanal sub-fisheries pose to Critically Endangered sharks and rays. This study is the first to map the spatially detailed fishing footprints and risk assessments of these species caught in Bangladeshi artisanal fisheries. The region of exposure outcomes varied according to gear type and species. However, all artisanal fishing, especially in shallower waters, poses major cumulative threats to sharks and rays in the Bay of Bengal. I identified potential areas of concern which needs to be managed spatially to reduce species and species interaction. Various species showed variable degrees of exposure for different sub-fisheries and species-specific overlap for critical habitats with fishing footprints, showing the potential for area-based management. I proposed potential future prioritisation for area-based management taking advantage of the 30x30 goal and management approaches applicable in the Bay of Bengal.

Eliminating risks to sharks and rays from fisheries requires pre-emptive measures that minimise capture of bycatch species (e.g., transformations to gear and fishing/net-deployment techniques, technical bycatch mitigation approaches, spatiotemporal closure with incentives ensuring compliance and fishing-quota depending on species' biological resilience).

This risk assessment approach can serve as a platform for developing fishing pressure response techniques at specific fishery levels for the sustainable management of sharks and rays in this region and globally and can guide future studies. These findings can be a preliminary step for regional management organisations like the Indian Ocean Tuna Commission (IOTC), national governing bodies, and conservation groups as they decide how and where to use their limited resources to lessen the adverse effects of fishing on species at risk. This can also support the Convention on Migratory Species (CMS) and more nuanced non-detrimental findings for the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). More locally, this might help managers make better decisions, particularly without sufficient data. Researchers, managers, and policy-makers can use this evaluation as a guide or a point of reference for setting objectives for the conservation and management of sharks and rays in the Bay of Bengal and future studies.

7.3. Recommendations

My work can offer valuable information for evidence-based conservation, given the current efforts of Bangladesh to conserve sharks and rays in this area. Although the previous version of the NPOA (National Plan of Action) for sharks and rays prepared by BFRI in Bangladesh was not implemented, this is an excellent opportunity to enhance the NPOA with achievable and time-bound activities to reduce the capture and trade of sharks and rays and create actions that are appropriate for the context (social, economic and cultural). My research recommendations can help the NPOA with evidence on diversity, fisheries, trade, and geographically unique risks for these species. Every chapter includes future directions that may guide potential study areas and recommendations to improve conservation and management decision-making.

Key recommendations are as follows-

- **Monitoring**

1. Enhanced monitoring at landing sites, fishing vessels, and trading hubs using low-cost and easy-to-use methods and technology
2. Improved understanding of elasmobranch diversity and occurrence within Bangladeshi waters in freshwater, coastal and marine ecosystems

- **Co-designing policies with fishers**

3. Meaningful fishers' and other stakeholders' involvement in management and policy-making
4. Research on incentive-based management for bycatch mitigation and enhanced compliance for fishers and traders

- **Market-based solutions**

5. Market-based solutions for trade mitigation and promoting sustainable trade

- **Management guided by specific risk**

6. Area-based management guided by fishery-specific risk to elasmobranchs
7. Spatial management to conserve critically important coastal areas where the encounter of elasmobranchs with fisheries is high

- **Bycatch mitigation**

8. Employing technical bycatch mitigation strategies

- **Research on sustainable practices**

9. Further research on sustainable practices for both catch and trade on elasmobranchs

They must be tested to determine whether the study findings can improve the sustainability of elasmobranch fisheries. In fisheries management, putting research findings to the test necessitates -

1. a cooperative and adaptable strategy that entails including stakeholders,
2. creating and implementing an action plan,

3. assessing the effects/outputs, and
4. making adjustments as necessary.

Ideally, managers would-

1. work with the researchers and related stakeholders to create a measurable, attainable, relevant, and time-bound action plan.
2. the stakeholders must be consulted by hosting meetings or workshops with fisheries managers, fishers, and other relevant actors to review the findings and suggested courses of action.
3. when the activities are carried out, it is crucial to monitor and assess the action plan results to ascertain whether the strategy is yielding the desired results.
4. the action plan may need to be modified based on the findings of monitoring and assessment. This might entail altering laws or rules, fishing practices, promoting behavioural changes, or developing new tactics to deal with pressing problems.

This doctoral research made four broad recommendations:

1. improved monitoring
2. market-based trade mitigation approaches
3. fishers' participation in conservation measures; and,
4. research on bycatch mitigation techniques, which may be launched and tested given available resources.

For instance,

1. utilizing cutting-edge technology and approaches (eDNA, vessel trackers, online/offline log books) for monitoring,
2. to test a collaborative monitoring regime at landing locations and fishing vessels that incentivize fishers and locals to share catch and landing data will be useful.
3. to test the market-based approaches to trade mitigation outlined in Chapter 5 by utilizing supply-driven tactics in cooperation with relevant parties (fishers, traders, managers, and policy-makers) is also recommended.

Finally, given the political interest regarding the Kunming-Montreal Global Biodiversity Framework, which sets the target 3- "Ensure and enable that by 2030 at least 30% of terrestrial, inland water, and coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem functions and services ..."; there are more opportunities to designate the heavily fished areas within the Bangladeshi coastal and marine waters under area-based management (see Chapter 6).

7.4. Future research ideas

While pursuig my doctoral research, I kept coming back to many questions, a few of which are listed below, which can help design future studies -

1. What would sustainable fisheries look like where both the fish and the livelihoods of fishers are preserved in a country with several other grave social and economic problems to address?
2. How can a cohesive goal for similar problems be created towards adaptive responses instead of too many and too different regulations in place?
3. What would work best- sustainable trade, a trade ban, or a mix of both concerning sharks and rays and what would be the in-field consequences of such tools?
4. Is bycatch mitigation possible at scale for 70000 artisanal boats, and what investments, research and incentives would be needed to achieve mitigated rates of bycatch for endangered species?

Although some of the topics were outside the scope of my thesis, they are pertinent to the problems I raised and can help guide future research. In the following sections, I have covered several of these issues to help shape the questions that future research may address.

7.4.1. Further taxonomic and biological research

Identifying species at landing and trade locations is difficult, yet knowing what species are present and being caught is fundamental to effective conservation and management. Identification of sharks and rays is challenging due to a lack of national species lists and guides, which may use incorrect or misapplied names (Hussain, 1970), and inadequately curated reference collections, frequently depending on regional and international identification guides. With reference images and genetic testing, my work has increased the ability to identify morphologically similar sharks and rays. However, I also identified a number of issues with species identification in field settings that require immediate attention, for instance, difficulty in the identification of carcasses, body parts, species landed on their dorsal side, limited on-field forensic capacity, and less time given by the buyers and traders to work on a landing site. Furthermore, many elasmobranch species have taxonomic issues that need to be resolved. For example, a large number of earlier ichthyologists' descriptions have recently been synonymized (White et al., 2017; Froese & Pauly, 2009; Last et al., 2016) or have not yet been classified to a species level (Bineesh et al., 2016; Psomadakis et al., 2020). More research is required to locate morphologically distinctive or geographical subpopulations of endemic or cryptic species. Different variations are currently being examined for greater taxonomic understanding due to the possibility of geographically isolated population variants and species that are novel to science. As such, it is crucial that researchers in the field in Bangladesh are connected to the international taxonomic research community and vice versa. A comprehensive checklist of species and identification guide unique to this region is necessary and distributed so that it is widely available. Furthermore, as the use of life history features from populations outside the research area raises issues since such groups may vary (Amaral et al., 2017; Brown & Roff, 2019; Kyne et al., 2021). Further studies should emphasize collecting biological and ecological data on sharks and rays in data-poor regions.

7.4.2. Bespoke versus umbrella approaches

My study found that in the absence of regional or national data, many regulations are posed as an umbrella ban on catch and trade as opposed to nuances and species-specific unique needs for conservation in Bangladesh.

In terms of Bangladesh policy and legislation, there has been an increased level of enforcement of the newly amended national law- the Wildlife (Conservation and Security) Act of 2012, protecting most shark and ray species by regulating catch and trade (Haque et al., 2022a). The enforcement activities are reflected as an umbrella ban on catch and trade on the majority of shark and ray species frequently observed during the field work. However, such blanket enforcements jeopardise the potential of sustainable shark fisheries and have not been shown to reduce shark mortality (Shiffman et al., 2017). Such interventions (primarily punitive measures, e.g., fines, seizures) without enabling actors to adhere to the law or promoting sustainable catches (e.g., awareness, incentives, trainings) have increased conflict and scepticism on the part of traders and fishers regarding the effectiveness of laws and motives of fishery managers. This has also exacerbated traders' fear of detection and reduced willingness to report catch and trade (Haque et al., 2022 b). Traders are adapting to this situation by changing shark and ray landings and sale locations, a common tactic (e.g., Milner-Gulland & Clayton, 2002), to bypass enforcement activities.

There is no species-specific management measure for sharks and rays in Bangladesh beyond legal protection (Haque et al., 2022 a). A nuanced approach to targeted management measures is necessary (Dulvy et al., 2017; Shiffman & Hammerschlag et al., 2016a, 2016b). Regional species status assessments and risk profiles can be more efficient in deciding which species to protect and which can be sustainably managed in response to the geographically and socially unique risk elements.

7.4.3. Understanding the difference between policing versus facilitating compliance as a means of enforcement

It was observed throughout the study period that punitive measures, such as sanctioning penalties or the likelihood of being caught by law-enforcement bodies, are used by fisheries managers to motivate compliance of fishers or traders. Although, it was beyond the scope of the study to look at in depth and needs further research.

Enforcement activities (mostly punitive measures, e.g., seizures, penalties- jail time, fines) have increased conflict, and traders' fear of detection has reduced willingness to report catch and trade, leading to a change of sale point (Haque et al., 2022b) as mentioned before. *Punitive measures* are the most common management strategy (Doumbouya et al., 2017; Hilborn et al., 2005) and are based on the concept that social behaviour is driven by profit-maximizing only (Schill et al., 2019). However, evidence suggests that non-economic elements (based on normative and legitimacy-based components) play a significant role in driving compliance (Bergseth & Roscher, 2018; Bova et al., 2017; Thomas et al., 2016; Oyanedel et al., 2020a). In small-scale fisheries systems, where the system's complexity may prevent straightforward solutions or assumptions regarding fisheries management (Mahon et al., 2008; Waylen et al., 2013; Haque et al., 2021 b, c, d). As punitive measures are not completely effective, a diverse toolbox for improving compliance is needed (Oyanedel et al., 2020a, 2020b; Oyanedel et al., 2021a). Therefore, it is crucial to assess the various motivations behind fishers' and traders' actions and how they differ across different geographical scales to tackle compliance concerns (Oyanedel et al., 2020a), as I have researched in chapter 5. Further research is needed to understand how to co-design management to ensure social justice and inclusion of these communities leading to improved compliance. Research that tackles the underlying social, economic, and institutional elements that affect equality, access, and participation in the sector is necessary to advance social justice and inclusion in the fisheries sector. Understanding power dynamics, gender equity, relationships of livelihoods and poverty alleviation, access and rights-based approaches, social impacts of conservation measures, developing social indicators and metrics, and policy and governance analysis will be necessary to understand the social aspects of fisheries and create evidence-based plans and policies to promote social justice, equity, and inclusion in the industry by doing research in these areas.

Understanding fishers' motivations for fishing activities and compliance with different conservation legislation might inform fisheries managers for targeted actions (Arias, 2015; Thomas et al., 2016), which often need to be highly dynamic (Mahon et al., 2008). A collection of policy tools (based on scientific research) rooted in a strong theory of compliance should help managers identify the conditions for which economic or social improvements might encourage compliance and when non-economic motives are required (Oyanedel et al., 2020). Shark and ray-specific studies in the Bay of Bengal region, especially looking at actors, trade, and market interventions, are scarce to predict such problems or recommend based on evidence. To begin to address the lack of information and understanding, chapter 4 of my thesis analyzed the trade dynamics of shark and ray products in the region, highlighting inadequacies in reporting methods and revealing an underreporting of trade. Under-reporting (due to the absence of reporting mechanisms) was identified as one of the primary issues impeding effective trade monitoring and management.

7.4.5. Research on what would work for Bangladesh? - sustainable trade or trade ban

Making trade illegal or enabling sustainable trade are two techniques adopted to preserve and protect threatened species. Although it was beyond the scope of this study to determine the effectiveness of a no-trade policy or permitting species-specific legal trade in conserving the Bay of Bengal's shark and ray populations, it is essential to recognize that either way, achieving such is challenging, and further research is needed to investigate this question. It is commonly believed that a species' chances of survival are better under a ban than under legal trade (Bennet et al., 2021a). However, without a highly resource-intensive incentive regime, it is almost impossible to completely outlaw the trade in species that contribute to a community's subsistence. As a result, when charismatic animals become endangered, we see a conservation community divided over which policy instrument to adopt (Bennett et al., 2021; Roe et al., 2014; Biggs et al., 2017; Felbab-Brown, 2017; Moyle, 2017). This debate is highly relevant for shark and ray fin and meat trade globally, mainly because it is a transboundary problem with a suite of stakeholders and a billion-dollar existing market (Okes & Sant, 2019) impacting globally threatened populations (Dulvy et al., 2021). Furthermore, there has been limited research on how sustainable legal trade can support shark or ray population survival and provide livelihoods simultaneously.

7.4.6. Research on consumer behaviour

Another aspect that needs further research in consumer behaviour. Consumer preferences, the availability of suitable alternatives, and the available wealth on the consumer end may all impact supply of a particular product (Bennet et al., 2021). Although demand-driven mechanisms were not documented for the majority of the fin trade in Bangladesh (see chapter 5), undocumented and emerging market signals (may be an increasing consumer demand) may cause the market to shift (e.g., very high demand for a particular species-sawfish products in our case study). Extreme rarity might be a precursor to yielding a significant price (Courchamp et al., 2006). Furthermore, if equivalent items or alternatives exist, demand for the species would fall as people seek out alternatives when prices increase above a certain point. If acceptable substitutes are unavailable, such as if consumers seek an item from the wild that has no substitutes due to its extreme rarity or cultural/religious belief in its unique medicinal efficacy, demand may continue to expand even though price levels are exceptionally high (Verheij et al., 2010; 't Sas-Rolfes & Fitzgerald, 2013). Our study was unable to analyze the access and motives of international consumers; nonetheless, there were signs that the potential increased demand may be matched by increased fishing efforts and stockpiling (Trader, pers. comm., 01 June 2021). Buyers (Bennet et al., 2021) or intermediaries/ traders (Haque & Spaet, 2021) can store non-perishable wildlife commodities (Eriksson & Clarke, 2015) (e.g., shark fins). Stockpiles can operate as a barrier between consumers and biological populations, causing a delay in offtake in response to shifting demand. As a result, the signal between supply and demand may become less transparent (Bennet et al., 2021), causing a significant delay in the assessment of a population decline. For a thorough picture of the supply-chain structure, more research is needed on this topic regarding the Bangladeshi shark and ray product trade.

7.4.7. Research on bycatch mitigation at various scales and types of gears

It is important to discuss that my study revealed that there is no bycatch mitigation strategy for sharks and rays to ensure sustainable fishing with monitoring and compliance, fishers need technical facilities to mitigate bycatch (e.g., mesh size restriction) (Osuka et al., 2021), an organized monitoring protocol at landing sites and species/taxon-specific harvestable quota (depending on biological sustainability). Techniques such as gear modification (e.g., mesh size modification for gillnets or increasing the size of hooks for unbaited longlines), using deterrents such as LED lights or acoustic devices, changing the duration and/or position in the water column where the gear is deployed mitigating chances of encounter and entanglement of threatened species (Senko et al., 2022; Piovano et al., 2010; Gilman, 2011, 2016, 2019; Kiszka et al., 2021; Bielli et al., 2020; Hanamseth et al., 2018; Mangel et al., 2018; Hamilton & Baker, 2019; Swimmer et al., 2020, 2017; Poisson et al., 2022; Afonso et al., 2021) – need to be tested within Bangladeshi context. Future research for gear-specific bycatch mitigation strategies is urgently needed to mitigate the adverse impacts of artisanal fisheries. Live and safe release mechanisms must be tested and tried with fishing communities (Haque et al., 2020; Wosnick et al., 2020; García-Rodríguez & Sosa-Nishizaki, 2020). Innovative approaches that go beyond changing the gear, such as combining satellite and various data sources to create adaptive management tools (Roberson et al., 2022) or working directly with fishing communities to develop context-specific strategies to prevent catching endangered species (Haque et al., 2022 b; O'Bryhim et al., 2016; MacKeracher et al., 2021; Hazen et al., 2018)- requires to be sought after.

7.5. Limitations

Limitations of the study was described in different chapters within the discussion sections (see chapter 2-6). To summarise, in the absence of previous dependable national and regional checklists and guides for shark and ray species, identification was challenging and a few specimens were unidentified awaiting genetic identification results. This is indicative of even this study has underestimated the total diversity of sharks and rays within this region. This is study also did not consider the industrial fisheries, potentially taking out deep sea species, which needs further work. The limited time given by the traders at landing sites and in absence of resources I couldn't survey the vessels to understand gear specific catch. For this information I had to depend on the fishers, thus it may have some bias. Although landing data can be used as a proxy for populations within the coastal areas, it still is fishery-dependent data, for in future needs more in-depth fishery-independent understanding for population level knowledge.

In the absence of the annual trade data, I was unable to present any temporal changes (i.e., trend) in traded amount quantitatively, however, traders log-books were investigated and partial view was presented. I also used interview data for a qualitative understanding on the trend regarding trade. The study excluded vendors and consumers, which created uncertainity in the market analysis (presented in the results in chapter 5). The research was unable to interview overseas consumers and end-of-chain vendors. Harvesters, traders, and intermediaries were the only actor kinds allocated as a consequence. With an additional layer of analysis (such as feasibility) that evaluates the effects of fisheries and actors participating in different practises, motives, and their impact on the sustainability problem while building solutions, the methodology of chapter 5 may be more effective. Before being put into practice, the recommendations must be piloted and evaluated to determine their viability. Similar studies need to be conducted in the face the changing behaviours of actors in response to enforcement.

Although the risk assessment of sharks and rays (see chapter 6) was carefully curated and residual risk assessments, data quality inspection and uncertainty were rigorously conducted and presented, it is essential to note that the assumptions and results can improve with the availability of more data. For instance, the fishery footprint was mapped using social data; however, fishing vessel tracking data could have been ideal for mapping the footprint more accurately, which I am collecting using a technologoical innovation for ground-truthing these results, as I write this thesis.

It is necessary to note that this particular availability (risk attribute of exposure) assessment does not consider temporal variability (such as when fishing operations occur during the day or night or how often the gear is deployed at different times of the day). It also does not consider seasonal variability (such as potential migrations or changing fishing efforts around a particular season) or ontogenetic changes in species (e.g. sharks and rays have juvenile stages with distinctive life history traits). These presumptions allow risk estimates to be inflated when the actual overlap between fishing and species is lower than anticipated and undervalued when the overlap is more than the results found (Roberson et al., 2022). Hence, these results need to be interpreted with caution.

The underlying assumption was that the species and fishing gear are distributed equally throughout the overlapped range and that the overlap is homogeneous across all areas (for encounterability- risk attribute of exposure). This presumption causes encounterability for species and gears that tend to concentrate in the same shallow region of their depth ranges to be underestimated. In contrast, encounterability for species that spend more time at depths outside of the region where the majority of fishing effort is concentrated is overestimated (e.g. many pelagic-associated sharks and rays are less likely to encounter unbaited longlines or prawn trawl gears than the depth overlaps suggest). The selectivity was based on proxy data instead of actual observations at sea. Although the results are very dependable, they can improve with gear-specific data. Management efficacy (risk element) looks at the existence of the management regime instead of the application and enforcement of those actions in the field. Hence, the results need to be understood with caution. It does not mean that the shark and ray populations are well-managed; it means that the policies and infrastructure are there to manage these species.

7.6. Concluding thoughts- my thoughts on different aspects of field work, sustainable fishery and conservation tools, revealed while writing this thesis

Throughout my DPhil research, I came to understand that 'appreciation of context' is a crucial component of any successful conservation regime. Suppose a country's or community's social, geopolitical, economic, and cultural context is not considered; in that case, a "state of the art" solution to an unsustainable problem in theory or on paper may not succeed in being implemented. There is no substitute for local efforts and innovations developed with genuine cooperation, and that is socially, culturally, and morally suitable if we are to accomplish the high throughput global goals (e.g., SDGs). As a result, it is imperative to co-create a local knowledge base, which my thesis has initiated for sharks and rays in Bangladesh. In the (sometimes) divided world of conservation researchers and practitioners, I conclude my thesis with a notion that I found challenging to convey to many of the people I interacted with: it is crucial to realize that there is more than one way to view the world. Recognizing and considering the perspectives of all impacted communities and stakeholders is crucial for achieving the shared objectives of species and habitat preservation and social justice.

I am in quite a different place than when I began my DPhil after reflecting on the process of reviewing the literature on shark and ray conservation and sustainable fishing, as well as conducting extensive fieldwork, surveys and using various methodologies for my case study. Conservation of sharks and rays gained global interest in the last two decades, much later in the global south. The interest in conserving them in the Bay of Bengal is more reactive towards the 'doom and gloom' narrative and the international interest than creating a national agenda depending on the countries' unique risks and needs. Before I started my DPhil work, I believed the preservation of endangered sharks and rays was a ‘goal’ for which I planned to create the evidence base and inform the decision makers about what needs to be done. However, after over three years, I understand that, it is rather a ‘process’ where a systemic change is necessary and the problem's narrative needs to be context-appropriate and well-articulated, and a lot more work needs to be conducted in the ecological, social, economic and political arena.

After visiting and conversing with Bangladeshi fishers with whom I worked in close proximity, I had both periods of intense optimism about the core nature of people to sustain the marine fauna; and utter frustration due to the difficulties and length of time required to address the ecological, social and political complexities before even beginning to notice a small amount of improvement for both the vis-à-vis fish and fishers.

When I wrote the proposal for my work, many questioned why the traders of illegal products would give you interviews or tell the truth. This came from a place of homogenizations of harvesters as 'bad' and as the problem of the doom of fisheries. And then, I got the exceptional chance to spend months close to fishing villages and weeks on a boat in the rivers and shallow waters of the Bay of Bengal (both before and after my DPhil fieldwork). I found out it is not appropriate to categorize fishing as either 'right' or 'wrong' without understanding how and why a fisher catches fish or how challenging it may be for them to follow restrictions. In addition to removing the reality and complexities of the action and tradition of a fishing-dependent community, homogenization of the narrative for fishers' or traders' actions as 'black and white' leads to adversity and non-compliance, which ultimately does not aid the goal of conservation.

But going into the field and conversing in depth with the community members can create other issues, such as the researcher's bias. I felt deeply connected with these communities, affected by their vulnerabilities and long-standing marginalization, as opposed to my utter privilege to go and ask them about their lives and work for my DPhil. This made me think about the ethics of data use and a researcher's relationship with the respondents, building trust and many other different ethical issues that may arise from such a relationship. On multiple occasions, fishers were weary of researchers' capacity and intention to truly help them. They felt they had been interviewed by many researchers and journalists, but nothing had changed for them. Often, the data collected from them were used to create a regulation without their knowledge of how that data will be used by NGOs, researchers and Government organizations. I felt conflicted by my role as a researcher - is it just reporting and creating a knowledge base? Or am I expected/ needed to act on them? What responsibilities do I have to these people who have given their precious time and shared knowledge of life-long experiences with me without asking for anything in return?

Finally, I felt that even the best ideas (such as science-based recommendations, suggestions or solutions for mitigating catch and trade of sharks and rays) might have unintended consequences. Even though the suggestions in my chapters were based on data we gathered and research on fishing systems comparable to Bangladesh's, many of them haven't been put to the test there. As a result, I focused on adaptable policies with space for development in light of newer information and shifting social and ecological demands. I suggest putting the recommendation to the test.

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Appendices

APPENDIX 1: SUPPLEMENTARY MATERIAL FOR CHAPTER TWO

Appendix 1.1. Supplementary tables and figures

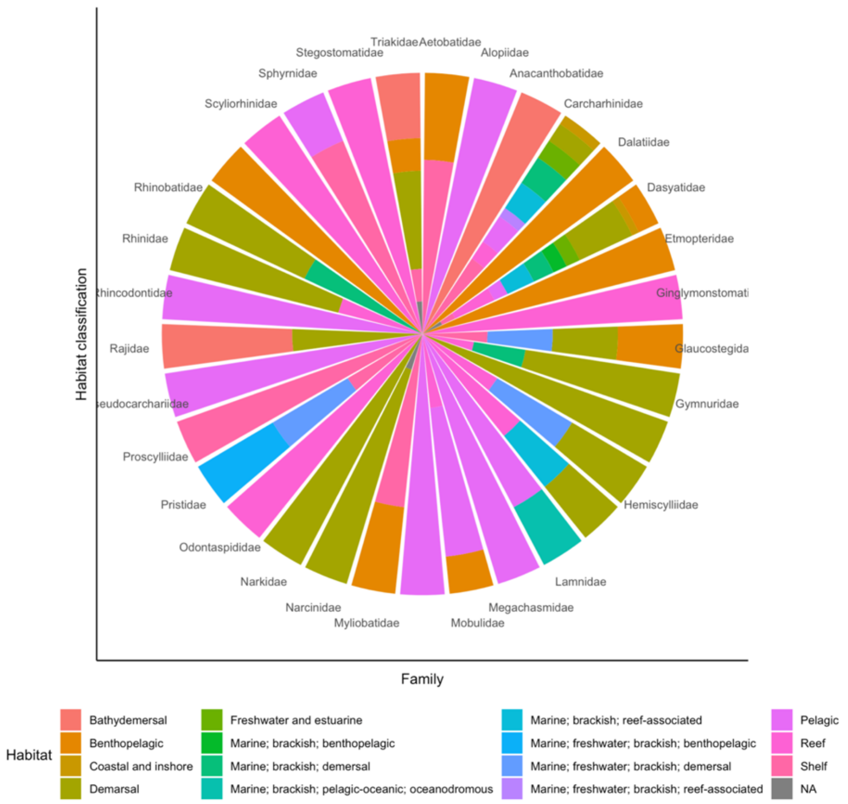

Figure S2.1. Habitat uses. Habitat and ecological niche of each species within each family of elasmobranchs reported in the checklist.

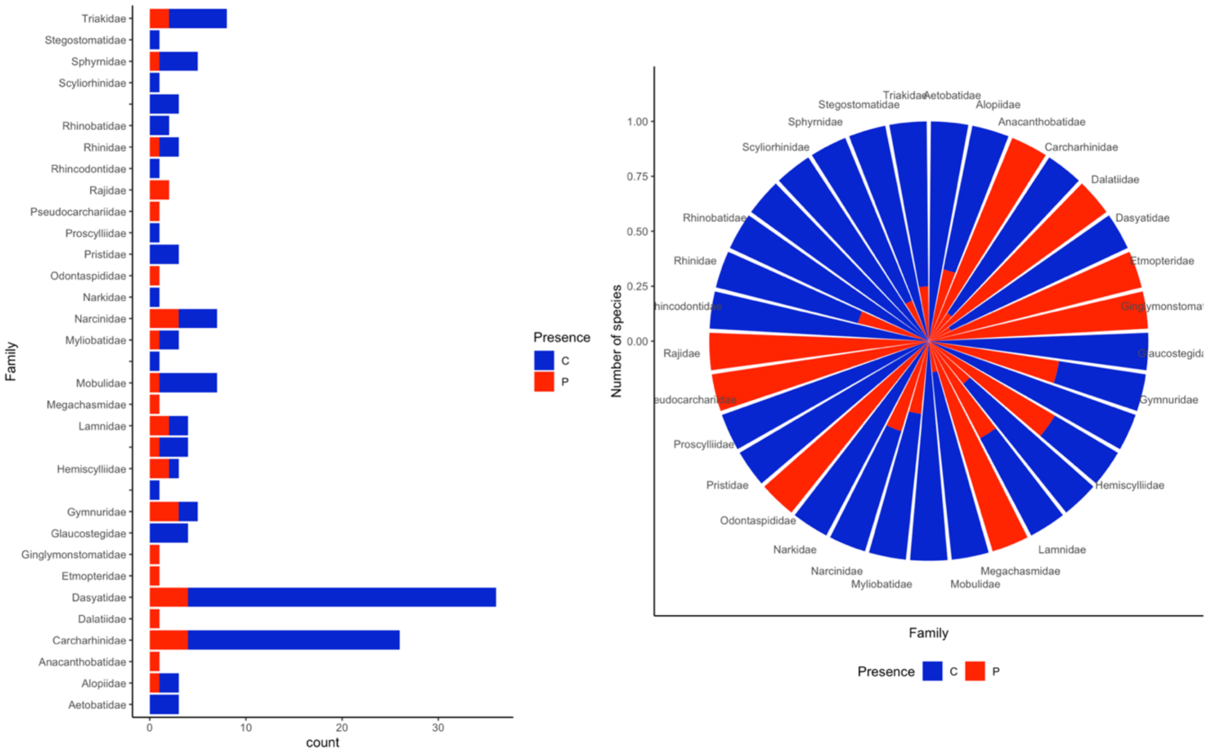

Figure S2.2. Species in each family reported in the checklist. Blue shows the species occurrence from the region was confirmed and evaluated following recent publications and globally accepted range studies and red stands for species needed further confirmation.

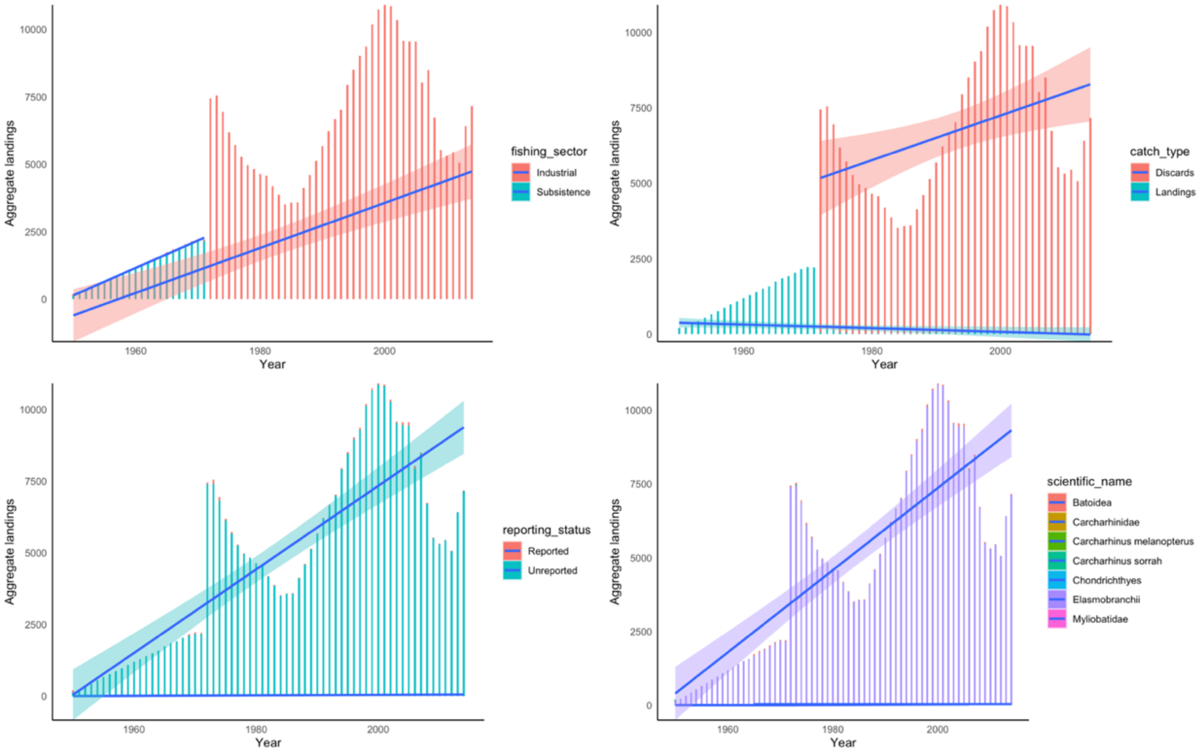

Figure S2.3. Landings of elasmobranchs from the Bay of Bengal, Bangladesh from 1950–2016 from the data obtained from Sea Around Us.

Table S2.1. Annotated checklist of elasmobranchs in Bangladesh (Until June 2020).

Sharks							
Family	Reported Name	Valid scientific name	Common name	Comments	IUCN	CITES (App.)	CMS (App.)
	Hypoprion palasorrah			Questionable identity: was reported by Hossain et al., 1970	-	-	-
Alopiidae	*Alopias pelagicus*	*Alopias pelagicus*	Thresher Shark	Reported from Bay of Bengal, Confirmation needed for Bangladesh	EN	II	II
Alopiidae	*Alopias superciliosus*	*Alopias superciliosus*	Bigeye thresher	CITES trade database	VU	II	II
Alopiidae	*Alopias vulpinus*	*Alopias vulpinus*	Common Thresher	CITES trade database	VU	II	II
Carcharhinidae	*Carcharhinus amblyrhynchoides*	*Carcharhinus amblyrhynchoides*	Graceful Shark	Confirmed presence	NT	-	-
Carcharhinidae	*Carcharhinus amboinensis*	*Carcharhinus amboinensis*	Pigeye Shark/ Java shark	Confirmed presence	DD	-	-
Carcharhinidae	*Carcharhinus brevipinna*	*Carcharhinus brevipinna*	Spinner Shark	Confirmed presence	VU	-	-
Carcharhinidae	*Carcharhinus dussumieri*	*Carcharhinus dussumieri*	Whitecheek shark	Confirmed presence	EN	-	-
Carcharhinidae	*Carcharhinus menisorrah*	*Carcharhinus falciformis*	Silky shark	Confirmed presence	VU	II	II
Carcharhinidae	*Carcharhinus hemiodon*	*Carcharhinus hemiodon*	Pondicherry shark	Fishbase and IUCN distribution map shows the range includes Bangladeshi waters.	CR	-	-
Carcharhinidae	*Carcharhinus leucas*	*Carcharhinus leucas*	Bull Shark	Confirmed presence	NT	-	-
Carcharhinidae	*Carcharhinus limbatus*	*Carcharhinus limbatus*	Blacktip Shark	Confirmed presence	NT	-	-
Carcharhinidae	*Carcharhinus longimanus*	*Carcharhinus longimanus*	Oceanic whitetip shark	CITES trade database	CR	II	I
Carcharhinidae	*Hypoprion macloti*	*Carcharhinus macloti*	Hardnose shark	Confirmed presence	NT	-	-
Carcharhinidae	*Carcharhinus melanoptera*	*Carcharhinus melanopterus*	Blacktip reef shark	Confirmed presence	VU	-	-

Carcharhinidae	*Carcharhinus sealei*	*Carcharhinus sealei*	Blackspot shark	Fishbase and IUCN distribution map shows the range includes Bangladeshi waters.	NT	-	-
Carcharhinidae	*Carcharhinus sorrah*	*Carcharhinus sorrah*	Spot-tail shark	Confirmed presence	NT	-	-
Carcharhinidae	*Carcharhinus ellioti*	*Carcharius ellioti / Hemipristis elongata*	Snaggletooth shark	Confirmed presence	VU	-	-
Carcharhinidae	*Galeocerdo cuvier*	*Galeocerdo cuvier*	Tiger shark	Confirmed presence	NT	-	-
Carcharhinidae	*Carcharhinus gangetica*	*Glyphis gangeticus*	Ganges shark	Confirmed presence	CR	-	-
Carcharhinidae	*Glyphis glyphis*	*Glyphis glyphis*	Speartooth Shark	Need further confirmation	EN	-	-
Carcharhinidae	*Lamiopsis temminckii*	*Lamiopsis temminckii*	Broadfin Shark	Confirmed presence	EN	-	-
Carcharhinidae	*Loxodon macrorhinus*	*Loxodon macrorhinus*	Sliteye shark	Confirmed presence	LC	-	-
Carcharhinidae	*Negaprion acutidens*	*Negaprion acutidens*	Sicklefin lemon shark	Need further confirmation	VU	-	-
Carcharhinidae	*Prionace glauca*	*Prionace glauca*	Blue shark	Need further confirmation	NT	-	II
Carcharhinidae	*Scoliodon walbeehmii*	*Rhizoprionodon acutus*	Milk Shark	Confirmed presence	VU	-	-
Carcharhinidae	*Rhizoprionodon oligolinx*	*Rhizoprionodon oligolinx*	Grey sharp nose shark	Confirmed presence	LC	-	-
Carcharhinidae	*Physodon mulleri*	*Scoliodon laticaudus*	Spadenose Shark	Synonym of Scoliodon laticaudus	NT	-	-
Carcharhinidae	*Scoliodon sorrakowah*	*Scoliodon laticaudus*	Spadenose shark	Confirmed presence	NT	-	-
Carcharhinidae	*Scoliodon macrorhynchos*	*Scoliodon macrorhynchos*	Pacific spadenose shark	Confirmed presence	NT	-	-
Carcharhinidae	*Triaenodon obesus*	*Triaenodon obesus*	Whitetip reef shark	Confirmed presence	VU	-	-
Dalatiidae	*Euprotomicrus bispinatus*	*Euprotomicrus bispinatus*	Pygmy shark	Circum-global range according to Fishbase weebsite.	LC	-	-

Etmopteridae	*Centroscyllium ornatum*	*Centroscyllium ornatum*	Ornate dogfish	Need further confirmation	LC	-	-
Ginglymonstomatidae	*Nebrius ferrugineus*	*Nebrius ferrugineus*	Tawny nurse shark	Need further confirmation	VU	-	-
Hemigaleidae	*Hemigaleus balfouri*	*Chaenogaleus macrostoma*	Hooktooth shark	Confirmed presence	VU	-	-
Hemiscylliidae	*Chiloscyllium burmensis*	*Chiloscyllium burmensis*	Burmese Bamboo Shark	Confirmed presence	VU	-	-
Hemiscylliidae	*Chiloscyllium* cf. *arabicum*	*Chiloscyllium* cf. *arabicum*	Arabian carpetshark	Need further confirmation	NT	-	-
Hemiscylliidae	*Chiloscyllium griseum*	*Chiloscyllium griseum*	Grey bambooshark	Confirmed presence	VU	-	-
Hemiscylliidae	*Chiloscyllium hasseltii*	*Chiloscyllium hasselti*	Hasselt's bambooshark	Confirmed presence	EN	-	-
Hemiscylliidae	*Chiloscyllium indicum*	*Chiloscyllium indicum*	Slender bambooshark	Confirmed presence	VU	-	-
Hemiscylliidae	*Chiloscyllium plagiosum*	*Chiloscyllium plagiosum*	Whitespotted bamboo shark	Fishbase and IUCN distribution map shows the range includes Bangladeshi waters.	NT	-	-
Hemiscylliidae	*Chiloscyllium punctatum*	*Chiloscyllium punctatum*	Grey Carpetshark	Need further confirmation	NT	-	-
Lamnidae	*Lamna nasus*	*Lamna nasus*	Porbeagle shark	CITES trade database	VU	II	II
Lamnidae	*Carcharodon carcharias*	*Carcharodon carcharias*	Great white shark	Cosmopolitan distribution according to Fishbase	VU	II	I & II
Lamnidae	*Isurus oxyrinchus*	*Isurus oxyrinchus*	Shortfin mako	Confirmed presence	EN	II	II
Lamnidae	*Isurus paucus*	*Isurus paucus*	Longfin mako	Circumglobal range according to Fishbase and IUCN	EN	II	II
Megachasmidae	*Megachasma pelagios*	*Megachasma pelagios*	Megamouth shark	Circumglobal range according to Fishbase and IUCN	LC	-	-

Odontaspididae	*Carcharias taurus*	*Carcharias taurus*	Sand tiger shark	Circumtropical according to Fishbase	VU	-	-
Proscylliidae	*Eridacnis radcliffei*	*Eridacnis radcliffei*	Pigmy ribbontail catshark	Confirmed presence	LC	-	-
Pseudocarchariidae	*Pseudocarcharias kamoharai*	*Pseudocarcharias kamoharai*	Crocodile shark	Tropical and subtropical waters of all oceans according to Fishbase	LC	-	-
Rhincodontidae	*Rhincodon typus*	*Rhincodon typus*	Whale Shark	Confirmed presence	EN	II	I & II
Scyliorhinidae	*Atelomycterus marmoratus*	*Atelomycterus marmoratus*	Coral catshark	Confirmed presence	NT	-	-
Sphyrnidae	*Sphyrna blochii*	*Eusphyra blochii*	Winghead shark	Confirmed presence	EN	-	-
Sphyrnidae	*Sphyrna lewini*	*Sphyrna lewini*	Scalloped Hammerhead	Confirmed presence	CR	II	II
Sphyrnidae	*Sphyrna mokarran*	*Sphyrna mokarran*	Great hammerhead shark	Confirmed presence	CR	II	II
Sphyrnidae	*Sphyrna tudes*	*Sphyrna tudes*	Smalleye hammerhead	Questionable record. Distributed through mainly Western Atlantic and eastern Pacific; Mediterranean Sea	CR	-	-
Sphyrnidae	*Sphyrna zygaena*	*Sphyrna zygaena*	Smooth hammerhead	Confirmed presence	VU	II	II
Stegostomatidae	*Stegostoma fasciatum*	*Stegostoma fasciatum/ Stegostoma tigrinum*	Zebra shark	Confirmed presence	EN	II	-
Triakidae	*Galeorhinus galeus*	*Galeorhinus galeus*	Tope shark	Questionable record. A temperate species.	CR	-	II
Triakidae	*Iago garricki*	*Iago garricki*	Longnose Houndshark	Confirmed presence	LC	-	-
Triakidae	*Iago* cf. *omanensis*	*Iago omanensis*	Bigeye houndshark	Confirmed presence	LC	-	-
Triakidae	*Iago sp.*	*Iago* cf. *omanensis*	Bigeye houndshark	Need further confirmation	LC	-	-
Triakidae	*Mustelus griseus*	*Mustelus griseus*	Spotless Smoothhound	Confirmed presence	EN	-	-

Triakidae	*Mustelus kanekonis*	*Mustelus kanekonis*	Spotless Smoothhound	Confirmed presence	NE	-	-
Triakidae	*Mytmillo manazo*	*Mustelus manazo*	Starspotted smooth-hound	Confirmed presence	EN	-	-
Triakidae	*Mustelus mosis*	*Mustelus mosis*	Arabian smooth-hound	Confirmed presence	NT	-	-
			Rays				
Anacanthobatidae	*Sinobatis andamanensis*	*Sinobatis andamanensis*	Andaman Legskate	Bay of Bengal is a range according to the maps of Last et al., 2016. Possible presence	LC	-	-
Aetobatidae	*Aetobatus flagellum*	*Aetobatus flagellum*	Longheaded Eagle Ray	Confirmed presence	EN	-	-
Aetobatidae	*Aetobatus ocellatus*	*Aetobatus ocellatus*	Ocellated eagle ray	Confirmed presence	VU	-	-
Aetobatidae	*Aetobatus narinari*	*Aetobatus narinari*	Spotted Eagle Ray	Confirmed presence	NT	-	-
Dasyatidae	*Brevitrygon heterura*	*Brevitrygon heterura*	Dwarf Whipray	Confirmed presence	NE	-	-
Dasyatidae	*Dasyatis (Amphotistius) imbricata*	*Brevitrygon imbricata*	Scaly Whipray	Confirmed presence	DD	-	-
Dasyatidae	*Dasyatis (Himantura) walga*	*Brevitrygon walga*	Dwarf Whipray	Confirmed presence	NT	-	-
Dasyatidae	*Dasyatis (Amphotistius) zugei*	*Dasyatis zugei*	Pale-Edged Stingray	Confirmed presence	NT	-	-
Dasyatidae	*Dasyatis sinensis*	*Hemitrygon sinensis*	Chinese Sting Ray	Confirmed presence	EN	-	-
Dasyatidae	*Dasyatis bennettii*	*Hemitrygon ben nettii*	Bennett's Cowtail, Bennett's Stingray	Confirmed presence	VU	-	-
Dasyatidae	*Dasyatis (Himantura) bleekeri*	*Himantura bleekeri/ Himantura uarnacoides*	Bleeker's Whipray	Confirmed presence	EN	-	-
Dasyatidae	*Himantura fluviatilis*	*Himantura fluviatilis / Pastinachus sephen*	Ganges Stingray/ Cowtail Ray	Synonym by IUCN, separate spp. by Fishbase, hence questionable identtity.	NE/ NT	-	-

Dasyatidae	*Himantura leoparda*	*Himantura leoparda*	Leopard Whipray	Confirmed presence	VU	-	-
Dasyatidae	*Dasyatis (Amphotistius) marginatus*	*Himantura marginata*	Blackedge Whipray	Not recognised by Last et al., 2016	NE	-	-
Dasyatidae	*Himantura tutul*	*Himantura tutul*	Fine-Spotted Leopard Whipray	A separate species by Bosra et al., 2013 and Farnendo et al., 2019. However, synonym of *Himantura uarnak* according to Last et al., 2016. Not a valid species	NE	-	-
Dasyatidae	*Dasyatis (Himantura) uarnak*	*Himantura uarnak*	Honeycomb Stingray	Confirmed presence	VU	-	-
Dasyatidae	*Himantura undulata*	*Himantura undulata*	Leopard Whipray	Confirmed presence	EN	-	-
Dasyatidae	*Maculabatis arabica*	*Maculabatis arabica*	Pakistan/ Arabic Whipray	Confirmed presence	CR	-	-
Dasyatidae	*Maculabatis bineeshi*	*Maculabatis bineeshi*	Short-Tail Whipray	Confirmed presence	NE	-	-
Dasyatidae	*Maculabatis macrura*	*Maculabatis macrura*	Sharpnose Whipray	Need further confirmation	EN	-	-
Dasyatidae	*Himantura pastinacoides*	*Maculabatis pastinacoides*	Round Whip Ray	Confirmed presence	EN	-	-
Dasyatidae	*Himantura gerrardi*	*Maculabatis ger rardi*	Sharpnose Stingray	Confirmed presence	EN	-	-
Dasyatidae	*Megatrygon microps*	*Megatrygon microps*	Smalleye Stingray	Confirmed presence	DD	-	-
Dasyatidae	*Neotrygon* Bay of Bengal varient	*Neotrygon* Bay of Bengal varient		Need further studies for taxonomic resolution among morphologically similar species	-	-	-
Dasyatidae	*Neotrygon caeruleopunctata*	*Neotrygon caeruleopunctat a*	Blue Spotted Maskray	Confirmed presence	NE	-	-
Dasyatidae	*Neotrygon* cf. *caeruleopunctata*	*Neotrygon* cf. *caeruleopunctat a*	Bluespotted Maskray	Confirmed presence	NE	-	-
Dasyatidae	*Neotrygon indica*	*Neotrygon indica*	Blue Spotted Maskray	Confirmed presence	NE	-	-

Dasyatidae	*Dasyatis (Amphotistius) kuhlii*	*Neotrygon kuhlii*	Blue-Spotted Stingray	Confirmed presence	DD	-	-	
Dasyatidae	*Neotrygon orientalis*	*Neotrygon orientalis*	Oriental bluespotted maskray	Need further confirmation	NE	-	-	
Dasyatidae	*Pastinachus ater*	*Pastinachus ater*	Broad Cowtail Ray	Confirmed presence	LC	-	-	
Dasyatidae	*Pastinachus* cf. *gracilicaudus*	*Pastinachus* cf. *gracilicaudus*	Cowtail Ray	Confirmed presence	-	-	-	
Dasyatidae	*Pastinachus gracillicaudus*	*Pastinachus gracillicaudus*	Narrow Cowtail Ray	Confirmed presence	NE	-	-	
Dasyatidae	*Dasyatis (Pastinachus) sephen*	*Pastinachus sephen*	Cowtail Stingray	Distribution through Northern Indian Ocean; Red Sea to Pakistan	NT	-	-	
Dasyatidae	*Pastinachus solocirostris*	*Pastinachus solocirostris*	Roughnose Stingray	Confirmed presence	EN	-	-	
Dasyatidae	*Himantura fai*	*Pateobatis fai*	Pink Whio Ray	Confirmed presence	VU	-	-	
Dasyatidae	*Himantura jenkinsii*	*Pateobatis jenkinsii*	Jenkins Whipray	Confirmed presence	VU	-	-	
Dasyatidae	*Himantura uarnacoides*	*Pateobatis uarn acoides*	Whitenose Whipray	Confirmed presence	EN	-	-	
Dasyatidae	*Pteroplatytrygon violacea*	*Pteroplatytrygo n violacea*	Violate Stingray	Confirmed presence	LC	-	-	
Dasyatidae	*Taeniura lymma*	*Taeniura lymma*	Ribbontail Stingray/Bluesp otted Fantail Ray	Confirmed presence	NT	-	-	
Dasyatidae	*Taeniura meyeni*	*Taeniurops meyeni*	Round Ribbontail Ray	Confirmed presence	VU	-	-	
Dasyatidae	*Telatrygon* cf. *crozieri*	*Telatrygon* cf. *crozieri*	Sharpnose Stingray	Need further confirmation	NE	-	-	
Dasyatidae	*Dasyatis zugei*	*Telatrygon zuge i*	Pale-Edged Stingray	Confirmed presence	NT	-	-	
Dasyatidae	*Urogymnus africana*	*Urogymnus asperrimus*	Porcupine Ray	Confirmed presence	VU	-	-	
Dasyatidae	*Urogymnus granulatus*	*Urogymnus granulatus*	Mangrove Whipray	Confirmed presence	VU	-	-	
Dasyatidae	*Himantura lobistoma*	*Urogymnus lobistoma*	Tube Mouth Whio Ray	Confirmed presence	EN	-	-	

Dasyatidae	*Urogymnus polylepis*	*Urogymnus polylepis*	Giant Freshwater Stingray	Confirmed presence	EN	-	-
Gymnuridae	*Gymnura japonica*	*Gymnura japonica*	Japanese Butterfly Ray	Confirmed presence	DD	-	-
Gymnuridae	*Gymnura micrura*	*Gymnura micrura*	Smooth Butterfly Ray	Questionable record. Distribution mainly Western Atlantic (northern USA to Brazil) and possibly Eastern Atlantic (Senegal to Angola)	DD	-	-
Gymnuridae	*Gymnura poecilura*	*Gymnura poecilura*	Long-Tailed Butterfly Ray	Confirmed presence	NT	-	-
Gymnuridae	*Gymnura tentaculata*	*Gymnura tentaculata*	Tentacled Butterfly-Ray	Indo–West Pacific; Red Sea to Bay of Bengal	DD	-	-
Gymnuridae	*Gymnura zonura*	*Gymnura zonura*	Zonetail Butterfly Ray	Indo–West Pacific; Bay of Bengal (India) to Philippines and Taiwan	VU		
Mobulidae	*Mobula alfredi*	*Mobula alfredi*	Reef Manta Ray/ Alfred Manta	Need further confirmation	VU	II	I & II
Mobulidae	*Mobula birostris*	*Mobula birostris*	Giant Manta Ray	Confirmed presence	EN	II	I & II
Mobulidae	*Mobula diabolus*	*Mobula eregoodootenke e*	Longhorned Mobula	Confirmed presence	EN	II	I & II
Mobulidae	*Mobula hypostoma*	*Mobula hypostoma*	Lesser Devil Ray	Questionable report as range is: Western and Eastern Atlantic; North Carolina (USA) to northern Argentina, and Mauritania to Angola.	EN	II	I & II
Mobulidae	*Mobula japanica*	*Mobula mobular*	Spinetail Mobula	Not a separate sp. Conspicific with M. mobular	EN	II	I & II
Mobulidae	*Mobula kuhlii*	*Mobula kuhlii*	Shortfin Devil Ray	Confirmed presence	EN	II	I & II
Mobulidae	*Mobula diabolus*	*Mobula mobular*	Devil Ray	Confirmed presence	EN	II	I & II
Mobulidae	*Mobula mobular*	*Mobula mobular*	Devil Ray	Confirmed presence	EN	II	I & II

Mobulidae	*Mobula tarapacana*	*Mobula tarapacana*	Smoothtail Mobula	Confirmed presence	EN	II	I & II
Mobulidae	*Mobula thurstoni*	*Mobula thurstoni*	Ocellated Eagle Ray	Confirmed presence	EN	II	I & II
Myliobatidae	*Aetomylaeus maculatus*	*Aetomylaeus maculatus*	Mottled Eagle Ray	Confirmed presence	EN	-	-
Myliobatidae	*Aetomylaeus milvus*	*Aetomylaeus milvus*	Brown Eagle-Ray	Need further taxonomic work	EN	-	-
Myliobatidae	*Aetomylaeus nichofii*	*Aetomylaeus nichofii*	Banded Eagle Ray	Confirmed presence	VU	-	-
Narcinidae	*Narcine brevilabiata*	*Narcine brevilabiata*	Shortlip Electric Ray	Need further confirmation	VU	-	-
Narcinidae	*Narcine atzi*	*Narcine atzi*	Oman Numbfish	Northern Indian Ocean; patchy, Gulf of Oman, Bay of Bengal and Andaman Sea.	DD	-	-
Narcinidae	*Narcine brunnea*	*Narcine brunnea/timlei*	Brown Numbfish	Not a separate sp. Synonym of Narcine timlei	NE	-	-
Narcinidae	*Narcine lingula*	*Narcine lingula*	Chinese Numbfish	Indo–West Pacific	VU	-	-
Narcinidae	*Narcine maculata*	*Narcine maculata*	Darkfinned Numbfish	Confirmed presence	VU	-	-
Narcinidae	*Narcine prodorsalis*	*Narcine prodorsalis*	Tonkin Numbfish	Confirmed presence	DD	-	-
Narcinidae	*Narcine sp.*	*Narcine sp.*	Andaman Numbfish	Confirmed presence, potential new species to science. Further taxonomic work is needed	-	-	-
Narcinidae	*Narcine timlei*	*Narcine timlei*	Spotted Numbfish	Confirmed presence	DD	-	-
Narkidae	*Narke dipterygia*	*Narke dipterygia*	Numbray	Confirmed presence	DD	-	-
Pristidae	*Pristis cuspidatus*	*Anoxypristis cuspidata*	Pointed Sawfish	Confirmed presence	EN	I	I & II
Pristidae	*Pristis microdon/ Pristis pristis*	*Pristis pristis*	Largetooth Sawfish	Confirmed presence	CR	I	I & II
Pristidae	*Pristis pactinatus*	*Pristis pectinata*	Smalltooth Sawfish	Questionable record as distribution through Atlantic and South-West Indian Oceans; once widespread	CR	I	I & II

Pristidae	*Pristis zijsron*	*Pristis zijsron*	Longcomb Sawfish	Confirmed presence	CR	I	I & II
Rhinidae	*Rhina ancylostoma*	*Rhina ancylostoma*	Bowmouth Guitarfish	Confirmed presence	CR	II	-
Rhinidae	*Rhynchobatus djeddensis*	*Rhynchobatus djiddensis*	Giant Guitarfish	Distributed through Western Indian Ocean; South Africa to Oman. Possibly misidentified for *Rhynchobatus laevis*	CR	II	-
Rhinidae	*Rhynchobatus laevis*	*Rhynchobatus laevis*	Smoothnose Wedgefish	Confirmed presence	CR	II	-
Rhinidae	*Rhynchobatus australiae*	*Rhynchobatus australiae*	Bottlenose Wedgefish	Possible presence according to Kyne et al., 2020. Indo–West Pacific; Mozambique to eastern Australia.	CR	II	II
Glaucostegidae	*Rhinobatos typus*	*Glaucostegus typus*	Giant Shovelnose Ray	Confirmed presence	CR	II	-
Glaucostegidae	*Glaucostegus* cf. *granulatus*	*Glaucostegus* cf. *granulatus*	-	Confirmed presence, potential new species.	-	-	-
Glaucostegidae	*Rhinobatos granulatus*	*Glaucostegus granulatus*	Granulated Guitarfish	Confirmed presence	CR	II	-
Glaucostegidae	*Rhinobatus obtusus*	*Glaucostegus obtusus*	Blunt Shovel Nose Ray, Grey Guitarfish, Widenose Guitarfish	Confirmed presence	CR	II	-
Glaucostegidae	*Rhinobatos thouini*	*Glaucostegus thouin*	Thouin Ray	Confirmed presence	CR	II	-
Rhinobatidae	*Rhinobatos annandalei*	*Rhinobatos annandalei*	Annandale's Guitarfish	Confirmed presence	DD	-	-
Rhinobatidae	*Rhinobatos lionotus*	*Rhinobatos lionotus*	Smoothback Guitarfish	Confirmed presence	DD	-	-
Rhinobatidae	*Rhinobatos ranongensis*	*Rhinobatos ranongensis*	Ranong guitarfish	Confirmed presence	NE	-	-
Rhinopteridae	*Rhinoptera bonasus*	*Rhinoptera bonasus*	American cownose Ray	Questionable record as distribution through Western Atlantic; New England (USA) to northern Argentina	VU	-	-
Rhinopteridae	*Rhinoptera adspersa*	*Rhinoptera javanica*	Flapnose Ray	Confirmed presence	VU	-	-

Rhinopteridae	*Rhinoptera javanica*	*Rhinoptera javanica*	Flapnose Ray	Confirmed presence	VU	-	-
Rhinopteridae	*Rhinoptera jayakari*	*Rhinoptera jayakari*	Oman Cownose Ray	Confirmed presence	NE	-	-
Rajidae	*Dipturus johannisdavisi*	*Dipturus johannisdavisi*	Travancore Skate	Bay of Bengal is a range according to the maps of Last et al., 2016. Indian Ocean; Bay of Bengal and India, possibly west to Tanzania. Possible presence	DD	-	-
Rajidae	*Orbiraja powelli*	*Orbiraja powelli*	Indian Ring Skate	Northern Indian Ocean; Arabian Sea (India) to Bay of Bengal (Myanmar). Possible presence	NT	-	-

Table S2.2. Observation on the abundance of different elasmobranch species in landing, plausible reasons and conservation implications.

Species	Abundance in landing	Reasons and conservation implications
		Sharks
S. laticaudus	Very common	The most commonly documented shark species was the spadenose shark, *S. laticaudus*, consistent with previous findings (Karim et al., 2017). The mortality of this species is high in this region at 1.31 yr-1 and fishing mortality of 0.745 yr-1 (Karim et al., 2012; Karim et al., 2017). This is presumably due to relatively high fecundity, its occurrence in shallow water (13 m) demersal habitats (Froese & Pauly, 2020), which frequently are exploited by a substantial number of artisanal boats deploying a substantial number of gears (Shamsuzzaman et al., 2017). However, the value of these sharks in the landing site was less than larger sharks due to no international demand for fin trade.
***Chiloscyllium* spp.**	Moderately common	*Chiloscyllium* spp. were also of less value, still landed in high numbers. This is presumably due to the practice of less discard in this region, and any value is vital for the fishers, no matter how small. At least six species of this genus are present in this region (*e.g. Chiloscyllium hasselti, C. burmensis, C. indicum, C. punctatum, C. griseum, C. cf. arabicum*) (Ahmed et al., 2019; Ahmed et al., 2020; Hoq et al., 2011); however, four species

		were reported during this study with one species needing further taxonomic identification (*C. cf. arabicum*) for confirmation. Since many gears in this region target demersal species (Haque et al., 2018), the catch of these species is quite prevalent.
C. sorrah, G. cuiver, C. ambionensis	Common	Carcharhinids were the most abundant sharks reported in this study; after spadenose shark especially spottail shark *C. sorrah*, blacktip shark *C. limbatus*, tiger shark *G. cuiver* and pigeye sharks *C. ambionensis* followed by bull shark *C. leucas*. All these species were landed in abundance at all sites and are reported to be extremely valuable because of the fin trade (Haque et al., 2018). These are a mix of freshwater, estuarine, reef-associated and pelagic species indicating the diverse nature of artisanal fisheries. These species are highly desired amongst the fishers and traders and increased retention and target with hooks. Although modified gill nets to target sharks have been reported (Karim et al., 2012) targeting larger sharks. However, this practice decreased over time, and during the study period, no substantial number of such practices were observed (Haque unpubl. data). Carcharhinids are highly important for both artisanal and commercial fisheries worldwide, contributing largely to marine fisheries landings (Castillo-Géniz et al., 1998; Compagno et al., 2005; White & Dharmadi, 2007; Last & Stevens, 2009; Henderson et al., 2016).
C. limbatus, C. leucas	Moderately common	
Carcharhinus falciformis, C. amblyrhynchoides, C. brevipinna and C. macloti	Uncommon	Although *Carcharhinus falciformis, C. amblyrhynchoides, C. brevipinna and C. macloti* were not abundantly reported, these were historically reported in greater numbers (Hoq et al., 2011). This is either due to depleted population in this region or sampling bias as smaller sharks in bigger piles of more than 500 individuals could not be identified; however, that is less likely, and most of them were spadenose sharks.
Lamiopsis temmincki	Very uncommon	Although *Lamiopsis temmincki* was reported in Cox's Bazar previously (Froese & Pauly, 2020), in this study, it was opportunistically sampled in two landing sites and was absent in St. Martin's Island.
Stegostoma fasciatum	Rare	*Stegostoma fasciatum* was recorded just once in this study whereas it was reported more frequently previously (Karim et al., 2012).
Hammerhead sharks	*S. lewini* is common,	The scalloped hammerhead shark was very commonly caught at all landing sites, including juveniles, and is extremely desirable to the fishers and traders due to the high value of fins (Haque et al., 2018). Although other hammerhead sharks were previously reported from this region (e.g. winghead shark *E. blochi*, great

	others are rare	hammerhead shark, *S. mokarran*) (Hoq et al., 2011; Roy et al., 2015), they were not recorded in the current study. This discrepancy may be due to an extreme *E. blochi, S. mokarran and Sphyrna zygaena* population decline in the region. This is a serious conservation concern as now the pressure is entirely on S. *lewini, an* Endangered species, and a global decline in populations is reported (IUCN, 2021). The demand is due to the larger size of the fins and the overall larger size of the shark providing comparatively higher value.
Thresher sharks		Consistent with our findings, Thresher sharks (family: Alopidae) are rarely reported within the Bay of Bengal, Bangladesh. Two species (e.g. *A. pelagicus* and *A. supercilious*) were previously reported from longlines and drift gill nets surveying pelagic waters (Krajangdara et al., 2019). The one Alopidae specimen recorded was identified to genus *Alopias* sp. based on a characteristic feature in this family of sharks, the elongated caudal fin (White & Dharmadi, 2007). The lack of reports is either since these species are highly pelagic and the range does not overlap with artisanal fisheries except for rare occasions
		Rays
G. poecilura	Very common	The most commonly found ray was *G. poecilura*, consistent with previous studies. Two species of butterfly rays have been reported from *Bangladesh (G. japonica and G. poecilura***)** previously (Hoq et al., 2011; Roy et al., 2015). The presence of different spot patterns and morphs that have been documented may be due to geographic population differences; however, none was confirmed to be *G. japonica***.** The traders value these moderately. The number could be higher due to higher breeding potential than many other elasmobranch species (Raje & Zacharia, 2009). The number of juveniles encountered was highest in the winter and pre-monsoon season, probably due to the presence of inshore nursery grounds (Raje & Zacharia, 2009).
Neotrygon spp.	Very common	The second highest species sampled belonged to the genus *Neotrygon*. Several species have been recently described under this genus (*Neotrygon australiae, Neotrygon caeruleopunctata, Neotrygon orientale, Neotrygon trigonoides, Neotrygon bobwardi, Neotrygon malaccensis, Neotrygon moluccensis, Neotrygon westpapuensis, Neotrygon vali)* (Borsa et al., 2013; Borsa, 2017; Borsa et al., 2018; Last et al., 2016) three variants morphologically most consistent with N. *kuhlii. N. indica and N. caeruleopunctata* were documented. The population variants of *Neotrygon* spp. in the Bay of Bengal need further taxonomic work as differentiation has been observed between populations (Borsa et al., 2013). All of these species are either reef associated or

		demersal inshore species hence overlap with artisanal bottom net fisheries and longline hooks. Hence the number landed were substantially high, although the demand was comparatively low from other bigger rays.
Himantura spp.	Very common	Amongst bigger rays the present study has documented three species under the genus *Himantura (H. leoparda, H. undulata and H. uarnak)*. Recently, a new ocellated whipray *Himantura tutul* has been described using DNA barcoding (Borsa et al., 2013), which has been described as a synonym for *H. uarnak* by Last et al., 2016. As a result, this has not been added to the species list, although morphologically similar specimens were documented. Species belonging to this family are highly valued, not only for meat consumption (Last et al., 2016) but also for the quality of the skin used as a raw material for accessories worldwide (Last et al., 2016).
Maculabatis spp., Brevitrygon spp., and Pateobatis spp., Urogymnus polylepis.	Moderately common	*Maculabatis, Brevitrygon, and Pateobatis* were moderately commonly observed, followed by *Urogymnus*. Species from the genus *Pastinachus, Telatrygon* were rarely recorded. These rays are bottom dwellers (Last et al., 2016) and are heavily exploited by the non-baited long lines targeting rays in these waters; however, the uncommon nature of landing could not be corroborated with any indication of population decline due to the absence of historical data.
Pastinachus spp., Telatrygon spp.	Uncommon	
Devil rays, Cownose rays and Eagle rays	Moderately common	Devil rays, Cownose rays and Eagle rays were also moderately abundant throughout the study period, especially *M. mobular, R. javanica, R jayakari and A. oscellatus*. Although these species are mostly pelagic or benthopelagic (rhinopteridae), inshore occurrences are not rare (Camhi et al., 2009). Devil rays are valuable to the traders due to the international demand of gill rakers (Camhi et al., 2009; Croll et al., 2016; Zeng et al., 2016). Whereas *Mobula mobular* was commonly encountered, *M. eregoodoo and M. birostris* were rarely observed, probably due to being highly pelagic or naturally rare in this region.
Narcine spp. and Narke sp.	Uncommon	The three numbfishes and one sleeper ray reported in this study were extremely rare in this region. Although reported to be found relatively commonly previously (Ahmed et al., 2020; Hoq & Haroon, 2014) the capture of these species was low in number in this study. In some cases, electric ray species with less market demand and values, such as *Narcine spp.*, might have been discarded at sea due to the fear of being electrocuted (Haque, pers. comm. fishers, January 2020) and thus are presumably not accurately represented in landings.

	Rhinopristoformes rays	
G. granulatus and G. obtusus followed by R. ancylostoma	Common	Rhinopristoformes rays **were** abundantly landed, especially *G. granulatus and G. obtusus, followed by R. ancylostoma*. These species are frequently targeted using non-baited long lines due to high fin price and meat consumption (Kyne et al., 2020). Despite frequent landings of these species, owing to both target and non-discarded/opportunistic fishing practices, little is known about their geographic distribution and species composition in the North Indian Ocean (Kyne et al., 2020). Although G. *granulatus, R. ancylostoma, G. typus*, and *R. djiddensis (*probably *R. lavies* or *R. australie,* as *R. djiddensis* does not occur in this region) were commonly previously reported (Hoq et al., 2011; Karim et al., 2012; Hoq & Haroon; 2014), the current study reported no *Rhynchobatas spp.,* presumably due to extreme population decline. A potential population depletion is corroborated by fishers, commonly referred to as a white-spotted guitarfish, which is not found anymore (Haque unpubl. data); however, a more comprehensive investigation is required to confirm this. The depletion of the Rhinopristoformes ray population in the wider Indo-Pacific is well documented, whereby 80-99% of the population declined throughout their range due to overfishing (Kyne et al., 2020). The scenario is similar in Bangladesh. Previous records documented substantially high landings of these species with a total of 10.448 MT of *R. djiddensis (probably R. australiae and R. laevis)* along with ~30 MT of *G. granulatus* landed in only two sites across coastal Bangladesh (Roy et al., 2014). A continuous landing was reported for *R. laevis* from 2006 to 2012 (Roy et al., 2012). Additionally, between 2011-12 a total of 2.30 MT of *R. laevis* along with 0.09 MT of *R. ancylostoma* and 27.16 MT of *R. typus (*presently *G. typus)* (Roy et al., 2014) were landed. However, the composition in landing has changed drastically now, whereby only *G. granulatus and G. obtusus* are currently observed in abundance, and all other species have substantially decreased. This is an early warning of extreme population decline and the pressure being replaced on *G. granulatus and G. obtusus* as they are extremely valuable in the international fin trade (Moore, 2017). If fisheries like this continue to occur at this rate, Bangladesh may see a complete collapse of Rhinopristoformes rays very soon. Proactive measure to manage these fisheries is crucial and highly recommended.
G. typus, R. lionatus*, and *R. annadalei	Very uncommon	
Rhynchobatas spp.,	Rare	

Pristis spp.	Rare	It is likely that the occurrence of extremely valuable rays, such as the largetooth sawfish, is unreported in most recent studies as incidental bycatch does not land in the formal landing sites. However, throughout the study period, a total of 33 largetooth sawfish was also recorded, indicating the landing is higher than documented previously. Although three sawfish species, the largetooth, green and narrow sawfish, were documented in a former study in Bangladesh (Roy et al., 2007; Hossain et al., 2015; Haque & Das, 2019; Haque et al., 2020), the current study did not document any recent landings of narrow sawfish. However, in 2006, three specimens of narrow sawfish were documented in Chittagong [33], and 1.145 MT of narrow sawfish landings were reported between 2006 and 2010 (Roy et al., 2014). The most recent study by Hossain et al. 2015, mentioned 53 sawfish ladings in Cox's Bazar from BFRI between 2010-2011, all of which were mistakenly identified as *A. cuspidata*; however, no landings of narrow sawfish were actually documented (Hossain et al., 2015) consistent with our study. This could be either because of data bias, as the study could not focus on the south central and south western coastal areas, or a very high possibility of a very steep decline of the population of sawfishes. The latter's possibility is stronger as the narrow sawfish has been reported to be 'rarely found' in Bangladesh waters (Hoq et al., 2011), and the green sawfish has been confirmed for the first time (Haque & Das, 2019). As a result, there has not been a confirmed record of narrow sawfish from Bangladesh waters since 2010. Even in India, narrow sawfish' landing has significantly reduced from 1989 to 2011 (Bineesh et al., 2014). However, a study conducted between 2010 and 2013 likely reported 19 sawfish individuals, wrongly naming it 'saw shark *Pristis cuspidatus'* (though confirmation could not be made).

Appendix 1.2.
New records of elasmobranchs in the Bay of Bengal, Bangladesh: further taxonomic research is essential

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Abstract

To evaluate the species diversity and strengthen the taxonomic identification of elasmobranchs in the Bay of Bengal, Bangladesh, a study was conducted in the southeast coastal region between January 2016 and March 2018. Using morphological and genetic identification techniques, this study presents 22 species from the region. Thirteen of these are new records. The new records consist of eight species from the family Dasyatidae, and one each from Mobulidae, Rhinobatidae, Narcinidae, Hemiscylliidae and Triakidae. Furthermore, four occurrences are first verified reports, and five are potential new records requiring further taxonomic investigation.

Introduction

Elasmobranchs, superorder Selachii (sharks) and Batoidea (rays and skates), represent over 1200 species globally and are amongst the most vulnerable groups of marine organisms, with approximately 36% threatened with extinction (Dulvy et al., 2014; IUCN, 2021). Elasmobranch taxonomy and nomenclature has changed and evolved over time (Last et al., 2016; Last et al., 2016a; White et al., 2017), with many potential new species recently described (Koeda et al., 2021). Taxonomical developments enhance existing knowledge on elasmobranch diversity, providing the foundation for updating species checklists. This work also furthers understanding of species-specific information, including life-history traits and distribution, fundamental for effective conservation and management strategies (White et al., 2017; O'Bryhim et al., 2017; Cardeñosa et al., 2019).

Southeast Asia's marine life is highly diverse, with a large portion of the region within the Coral Triangle (Veron et al., 2011). As part of this, the Bay of Bengal has high species richness and endemicity due to its isolation, coastal distribution, infusion of nutrients and biological productivity (Amaral et al., 2017; Fernando et al., 2019). However, evidence from limited marine and coastal aquatic surveys (Fischer et al., 2012) indicates that species richness, evolutionary distinctiveness and endemicity have likely been underestimated, including elasmobranchs. This study focuses on Bangladesh, which lacks comprehensive historical elasmobranch diversity data. The earliest checklist of Bangladeshi (East Pakistan in 1970) marine fauna was published in 1970, including 53 elasmobranchs (25 sharks and 28 rays) (Hussain, 1970), though advances in taxonomy and distribution research challenge its accuracy. Current Bangladeshi elasmobranch fauna is understood from project reports, checklists, and brief key and guides, mostly published in the last decade (Hoq et al., 2011), supplemented by fisheries reports, unpublished graduate theses, and published studies.

A total of 104 species of elasmobranchs (46 sharks, 58 rays), belonging to 22 families, have now been recorded from Bangladeshi waters (Hoq et al., 2011; Roy et al., 2014 a, Roy et al., 2014b, Roy et al., 2014 c; Roy et al., 2015; Haque et al., 2019a; Badhon et al., 2019; Habib et al., 2020; Ahmed et al., 2020). Several species, however, have been misidentified due to similarity to closely related species, highlighting an urgent need to validate the current taxonomic records. While no elasmobranch targeted genetic studies have been conducted (reference year 2018), genetic studies on marine species have included a limited number of elasmobranchs (Habib et al., 2020; Ahmed et al., 2020). Recent rapid survey efforts provided several new records for the country (e.g. green sawfish *Pristis zijsron*, Burmese bambooshark *Chiloscyllium burmensis*, Arabian smoothhound shark *Mustelus mosis*) (Haque et al., 2018; Haque et al., 2019a, Haque et al., 2019b; Haque et al., 2020; Habib et al., 2020), though the true diversity of Bangladeshi elasmobranchs is likely higher.

Fisheries data can provide important information on elasmobranch diversity. However, species-specific information on elasmobranchs in Bangladesh's territorial waters is absent due to their broad classification of 'sharks, rays and skates' in aggregate landing accounting systems (DoF, 2017). Coastal and marine fisheries in Bangladesh are primarily described as artisanal, multi-species and multi-gear (Ullah et al., 2014), with 67,669 boats and 188,707 gear units in operation in 2017 (DoF, 2017; Shamsuzzaman et al., 2017). Fishers use gear including gillnets, seine nets, set-bag nets, trammel nets, longline and hooks, all of which catch elasmobranchs (Haque et al., 2020; Haque unpubl. data). These fleets operate within the Exclusive Economic Zone (EEZ), from inshore to more than 200m deep (Shamsuzzaman et al., 2017; Ullah et al., 2014). The majority of elasmobranchs are landed in areas adjacent to the elasmobranch processing centres, with the largest landing sites situated in the south eastern region (Ullah et al., 2014; Haque et al., 2018). Although the main marine fisheries landing sites are operated by the Bangladesh Fisheries Development Corporation (BFDC), there are numerous informal landing sites. There is also substantial illegal, unregulated and unreported (IUU) fishing, in the form of under-reported commercial catch, discarded bycatch and subsistence catch (Ullah et al., 2014). It is likely that the increasing number of mechanized, non-mechanized and industrial trawlers in the Bay of Bengal is the primary reason for overfishing, resulting in population depletions, including those of threatened species (e.g. *Rhynchobatus* spp. in Haque unpubl. data), and negatively impacting the marine fisheries sector. Such increasing fishing pressure, combined with the absence of empirical research, presents significant challenges for the implementation of sustainable fisheries management.

Methods

To evaluate elasmobranch diversity and catch in this region a two-year study of artisanal elasmobranch fisheries was initiated in January 2016. Four landing sites (Figure 1.2.1) were visited every month for at least seven to ten field days to collect morphological data and samples from landed elasmobranchs. Whenever possible, specimens were identified to species level using relevant identification guides, e.g. Compagno et al. (2005) and Last et al. (2016a), (while noting that a region-specific guide is currently lacking), counted, measured to the nearest 1cm and weighed. When possible, tissue samples were collected, preserved in 98% ethanol and stored at -20 C. New records (i.e. new records for the region and range extensions), from the data collected between January 2016 and March 2018, are presented here.

DNA was extracted from tissue samples and the NADH2 region of the mitochondrial genome was subjected to PCR amplification following Henderson et al. (2016) and Naylor et al. (2012). The NADH2 sequences were BLASTED against a reference database of known identities from the Florida Museum of Natural History's Chondrichthyan Tree of Life (CTOL) database (see https://sharksrays.org). Identification of the samples from this study was established using phylogenetic trees (G. Naylor, unpubl. data; Table 1.2.1) to evaluate which known species they clustered with (Naylor et al., 2012). The NADH2 gene was selected as it is one of the fastest evolving mitochondrial protein-coding genes, providing an advantage when compared to other markers in distinguishing between closely related species, cryptic species, or geographic variants (Naylor et al., 2012). Data were included in the CTOL database which consists of expertly identified chondrichthyan sequences, many of which are supported by museum voucher specimens.

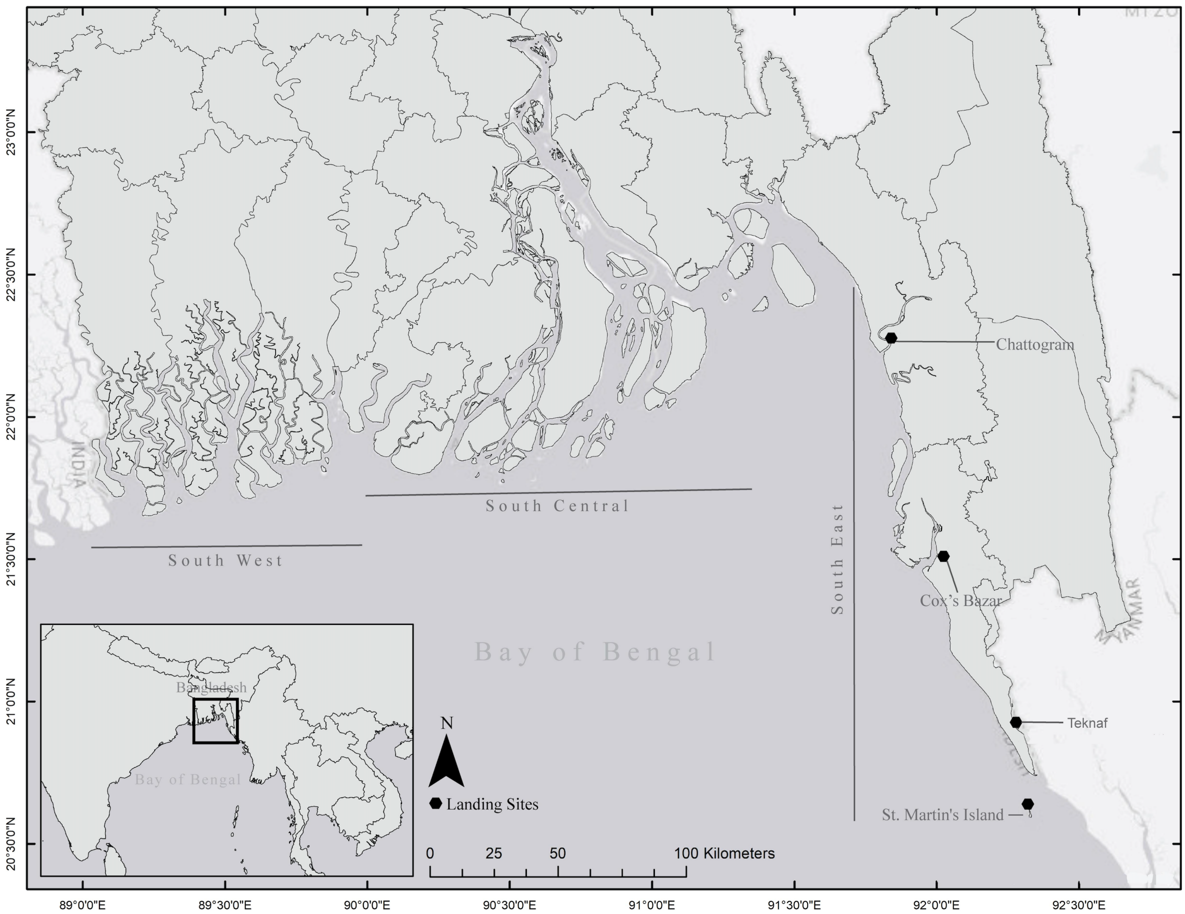


Figure 1.2.1. Map: Bay of Bengal in North Indian Ocean (inset). Black hexagons: Study areas (landing sites: Chattogram fish landing site, Cox's Bazar BFDC fish landing site, Teknaf fish landing site and St. Martin's Island) in the southeast coastal Bangladesh.

Results and Discussion

We report 22 species of which 13 are new records of elasmobranch species for the region (11 rays and two sharks). Furthermore, we report on three ray species verified for the first time in Bangladesh and one shark's distribution extension. An additional five records of elasmobranchs (one shark and four rays) were also documented, although further taxonomic verification is recommended before confirming their presence (Table 1.2.1).

Table 1.2.1. List of species reported in this paper from the southeast coastal region of Bangladesh with habitat type and global distribution (Last et al., 2016a, Froese & Pauly, 2000), Global IUCN Red List of Threatened status (EN: Endangered; NT: Near Threatened; VU: Vulnerable; DD: Data Deficient; LC: Least Concern; NE: Not evaluated), assessment dates, CITES, and CMS status are given with comments on their identifications.

	Family	Scientific name	Common name	Habitat	Previous distribution	Range extension	IUCN	Comments on identification
				New records				
1	Dasyatidae	*Brevitrygon heterura*	Dwarf whipray	Demersal on inner continental and insular shelf; depth ~50 m	Indo–Malay Archipelago; Java and Borneo to western Thailand	✓	NE	Morphologically identified (Figure 1.2.2)
2		*Maculabatis bineeshi*	Short-tail whipray	Marine; demersal; depth range 13-22 m	Northern Indian Ocean; Arabian Sea (Pakistan) and Bay of Bengal (Odisha, India)	✓	NE	Morphologically and genetically identified (Figure 1.2.3)
3		*Maculabatis arabica*	Pakistan whipray	Marine; demersal; depth range 15-29 m	Northern Indian Ocean; Arabian Sea (off Pakistan and western India)	✓	CR	Morphologically and genetically identified (Figure 1.2.4)
4		*Neotrygon* cf. *caeruleopunctata*	Bluespotted maskray	Marine; reef-associated	Indian Ocean; southern Indonesia, possibly westward to Africa	-	NE	Morphologically identified (Figure 1.2.5). Genetically sampled specimens were labelled as *Neotrygon* Bay of Bengal variants
5		*Pastinachus* cf. *gracilicaudus*	Narrow cowtail ray	Demersal inshore on continental insular	Indo–West Pacific; eastern India, Java (Indonesia) and Borneo	-	NE	Morphologically and genetically identified (Figure 1.2.10)

				shelves; depth up to 60 m				
6		*Pastinachus ater*	Broad cowtail ray	Marine; brackish; reef-associated	Indo–West Pacific, widespread; Madagascar to New Caledonia	-	LC	Morphologically identified (Figure 1.2.7)
7		*Pastinachus solocirostris*	Roughnose Cowtail Ray	Marine; brackish; demersal inshore on continental insular shelves; depth up to 30 m	Western Central Pacific, Borneo, Malaysia, Indonesia and Thailand	✓	EN	Morphologically identified (Figure 1.2.8)
8		*Urogymnus granulatus*	Mangrove whipray	Marine; brackish; reef-associated; depth range 1-85 m	Indo–West Pacific; Red Sea to Oceania, distribution considered patchy	✓	VU	Morphologically and genetically identified (Figure 1.2.11)
9	Mobulidae	*Mobula thurstoni*	Bentfin devil ray	Marine; pelagic-oceanic; depth range 0-100 m	Known distribution patchy but probably circum-global in warm seas	-	EN	Morphologically identified (Figure 1.2.13)
10	Narcinidae	*Narcine* sp.	Andaman numbfish	Marine; demersal; depth range 73-89 m	Indian Ocean; Myanmar and Bangladesh only	-	NE	Morphologically identified (Figure 1.2.14)
11	Hemiscylliidae	*Chiloscyllium* cf. *arabicum*	Arabian carpetshark	Marine; demersal; depth range 2-100 m	Western Indian Ocean: India, Pakistan, and the Persian Gulf between Iraq and the Arabian Peninsula.	✓	NT	Morphologically identified (Figure 1.2.17)
12	Triakidae	*Iago* cf. *omanensis*	Bigeye houndshark	Marine; bathydemersal; depth range 110 - 2195 m	Western Indian Ocean; Red Sea, Gulf of Aqaba and Gulf of Oman to Pakistan and southwestern India.	✓	LC	Morphologically identified (Figure 1.2.18)

13	Rhinobatidae	*Rhinobatos ranongensis*	Ranong Guitarfish	Marine; depth range 69 m	Indian Ocean including Bay of Bengal, Andaman Sea	-	NE	Morphologically identified (Figure 1.2.15)
First verified reports								
1	Dasyatidae	*Pateobatis jenkinsii**	Jenkins' whipray	Marine; brackish; demersal; depth range 33-50 m	Indo–Pacific; South Africa to New Guinea, north to Philippines	-	VU	Morphologically and genetically identified (Figure 1.2.6)
2		*Urogymnus polylepis**	Giant freshwater whipray	Freshwater; brackish; demersal	Indo–West Pacific; India (Bay of Bengal) to Borneo	-	EN	Morphologically and genetically identified (Figure 1.2.12)
3	Hemiscylliidae	*Chiloscyllium hasseltii**	Hasselt's bambooshark	Marine; reef-associated; depth range 0-12 m	Indo-West Pacific; Thailand, Singapore, Malaysia, Indonesia, Myanmar and Vietnam.	✓	NT	Morphologically identified (Figure 1.2.16)
4	Rhinobatidae	*Rhinobatos lionotus**	Smoothback guitarfish	Marine; brackish; demersal; amphidromous; depth range 70 m	Northern Indian Ocean; upper Bay of Bengal, West Bengal to Myanmar, and possibly in the Arabian Sea	-	DD	Morphologically and genetically identified
Reports needing further specimen collection or genetic analysis								
1	Mobulidae	*Mobula alfredi*	Reef manta ray/ Alfred manta	Marine; benthopelagic; depth range 1-120 m	Circum-tropical, apart from Eastern Pacific and Western Atlantic	✓	VU	Genetic analysis of gill rakers confirmed the presence of *Mobula birostris/alfredi*
2	Dasyatidae	*Telatrygon* cf. *crozieri*	Indian sharpnose ray	Demersal on continental shelf;	Northern Indian Ocean; Arabian Sea (India) to Myanmar	✓	NE	Further specimen collection is mandatory for confirming the record

				Thought to move inshore to breed				
3		*Maculabatis macrura*	Sharpnose whipray	Mainly benthic on soft bottoms from inshore to depths of at least 60 m	Western Pacific; Indo–Malay Archipelago, Nusa Tenggara (Indonesia) to Taiwan	✓	EN	Seven specimens of a *Maculabatis* species morphologically most similar to *M. macrura* were examined
4		*Pastinachus* cf. *sephen*	Cowtail stingray	Marine; freshwater; brackish; reef-associated; depth range 0 - 60 m	Northern Indian Ocean: Red Sea to Pakistan	✓	NT	Morphologically identified (Figure 1.2.9)
5	Carcharhinidae	*Loxodon macrorhinus*	Sliteye shark	Marine; demersal; depth range 7-100 m	Indo-West Pacific: Red Sea and East Africa to Indonesia, north to Japan, south to Australia	-	LC	Further specimen collection is mandatory for confirming the record

Family Dasyatidae

Dasyatidae (stingrays) are the dominant group of rays in the coastal tropical Indo-West Pacific. While stingray taxonomy is problematic, recent revisions have vastly improved knowledge of this family (Last et al., 2016a). Dasyatidae are amongst the most commonly landed ray groups in Bangladesh, with high demand for consumption and accessories (Last et al., 2016a; Haque et al., 2018). This report identified seven species of Dasyatidae rays in addition to the 24 species previously reported in Bangladesh (Roy et al., 2015).

Genus *Brevitrygon*

Two species within the genus *Brevitrygon* (*B. walga* and *B. imbricata)* have previously been reported in Bangladesh (Hoq et al., 2011). This study confirmed an additional eight specimens morphologically consistent with *Brevitrygon heterura* (Figure 1.2.2).

Figure 1.2.2. Dorsal image of *Brevitrygon heterura* from Moheshkhali, Cox's Bazar.

Genus *Maculabatis*

The new genus *Maculabatis*, as well as several new species, was recently assigned to a group of morphologically similar stingray species (Last et al., 2016c; Manjaji-Matsumoto & Last, 2016). The recently described *Maculabatis bineeshi* was recorded in Bangladesh for the first time in this study (Figure 1.2.3), with a total of 21 specimens recorded, both morphologically (Manjaji-Matsumoto & Last, 2016) and genetically. *M. arabica* (Figure 1.2.4) was genetically identified from one specimen and morphologically identified from another 18 specimens. In addition, seven specimens that were morphologically most consistent with *M. macrura* were examined. *M. macrura* has only recently been established as a valid species, and is morphologically very similar to *M. gerrardi* (Last et al., 2016a), with distinguishing characteristics poorly understood. Further genetic studies are therefore recommended to assign these specimens to the correct species.

Figure 1.2.3. Dorsal and ventral image of *Maculabatis bineeshi* from Cox's Bazar (Male, DW= 43.18 cm).

Figure 1.2.4. Dorsal image of *Maculabatis arabica* from Cox's Bazar (Female, DW= 48.26 cm).

Genus *Neotrygon*

The *Neotrygon kuhlii* species complex has recently been expanded (Last et al., 2016). These taxonomic revisions, however, did not consider Bay of Bengal specimens in detail. To date, two species have been recorded from Bangladesh; *N. indica* and *N. kuhlii* (Haque et al., 2019a; Hoq et al., 2011). In this present study, a total of 649 specimens were examined, and five sampled for genetic analysis. Morphological differences were observed, including the dorsal coloration and tail banding. Several specimens were most consistent with *N. caeruleopunctata*, but have been preliminarily identified as *N.* cf. *caeruleopunctata* (Figure 1.2.5) due to possible genetic differences in the Bay of Bengal specimens. It is likely that previous records of *N. kuhlii* represent this species, with *N. kuhlii* now considered to occur only from the Solomon Islands, and adjacent island groups (Last et al., 2016a). All genetically sampled specimens were labelled as *Neotrygon* Bay of Bengal variants.

Figure 1.2.5. Dorsal and ventral image of *Neotrygon* cf. *caeruleopunctata* from Cox's Bazar (Female, DW= 30.48 cm).

Genus *Pateobatis*

A total of 21 specimens were identified as *Pateobatis jenkinsii* (Figure 1.2.6), based on morphology and genetic analysis. As Ahmed, (2020) included this species in a checklist (as *Himantura jenkinsii*), it is not considered a new record for Bangladesh, but it represents the first verified record.

Figure 1.2.6. Dorsal image of *Pateobatis jenkinsii* from St. Martin's Island.

Genus *Pastinachus*

The current study confirmed two *Pastinachus ater* (Figure 1.2.7) specimens in Bangladesh and 18 specimens of *Pastinachus solocirostris* (Figure 1.2.8). It is assumed that, *P. ater* has been previously reported from Bangladesh as *P. sephen* (Roy et al., 2015), though a recent taxonomic study found that *P. sephen* is only found in the Western Indian Ocean (Red Sea to Pakistan) (Last & Manjaji-Matsumoto, 2010). However, four specimens were morphologically very close to *P. sephen* and referred to as *P.* cf. *sephen* (Figure 1.2.9) needing further taxonomic work. We also recorded two specimens of a third species of *Pastinachus*, which are morphologically consistent with *P. gracilicaudus*. Further taxonomic examination is required, however, as differences were found between the NADH2 sequences of the Bangladesh as compared to Borneo specimens. This species is tentatively referred to as *Pastinachus* cf. *gracilicaudus* (Figure 1.2.10).

Figure 1.2.7. Dorsal image of *Pastinachus* cf. *ater* from Cox's Bazar (Male, DW= 33.02 cm).

Figure 1.2.8. Dorsal image of *Pastinachus solocirostris* caught from southcentral Bangladesh (Male, DW= 71.12 cm).

Figure 1.2.9. Dorsal image of *Pastinachus* cf. *sephen* (Female juvenile. DW= 20.32cm).

Figure 1.2.10. Dorsal image of *Pastinachus* cf. *gracilicaudus* caught from southcentral Bangladesh (Pregnant female, DW= 83.82 cm).

Genus *Telatrygon*

Three specimens of a sharp-snouted stingray were preliminarily identified as *Telatrygon crozieri*, based on morphology. Samples were not obtained for genetic analysis and so further work is needed to confirm the identification and to distinguish *T. crozieri* from the recently described *T. biasa* recorded from Indonesia (Last et al., 2016d).

Genus *Urogymnus*

Urogymnus granulatus (Figure 1.2.11) was reported for the first time from Bangladesh, based on three specimens from one study site. NADH2 sequence analysis from one of the three specimens supported this identification. This confirms that four species of *Urogymnus* occur in Bangladeshi waters; *U. asperrimus*, *U. granulatus* (likely previously misidentified as *U. Africana) (*Hoq et al., 2011; Roy et al., 2015), *U. lobistoma* and *U. polylepis*, especially around mangrove areas in the southwestern region. *Urogymnus polylepis* (Figure 1.2.12) has been recorded in news articles but has not yet been added to checklists. Hence, while this is not considered a new record for Bangladesh, it is the first verified record from 52 specimens.

Figure 1.2.11. Dorsal image of *Urogymnus granulatus* from Cox's Bazar.

Figure 1.2.12. Dorsal image of *Urogymnus polylepis* from Cox's Bazar and caught from Sundarbans (Male, DW= 185.42 cm).

Family Mobulidae

Two species of *Mobula* have previously been recorded from Bangladesh; *Mobula mobular* and *M. kuhlii (*Hoq et al., 2011; Roy et al., 2014a*)*. In this study, *M. birostris, M. tarapacana, M. eregoodoo* and *M. thurstoni* (Figure 1.2.13) were recorded following examination of 97 mobulid specimens. Genetic analysis confirmed species identification for *M. tarapacana*, *M. kuhlii and M. mobular*, and the presence of either *M. alfredi* or *M. birostris*, but the NADH2 sequences alone cannot distinguish between these two species due to overlapping sequence polymorphism (G. Naylor, unpubl. data). This study confirms the presence of at least six mobulid species in Bangladesh; *M. alfredi* or *M. birostris*, *M. eregoodoo*, *M. kuhlii*, *M. mobular*, *M. tarapacana* and *M. thurstoni* where *M. thurstoni* has been reported for the first time with possible presence of *M. alfredi*.

Figure 1.2.13. Dorsal and ventral image of *Mobula thurstoni* from Cox's Bazar (Female juvenile).

Family Narcinidae

One specimen of *Narcine* was recorded which appears to be consistent with *N.* sp. of Psomadakis et al. (2020). This appeared to be morphologically similar to *N. brevilabiata* and *N. atzi*. Further specimens are required to confirm the species identification therefore this species is tentatively identified as *Narcine* sp. (Figure 1.2.14). (*sensu* Psomadakis et al., 2020).

Figure 1.2.14. Dorsal image of *Narcine* sp. from a commercial scale vessel in Chattogram.

Family rhinobatidae

Rhinobatos ranongensis (Figure 1.2.15), which was recently described from the Bay of Bengal and Arabian sea (Last et al., 2019), was recorded from >300 specimens from a single site. With the record of this *Rhinobatos* species, a total of at least eight species of Rhinopristiformes, including giant guitarfish (Glaucostegidae), guitarfish (Rhinobatidae) and wedgefish (Rhinidae), have been confirmed in the territorial waters of Bangladesh. Although not a new record, one specimen from one site and one genetic sample collected from the processed meat of an unknown species was confirmed to be *Rhinobatos lionotus* representing the first verified report from Bangladesh.

Figure 1.2.15. Several specimens' dorsal and ventral image of *Rhinobatos ranongensis* from Chattogram.

Family Hemiscylliidae

Bamboo sharks are poorly studied in the Bangladesh region, though a total of five species have been recorded; *Chiloscyllium burmensis, C. griseum, C. indicum and C. punctatum* (Hoq et al., 2011; Haque et al., 2019a) and most recently *C. hasseltii* (Datta et al., 2020). In this study, a total of 129 specimens of *Chiloscyllium hasseltii* (Figure 1.2.16) were morphologically identified. Eleven specimens that appeared morphologically consistent with *Chiloscyllium arabicum* (Figure 1.2.17) were also recorded, but in the absence of genetic data this warrants further investigation.

Figure 1.2.16. Dorsal and ventral image of *Chiloscyllium hasseltii* from Cox's Bazar (Female, TL= 31.24 cm).

Figure 1.2.17. Dorsal and ventral image of *Chiloscyllium* cf. *arabicu*m from Chattogram (Male, TL= ~31 cm).

Family Triakidae

Three houndshark species have been previously recorded from Bangladesh, i.e. *Mustelus manazo*, *M. mosis* and *Iago garricki* (Hoq et al., 2011; Habib et al., 2020). A total of 31 specimens of a second species of the *Iago omanensis* complex (which includes the poorly defined *I. mangalorensis,* if considered valid (Sen et al., 2020; Weigmann 2016; Maduna & Bester-van der Merwe, 2017) were recorded in this study. There is a possibility the recorded *Iago* sp. could be a new species to science as two separate species (*Iago* sp. A and *Iago* sp. B) have been theorised to be present in the Indian waters (Bineesh et al., 2017). This species is tentatively identified as *Iago* cf. *omanensis* (Figure 1.2.18) pending further taxonomic investigation. It brings the total number of triakid species in Bangladesh to four, with the taxonomy of the *Mustelus* species in this region being investigated by one of the authors (WW).

Figure 1.2.18. Dorsal and ventral and head region image of *Iago* cf. *omanensis* from Cox's Bazar (Female, TL= ~33 cm).

Family Carcharhinidae

Species from the family Carcharhinidae are the most commonly landed shark in Bangladesh, with *Scoliodon laticaudus* the most frequently caught. Smaller carcharhinids tend to be piled together, and are difficult to sample individually. The presence of *loxodon macrorhinus* was confirmed, warranting further investigation, including specimen collection and genetic analysis.

Most of the reported species in this study inhabit depths between 40-100 m, while a few species are known to occur at depths over 100 m (e.g. *Mobula* spp., *Iago* cf. *omanensis*). Many of the species, particularly the stingrays (Dasyatidae) mostly occur in coastal and inner shelf waters (mostly <100m depth), particularly around mangroves (Last et al., 2016a). Almost all shallow water coastal and marine areas are exploited by artisanal fishing. The lack of deep-water species is expected as artisanal fishing is limited to waters shallower than 200 m. Future sampling of the catch from mid and deep-water industrial vessels may result in further new records for the country.

Of the possible new records, one species, *Maculabatis arabica,* is designated as Critically Endangered, four as Endangered (*Mobula thurstoni, Urogymnus polylepis, Maculabatis macrura and Pastinachus solocirostris*) and three as Vulnerable by the IUCN Red List of Threatened Species (Table 1.2.1), though many have not yet been evaluated. One species (*M. thurstoni)* is listed by the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) and The Convention on Migratory Species (CMS). Bangladesh protects 29 species of elasmobranchs under the Wildlife (Conservation and Security) Act, 2012. Recently, Bangladesh has responded to global concern for elasmobranch populations, by planning the amendment of this Act for better protection of the most threatened species (J. Kabir, Director, Sheikh Kamal Wildlife Centre, Bangladesh Forest Department, pers. comm. 28 Feb, 2020). Moreover, developing non-detrimental findings (NDFs) (Rose, 2014) is also a top priority for the country in 2020. However, such initiatives need to be underpinned by solid scientific understanding, such as provided in this study, as a lack of accurate taxonomic and species-specific information impedes conservation efforts.

In the absence of a regional identification guide and reliable species checklist, field-level research work is impeded. The current study and our ongoing work (Haque et al., 2021a) will lead to such a guide in the future, contributing to better taxonomic resolution for several species.

Conclusion

Here we provide formal records of elasmobranch species that have likely previously been observed in the area but have lacked verified records due to limited taxonomical research, misidentification and limited surveys and publications. This study has enhanced our knowledge of the diversity of elasmobranchs in the Bay of Bengal, improving what is known from existing literature and has important conservation implications.

APPENDIX 2: SUPPLEMENTARY MATERIAL FOR CHAPTER THREE

Table S3.1. Semi-structured questionnaires targeted at fishers

Questionnaire

তথ্যদাতা/ মৎস্যজীবী

Product and Processing

1. হাঙর তীরে আনার পর তারা কী করেন? What do you do with the sharks once you bring them ashore?
2. বিক্রয়ের পূর্বে তাদের কি ধরনের প্রক্রিয়াজাতকরণ করতে হয়? How do you process sharks before onward sale?
3. কোন অংশগুলো তারা বিক্রি করেন? What parts of the sharks do you sell?
4. অবিক্রিত অংশগুলো দিয়ে তারা কী করেন? What do you do with the rest of the parts which are not sold?
5. কোন আকারের হাঙর বিক্রয়ের উপযুক্ত? What size of the shark is preferable to you?

Supply Chain Structure:

1. উত্তরদাতাকে ছবি অথবা ম্যাপ আঁকতে বলা যেখানে হাঙর ধরা থেকে শুরু করে তার ক্রেতা পর্যন্ত যা যা ঘটে, পরিবহন, জায়গাগুলির নাম, কিভাবে পরিবহন করা হয়, কী কী পরিবহন ব্যবহার করা হয়, সংশ্লিষ্ট লোকজন ইত্যাদি সম্পর্কিত তথ্য থাকবে। Ask the respondent to draw a map or picture of what happens to the shark products from catching to the person buying them, transport route, names of places, how they are transported, what vehicles are used, different people affiliated and etc.
2. কাদের কাছে তারা হাঙরের বিভিন্ন অংশ বা পণ্য বিক্রয় করছেন? To whom do you sell the different parts/products of the shark?
3. তাদের ক্রেতা এক না একাধিক? একজন হলে কেন? Do you sell it to one buyer or many? why?
4. ক্রেতারা তাদের কাছে কতটুক সহজলভ্য? How available are the buyers to you?

5. তারা কি ক্রেতা ব্যতীত কোন সংগ্রাহকের কাছে বিক্রয় করেন? করলে কেন? Do you sell it to collectors or buyers? why?
6. তারা যদি বিভিন্ন পয়েন্টে সংগ্রাহকদের নিকট বিক্রয় করেন, সেগুলো কোন জায়গা? If you sell it to collectors at different points, where do you do it?
7. সংগ্রাহকেরা পণ্যগুলো কোথায় বিক্রয় করেন? Where do the collectors sell the products?
8. সংগ্রাহকেরা যদি সেগুলো বাজারে বক্রয় করেন, জেলেরা সেগুলো নিজেরা বিক্রয় করেন না কেন? If the collectors sell it to the markets, why can't the fishers sell it themselves?

Fishing gear /Fishing:

1. তারা কেন এই পেশায় এসেছেন? Why did you start selling sharks?
2. কখন এসেছেন? When did you start?
3. তিনি কি প্রধানত হাঙর ধরেন? Are you a target shark fisherman?
4. অন্যান্যরা হাঙর ধরার পেশায় আসছে না কেন? Are others in your community interested in shark fisheries?
5. অন্যান্যরা হাঙর ধরার পেশায় আসছে না কেন? What has stopped others to become shark fisherman?
6. তারা কি শুধু হাঙর ধরেন? Do you only catch shark? Or other fish as well?
7. হাঙরজাত পণ্যই কি তাদের মূল আয়/ বৃহত্তর আয়? Are shark products sale your main earning source (bring the most proportion of the earning)?
8. তারা কি শুরু হাঙর ধরে জীবিকা নির্বাহ করতে পারবেন? Can you survive just by shark fishing?
9. হাঙর ধরা কি মৌসুমী? Is shark fishing seasonal?
10. তারা প্রধানত কখন হাঙর ধরেন? When do you fish for shark mainly?
11. তারা যদি অন্যকিছু ধরেন, সেখান থেকে তাদের কেমন আয় হয়? সেগুলো কতটা গুরুত্বপূর্ণ? যদি তারা হাঙর না ধরেন, তারা কি অন্য কোন পেশায় যথেষ্ট আয় করতে পারবেন? If you fish for other fish, how much money do you earn from these? If you don't catch shark, can they make enough money from other jobs/fishing on other species?
12. কি ধরনের উপকরণ তারা ব্যবহার করেন? What fishing gear do you use?
13. সেসব তারা কোত্থেকে পান? সেগুলো কি নৌকা, ট্রলার মালিকের সম্পত্তি? কেউ কি এগুলো কিনতে সাহায্য করেছে? How did you acquire the fishing gears? Does it belong to the owner of the boat? Did anybody help in buying this?

14. তারা এগুলোর ব্যবহার শিখেছেন কোথায়/কীভাবে? How did you learn to use these gears?
15. উপকরণের মূল্য কত? How much the gear cost? (minimum to max.)
16. কয়দিন পর পর তাদের এগুলো মেরামত করতে হয়? তাতে খরচ কেমন পরে ইত্যাদি How often do you have to repair the gear? What are the maintenance cost of the gears?
17. কী ধরনের নৌকা ব্যবহার করেন? What type of boat do you use?
18. নৌকার দৈর্ঘ্য কত? Length of boat (measurement)?
19. নৌকার মূল্য How much the boat cost?
20. প্রত্যেক ট্রিপে কী পরিমান জ্বালানী দরকার হয়? How much is the fuel cost per trip?
21. নৌকা মেরামতে কী ধরনের খরচ হয়? How much us the maintenance cost of the boat?
22. মোটরের হর্স পাওয়ার (প্রযোজ্য ক্ষেত্রে)- Size of the engine if they use it
23. তারা কতটুক দূরত্ব পর্যন্ত যান? What distance/how far do you go?
24. সেই জায়গার/ জায়গাগুলোর নাম- Can you name the locations of the fishing grounds?
25. তারা ম্যাপে সেই জায়গা চিহ্নিত করতে পারেন কিনা? Can they show these locations on the map?
26. কোথায় হাঙর বা শাপলাপাতা মাছ বেশি পাওয়া যায়? Where can you find the most number of sharks and rays?
27. কতটুক গভিরতায় তারা মাছ ধরেন? In which depth do you fish in?
28. হাঙর ধরতে তারা প্রতিদিন কতক্ষণের ট্রিপ দেন? How long is the fishing trip is for sharks?
29. দিনের কোন সময় সবচেয়ে বেশি হাঙর ধরা পড়ে? What time of the day would you catch most sharks?
30. নৌকার সাথে সংশ্লিষ্ট লোক কতজন? How many people are involved in your boat?
31. নৌকার লোকজনের কীভাবে পারিশ্রমিক দেয়া হয়? How are the crew paid?
32. প্রত্যেক ট্রিপে কত খরচ হয়? How much does it cost for each fishsing trip?
33. কয়দিন পর পর তারা ট্রিপে যান? How frequently do you go for these trips? How long is each trip?
34. প্রত্যেক ট্রিপে তারা মোটামুটিভাবে কত আয় করেন? Grossly how much do you earn from each trip?
36. যখন হাঙর ধরেন, প্রতিটি ট্রিপে গড়ে কত খরচ হয়? When you catch shark, how much does an average fishing trip cost?

37. বছরের কোন কোন মাসে মাছ ধরেন? নির্দিষ্ট কোন মাস আছে কি? What months of the year do you fish? Is there a favoured fishing season?
39. হাঙর ধরার জন্য গ্রামে কয়টা নৌকা আছে? কয়জন জেলে? Do you know how many boats in this village fish for shark? How many fishermen?
40. Estimate total number of boats in the village/ fishermen in the village?
41. উপকূল বরাবর কতগুলো নৌকা বা ট্রলার আছে? Estimate total number of boats along the coast?

Target Species:

1. কোন প্রজাতিগুলো বেশি ধরা পড়ে? Which species of sharks are mostly caught? (pictorial guide)
2. কোন নির্দিষ্ট প্রজাতি টার্গেট করেন কি? কোনগুলো? Do you target any particular species? Which ones?
3. কেন? Why?
4. কীভাবে? How?
5. কোন প্রজাতিগুলো সবচেয়ে মুল্যবান এবং কেন? Which species are the most valuable to you and why?
6. কোনগুলো সবচেয়ে কম মুল্যবান, কেন? Which species are least valuable to you and why?
7. তারা ধরেন এমন প্রজাতিগুলোর নাম (তালিকা হবে) What are the species you catch? (Make a list)
8. মোটামুটিভাবে কতগুলো পূর্ণবয়স্ক হাঙর ধরা পড়ে? সপ্তাহে, মাসে, ট্রিপে (সর্বনিম্ন থেকে সর্বোচ্চ)? On an average how many adult sharks do you catch a week? a month? Per trip? (min to max)
9. মোটামুটিভাবে কতগুলো বাচ্চা হাঙর ধরা পড়ে? সপ্তাহে, মাসে, ট্রিপে (সর্বনিম্ন থেকে সর্বোচ্চ)? On an average how many small sharks do you catch a week? a month? Per trip? (min to max)
10. মোটামুটিভাবে কত কেজি পাখনা পাওয়া যায় সপ্তাহে, মাসে, ট্রিপে (সর্বনিম্ন থেকে সর্বোচ্চ)? On an average how many kg of fins per week/ month/ per trip can you sell? (Min. to Max.) ** তাজা না শুটকি? Clarify if dry or wet.
11. ধরা পড়া মাছের পরিমান কি বাড়ে, কমে না একই থাকে? Does the catch remain the same throughout the season? (make a time line)

12. বাড়া বা কমার কারণ টা কি? Why do you think there is this trend of increasing or decreasing pattern of catch/seassonality? (list reasons)

Prices:

1. পাখনার কি কোন শ্রেণিবিভাগ আছে? Is there a fin gradation system?
2. কীভাবে ভাগ করা হয়? কী কী প্রকারের পাখনা আছে? Can you tell me how fins are graded and what are the different qualities?
3. বিভিন্ন পাখনার মূল্য কেমন? What are the prices of these different qualities?
4. কোন ধরণের পাখনার দাম সর্বোচ্চ? What type of fins fetch the highest price?
5. হাঙরের অন্যান্য অংশ তারা কত দামে বিক্রি করে? *fin, leather, meat, liver, how much do you sell these parts of the shark for?

নিয়মনীতি/ আইনকানুন Regulations/ Laws:

1. কোন আইন আছে কি? Are there any laws regarding the catch and trade of sharks and rays?
2. তারা কি আইনগুলো সম্পর্কে বলতে পারবেন? Can you describe these laws?
3. তারা কি আইন এর অনুগত? Do you abide by them?
4. কোন আইন থাকা উচিত কিনা? Do you think there should be laws for conserving sharks and rays?

** যেসব সংগ্রাহকের সাথে কাজ করেছেন বলে তারা উল্লেখ করেছেন তাদের নাম ঠিকানা দিতে পারবেন কিনা? অথবা আর যেকোন তথ্য। Can you provide the contact details of any collectors they work with? Or Any information about the collectors or buyers?

Table S3.2. Population trend

১। আপনি যতদিন থেকে মাছ ধরছেন, আপনি যতদিন থেকে মাছ ধরছেন, হাঙ্গরের সংখ্যাতে বা আকারে কোনো পরিবর্তন লক্ষ্য করেছেন কি? যদি করে থাকেন, তাহলে তখন থেকে হাঙ্গরের সাইজ এবং সংখ্যা বেড়েছে না কমেছে?

Have you noticed any changes in the number or size of sharks since you have been fishing? If so, has the size and number of sharks increased or decreased since then?

I. সংখ্যা বেড়েছে/ কমেছে - Number increased/decreased

II. সাইজ বেড়েছে/ কমেছে - Size increased/decreased

III. দুটোই- Both

IV. কোনো পরিবর্তন নাই- No change observed

২। আপনি যতদিন থেকে মাছ ধরছেন, তখন থেকে আপনার ধরা সকল মাছ প্রজাতির মধ্যে কি কোন পরিবর্তন আপনি লক্ষ্য করেন?

Since you have been fishing, have you noticed any changes in shark species you have caught?

যদি করেন- If so,

I. প্রজাতি বেড়েছে- Species number increased

II. প্রজাতি কমেছে- Species number decreased

III. বড় হাঙ্গরের সংখ্যা বেড়েছে- Large shark species number increased

IV. বড় হাঙ্গরের সংখ্যা কমেছে- Large shark species number decreased

V. বিরল প্রজাতি বেড়েছে- Rare shark species number increased

VI. বিরল প্রজাতি কমেছে- Rare shark species number decreased

VII. অন্যান্য ----------------- others -

৩। আপনি যদি মনে করেন আপনার ধরা হাঙ্গর প্রজাতিগুলোর মধ্যে কোন পরিবর্তন এসেছে তবে তার পিছনে কি কারণ থাকতে পারে? (যদি প্রথম প্রশ্নের এর উত্তর হ্যা হয়ে থাকে).

If you think there has been a change in the species of sharks you catch, what could be the reason behind it? (If the answer to the first question is yes).

হ্যাঁ বা না? - Yes/No

I. মাছ বেচাকেনার বন্দরের সংখ্যা বৃদ্ধি- Number of ports increased

II. মাছ ধরা বন্ধ হয়ে যাওয়া- Fishing closures

III. অতিরিক্ত মাছ ধরা- Overfishing

IV. অন্যান্য -------------- Others

৪। আপনি যখন প্রথম হাঙ্গর ধরা শুরু করলেন এমন কি কোন প্রজাতি ধরা পড়ত যা এখন আর ধরা পড়ে না? যদি থাকে এমন প্রজাতি তাইলে কোনটি?

I. হ্যাঁ- Yes

II. না- No

III. প্রজাতির নাম- Name of the species

৫। আপনার মতে, এদের মধ্যে কোন কোন হাঙ্গর প্রজাতিগুলোর সংখ্যা বেড়েছে অথবা কমেছে-

Which of these shark species do you think has increased or decreased in numbers?

Tiger shark   hammerhead shark   whale shark   black tip   silky   sawfish

Guitar fish   Carchariniforms sharks   Rhynchobatus spp.

৫-১০ বছর- 5-10 yrs বেড়েছে/Increased   কমেছে/ Decreased   কোন পরিবর্তন নেই/No change বিলুপ্ত/ can not be found

১০-২০ বছর- 10-20 yrs বেড়েছে/Increased   কমেছে/ Decreased   কোন পরিবর্তন নেই/No change বিলুপ্ত/ can not be found

6. Overall decrease: (in years)-

Table S3.3. Detailed methodology and results of Focus Group Discussions (FGD) to characterise ray fisheries

Characteristics of fishers interviewed	• 32 to over 60 years of age. • All male • 5-35 years of experience • Except for two retired fishers (activity period from 1979 to 2002) all interviewees were still actively involved in elasmobranch fisheries • 5 boat captains, 6 boat owners, who all received a share of the profit

	• 30 fishers (salary between US$ 24 and US$ 56 per fishing trip) • Primary income source for all participants: ray fisheries.
Characteristics of targeted ray fisheries	The authors conducted four focus group discussions with fishers targeting rays with longline hooks, upon encountering hooks attached to the pectoral fins and sometimes mouth of the rays at landing sites (Haque unpubl. data) and less representation of target ray fishers in the semi-structured interviews. The discussions were in the fishing villages of Cox's Bazar, and Teknaf between 30 October 2017 and 28 January 2018 from 10.30 am and 5 pm. A total of 43 fishers participated in these discussions (8 and 13 in each discussion). Each discussion was conducted in a very informal manner for three to five hours. However, 41 fishers participated in the whole discussion, and two left before the discussion ended. Fishers were made free to join or leave anytime they wanted. Anonymity was ensured, and verbal permission was taken after a brief of the study being conducted. In one occasion a target ray fisher and boat owner hosted the discussion in his house. The discussion topics were broadly based on 1. The demographics of the fishers and historical trend of ray fishery 2. Fishing practices 3. Targeted species 4. Ray products and national and international trade 5. Supply chain structure 6. Prices and dependency 7. Laws and enforcement. One trip in the sea was conducted renting a boat for a day (12 hours) with experienced fishers to understand targeted ray fishery with long lines. The journey started from Cox's Bazar. One km long line with >50 hooks was deployed to understand the operation. The authors also stopped by other fishing boats to observe their fishing operations. All participants were male fishers targeting rays ranging from 32 and >60 years of age (as females do not fish in the sea). They had five to 35 years with two retired fishers (active from 1979 to 2002). Five of them were captain of the boat, six were boat owners, and the rest were fishing workers at boats on a trip basis salary between US$ 24 and US$ 36. The boat owner and the captain get a share from the profit. Majority of them were local (e.g., from Nuniyarchora and Moheshkhali) to Cox's Bazar except four who settled here for livelihoods. Majority of the fishers started fishing in their teenage and learnt the operation from elders in the family and took on the family business. Ray fishing is their primary source of income with minimal secondary opportunities or expertise. However, over the years due to population and catch rate decline, currently it isn't easy to have a livelihood just by ray fishing.
Ray fisheries	Both motorized and non-motorized boats were used for this operation. Motorized boats were between 1280 cm to 1370 cm in length with engines

between 33 and 100 hp (Table 3.3). They went for fishing in the nearshore coastal areas on an average of 12 hours sailing from the river mouth of Naaf to near southcentral (Mohipur, Patharghata, Alipur, Kuakata, and many coastal islands) and southwest near the border of India (e.g., Sundarbans). Each trip consisted of five to seven days—the fishers, fish between 4.8 m and 36.5 m depth. Usually, there were ten to fourteen fishers in one such boat fishing for rays. They operated two to three trips per month (14-21 fishing days). Whereas the non-motorized boats are smaller with 3-4 fishers goes on a day trip in nearer waters.

Each motorized boat costs US$5920 and US$9472. Gears (rope, buoy, hooks) cost between US$1700 and US$1800. Annual maintenance cost was between US$ 710 and US$ 1000. For each trip, the logistic cost was between US$ 1700 and US$ 2500, including the fuel.

Target ray fishery is more than a four-decade-old practice in Bangladesh. The technique of fishing has been passed down to generations.

In Cox's Bazar about 100 fishers target only rays as their primary livelihood option and at least ten mechanized boats are in operation with many non-mechanized boats. Similarly, targeted ray fishery was also reported in the southcentral and southwest coastal Bangladesh. The fishers report more than 80 mechanized boats in practice deploying an estimated 4000000 to 8000000 hooks in long lines (each one ~15 km) every day of their fishing season in the whole nearshore coastal zones of Bangladesh. Apart from target fishery rays are also profusely caught as a non-discarded bycatch by almost all types of marine fisheries and gears.

Trade in rays

Fishers sell their catch at the landing sites to a syndicate of more than 20 buyers and traders who are readily available in the landing site in Cox's Bazar. The rays are kept in the boat's ice storage, and traders seldom contact the boats. They sell the whole body in per kg manner in the landing sites and do not sell it in local markets as in those markets; there is not much value given. The traders and intermediaries buy what they need according to their business's demand from the landing sites. They process the products in twelve exclusive elasmobranch processing centres dealing only with elasmobranchs in the south-eastern region. Opportunistic traders also source rays from the landing sites. Apart from that, individual consumers also buy from the landing sites.

An array of products is made depending upon the species, size and demand. Majority of rays are de-skinned at the landing site (Fig.1), and skins are seldom sold to buyers only trading on and exporting skins from Cox's Bazar and

Chattogram. The other traders buy the meat. However, mostly all the products are bought by a single trader. In the processing centres, the rays are sorted according to their size (small, medium and large) and species. Smaller rays are dried in Najirtek and Moksedapara (Fig. Map) whereas other products are made in all study sites.

Overall, the price depends on the quality of the product and sold with an array of prices. For example, meat that is not treated with insecticides or salt is more expensive than the treated ones.

Rays have both national and international demand. An array of products is being made and delivered to different markets and consumers according to the demand. At the same time, fresh rays are sent to metropolitan cities (e.g., Dhaka and Chattogram). Rays are being eaten predominantly by minorities and tribal communities. However, it also has a rising demand for the mass. Dried whole bodies smaller rays have a demand in the coastal villages and tribal areas (e.g., Teknaf, Cox's Bazar) and the three hill districts of Chattogram (Rangamati, Bandarban and Khagrachori). However, international demand is also high. Dried meats, skin and gill rakers are predominantly exported to Myanmar. The highest prices are sources from guitarfishes, sawfishes and large dasyatid rays.

Supplementary information S3.1. Limitations of the study

Despite a long-standing tradition of targeting elasmobranchs and retaining bycatch, the species-specific understanding of interviewed fishers was low for morphologically similar species. Our results are hence limited to species that fishers could reliably identify, i.e. spottail shark, spadenose shark, bamboo shark, tiger shark, hammerhead shark, whale shark, giant guitarfish, guitarfish, wedgefish as a group, and sawfish. Our results, therefore, likely underestimate the extinction threat of several unidentified species. The data collected on fishing locations and perceived catch decline included some margins of error. This could be for a combination of reasons, such as the inability to read maps, overestimation for target catch or under-estimation of bycatch, and most importantly, the inability to identify many carcharhinid sharks to the species level. Hence ranges in catch numbers were used, and expansive fishing grounds were identified rather than the exact location. Deep sea fishing was not assessed due to the small sample size within the current study. Owing to all these factors together with the absence of a historic baseline, our results should be interpreted carefully. However, it was evident that fishers were sharing information accurately, true to the current elasmobranch fishery status and were not restricted due to legality concerns (e.g., fishers shared information about fishing during ban periods). This could be either because of a genuine interest in sharing small-scale fishers' challenges or being unaware of the regulations, the limited enforcement leading to rare penalties.

Table S3.4. Artisanal fishers' fishing location indicated by interviewed fishers (n=66). A total of 208 responses were recorded. (SE-Southeast, SW-Southwest, and SC- Southcentral)

Names	Region	Respondents (%)
Rupar char	SC	15 (7.21)
Dhal char	SC	15 (7.21)
Mohipur	SC	19 (9.13)
Matha Vanga	SW	13 (6.25)
Shaplapur	SE	4 (1.92)
Jinjira	SE	3 (1.44)
Sundarban	SW	9 (4.33)
Kuakata	SC	9 (4.33)
Shondip	SE	2 (0.96)
Patilar Char	SC	7 (3.37)
St. Martin's Island	SE	13 (6.25)
Shonar Char	SC	17 (8.17)
Myanmar border	SE	10 (4.81)
Teknaf	SE	3 (1.44)
Mongla	SW	15 (7.21)
Lama	SE	11 (5.29)
Shibchar	SC	7 (3.37)
Baulla	Inconceivable	5 (2.40)
Hatia	SC-SE	8 (3.85)
Shonadia	SE	13 (6.25)
Kalkini	SC	6 (2.88)
Moheskhali	SE	4 (1.92)

Table S3.5. Number and type of interviews conducted by study site and respondent type. N/A stands for no individual of this particular profession was present in respective area during the time of interview and 0 stands for there might be people with that profession however, they were not interviewed.

Respondent characteristics/ Study sites	Cox's Bazar	Teknaf	St. Martin's Island	Total	Type of interview

Fishers (bycatching elasmobranchs)	26	6	34	66	Semi-structured
Fishers (population trend analysis)	40	6	34	80	Semi-structured
FGD (ray fishers)	2 (24 participants)	2 (18 participants)	0	4 (43 participants)	Thematic
Identification capacity exercise	25	-	-	-	Photo booklet
Total	84	28	68		
Details of respondents	• 19 to 65 years of experience (mean = 40.71 ±12.07 SD) • 2 and 40 years of fishing experience (mean = 22.31 ±10.25 SD). • Fishing was the primary means of livelihood. • 9% (n=5) of fishers had secondary or alternative means especially in fishing ban periods (June- July), such as farming, labouring or retail. • The boat owners retained a significant share of the profit • the fishers, technicians and labourers were either paid per trip or received a share of the profit (e.g., captains). • All fishers concurred that this is an unfair financial arrangement. • Although fishing was a family tradition for most (95%, n=63) • Only a few fishers wanted their next generation to continue fishing due to low income and risk.				
Details on fisheries practices	• Wooden- motorised and wooden-unmotorized boats • Engine powers related to the distance covered • Fishing trip length varied by boat size, ranging from one to 12 d per trip and 1-3 trips per month for large vessels (>15m in length) and 25-30 trips for small vessel (<10 m) belonging to daily fishers • Vessels covered straight-line distances between 1-> 250km from their homeports, with some occasionally fishing in Indian waters (n=26) • About 60.6% were fishing within 100 km from the port of departure and 39.4% were fishing between 100->250 km distances from the port • Fishing locations were predominantly in shallow to moderately deep (5-115m) nearshore areas (Figure 1) • 75% were unable to define exact catch locations for elasmobranch.				

Table S3.6. Characteristics of fishing trips, vessel types, fishing locations, gear used, species of targeted and bycaught ray species with the trade and value of traded products according to focus group discussions participants

Target ray fisheries			
	Boat type	Motorized vessel	Non-motorized vessel
	Length	12.80-13.70 m	<10 m
	HP	33-100	-
	Trip duration	5-7 d	1-2 days (mostly daily)
	Trip per month	2-4	~ 30
	Fishing days per month	14-21 d	30
	Distance covered	5-12 hours from the homeport	Very close to the shore and homeports
	Fishing grounds	South-central and south-western shallow coastal waters	-
	Length of lines	5-15 km	<5 km
	No. of hooks per km of line	10000-30000	5000-10000
	Depth at fishing	4.8-36.5 m	<20 m
	No. of active boats	80	>100
	No. of fishers per boat	8-15	3-5
	No. of large individual rays caught per trip	1- >50	0-5
	Fishing season	November to April	All year round
Bycaught species			• The primary target was rays, • Fishers also catch an array of finfish (e.g. croakers, seabream, snapper, grouper, coastal catfish, barramundi)
Target species	*Abundance*	*Most frequently caught species*	• *Glaucostegus* spp. giant guitarfishes • *Gymnura* spp. butterfly ray • *Himantura* spp. spotted stingrays (both large and small individuals)

			• *Bevitrygon* spp. whiprays • *Pateobatiss* spp. whiprays • *Maculabatis* spp. whiprays • *Neotrygon* spp. maskrays
		Less frequently caught species	• *Hemitrygon* spp. stingrays • *Telatrygon* spp. sharpnose rays • *Maculabatis gerrardi* whitespotted whipray • *Urogymnus* spp. mangrove whiprays • *Urogymnus polylepis* giant freshwater ray
		Rare species	• *Urogymnus asperrimus/africana/lobistoma* mangrove whiprays • *Pristis* spp. sawfishes • *Rhynchobatos* spp. wedgefishes • smaller guitarfishes • *Narcine* spp. electric rays • *Mobula spp.* devil rays • *Aetomylaeus* spp. eagle rays.
	Value of species	*Most valuable species*	• All rhinopristiformes rays (especially sawfish and *Rhynchobatos spp.)* • Large dasyatid rays • *Mobula* rays devil rays
		Less valuable species	Small species as skin is unobtainable
		Least valuable species	• *Narcine* spp. electric rays • Very small rays
Trade	*Products*	*Most valuable products*	• Meat • Skin and • Gill plates
		Less valuable products	• Meat of smaller rays • Liver • Tail
	Destination of products	*National*	• Meat: Coastal communities, tribal communities, and certain cosmopolitan cities
		International	• Dried meat • Skin • Gill plates to Myanmar

Seasonality, target and valuable species of fishing vessels operating in Cox's Bazar, Teknaf and St. Martin's Island. Primary gear type indicates gear used to catch the main target species; secondary gear type indicates additional gear used to catch non-target species

Seasonality	● 72% fishers did not fish in the monsoon season (June-July) due to adverse weather conditions and fishing restrictions on *Tenualosa ilisha hilsa* (except those from St. Martin's Island); ● 17% fishers fished all year-round (Table 3.2). ● 91% fishers reported winter (November to January) as a primary season for catching sharks, followed by summer to pre-monsoon (February to May). ● Fishers identified the late summer (March) to pre-monsoon (May) as the potential breeding season for most of the shark species due to frequently caught gravid individuals.
Catch location	● Fishers exploited extensive shallow coastal waters from southeast to southwest region (Table S3.4). ● 56% identified nearshore char areas (shallow water dynamic islands in south-central Bangladesh) as prime locations for targeting guitarfishes and ray species. ● 32% mentioned these as preferred areas to catch pregnant rays. ● 32% mentioned bigger sharks and rays (>2 m) to be found in deeper waters (> 100m), whereas pups and sometimes pregnant individuals are found near shore. ● Most elasmobranchs were caught in shallow (1-35m) to medium (36-60m) nearshore waters.
Target species	● *Tenualosa ilisha* hilsa ● *Pampus* sp. pomfret ● *Harpadon nehereus* Bombay-duck ● Sardine (Clupeidae) ● Jewfish (Sciaenidae) ● Catfish (Ariidae) ● *Penaeus monodon* tiger shrimps ● Groupers (Serranidae) and ● Snappers (Lutjanidae)
Most valuable species	● *Carcharhinus amboinensis* pigeye shark, ● *Galeocerdo cuvier* tiger shark, ● *Carcharhinus leucas* bull shark (mostly bigger carcharhinids) ● *Sphyrna* spp. hammerhead sharks (due to of their large size and quality of fins) ● Rhinopristiformes rays (giant guitarfish, guitarfish, wedgefish, including sawfish) ● *Mobula* rays and bigger dasyatid rays

Least valuable species	•	*Scoliodon laticaudus* spadenose shark • *Carcharhinus amblyrhynchos* grey reef shark • *Rhizoprionodon acutus* milk shark • pups of *Carcharhinus limbatus* blacktip shark and *Carcharhinus sorrah* spottail shark • *Chiloscyllium* spp. bamboo sharks (<70 cm), • Small sized species • Despite their low value small sized species were traded, with *Chylloscilium* spp., for example, sold at a nominal price (0.6 USD per kg).

Table S3.7. Results for the Poisson GLM (generalised linear models)

1. **Outcome: Number of elasmobranchs caught per month (family=quasipoisson)**				
Outcome: Number of elasmobranchs caught per month				
Independent variable	Estimate	Std. Error	Statistics	p-value
(Intercept)	8.163265	1.054351	7.742	4.92e-13 ***
Fishing depth	-0.015386	0.015120	-1.018	0.3101
Mesh size of gear used	-0.151837	0.063199	-2.403	0.0172 *
Monthly fishing days	-0.005890	0.045912	-0.128	0.8981
Distance from homeport	0.002612	0.002009	1.300	0.1951
Model Fit: $\chi^2(4)$ = 70289.99, p = 0.01; Nagelkerke's R2 = 1.00; Pseudo-R^2 (Cragg-Uhler) = 1.00; Pseudo-R^2 (McFadden) = 0.16				
2. **Outcome: Number of elasmobranchs caught per month**				
Here, Nagelkerke's R^2 = 1.00. The model's intercept, corresponding to Area = Cox's Bazar, Season = All seasons and Gear = Floating gill net, is at 5.88 (95% CI [5.81, 5.94], p < .001).				
Independent variable	Estimate	Std. Error	Statistics	p-value
(Intercept)	8.8480	1.1987	7.381	4.24e-12 ***
Area - St. Martin's Island	-1.7043	0.5198	-3.279	0.00123 **
Area - Teknaf	-0.6124	0.8564	-0.715	0.47539
Season-Monsoon	-1.2293	1.1325	-1.085	0.27906
Season-Summer	-1.9137	1.1780	-1.625	0.10585
Season-Winter	-2.9219	1.3273	-2.201	0.02886 *
Gear-Hilsa gill net	-0.9191	0.4446	-2.067	0.04002 *
Gear-Large-mesh gill net	-3.4043	1.8231	-1.867	0.06334 ·
Gear-Longlines	-1.4724	1.8377	-0.801	0.42396
Gear-Monofilament gill net	1.2918	0.9198	1.404	0.16178
Gear-Others	-2.9537	2.8797	-1.026	0.30630
Gear-Seine net	-2.8083	4.0955	-0.686	0.49370

Gear-Set-bag net	2.2301	0.7708	2.893	0.00424 **
Gear-Submerged gill net	0.1910	0.9182	0.208	0.83544
Model fit: χ^2 (13) = 169358.23, p = 0.00; Nagelkerke's R^2 = 1.00; Pseudo-R^2 (Cragg-Uhler) = 1.00; Pseudo-R^2 (McFadden) = 0.39				

Table S3.8. Species used in the pictorial guide to assess the fishers' identification capacity of different elasmobranch species with notes on identification capacity, group assigned depending on the identification capacity, IUCN Red List, CITES and National protection status.

	Scientific, common and local species names (in Bangla)	Identification capacity	Group assigned	IUCN status	CITES App.	National Protection (Schedules)
			Sharks			
1	*Carcharhinus amblyrhynchoides* (Graceful Shark, ইলিশ্যা, পাক্কালা)	Inconsistent identification	Large carcharhinid sharks	NT (2005)	-	-
2	*Carcharhinus amboinensis* (Pigeye Shark, মহিলা/ভোতা)	Inconsistent, frequently identified as bull shark, ganges shark etc.		DD (2005)	-	-
3	*Carcharhinus falciformis* (Silky Shark, ইলিশ্যা, তম্মি)	Inconsistent, frequently identified as graceful sharks, hardnose shark etc.		VU (2017)	II	I
4	*Carcharhinus leucas* (Bull Shark, গোয়াইন/ইলিশ্যা/ভোতা)	Inconsistent, frequently identified as pigeye shark, ganges shark etc.		NT (2005)	-	-
5	*Carcharhinus melanopterus* (Blacktip Reef Shark, গোয়াইন)	Inconsistent, sometimes identified as a separate species based on fin spots		VU (2020)	-	-
6	*Carcharhinus longimanus*			CR (2018)	II	-

	(Oceanic whitetip shark, ইলিশ্যা)	Inconsistent, frequently identified as bull shark, pig-eye shark However, several fishers could identify *Lamiopsis temminckii* as a different species with a different local name				
7	*Glyphis gangeticus* (Ganges Shark, ইলিশ্যা)			CR (2007)	-	I
8	*Glyphis glyphis* (Speartooth Shark, ইলিশ্যা)			EN (2005)	-	
9	*Lamiopsis temminckii* (Broadfin Shark, বোতা/ভোতা/ চ্যানারি)			EN (2008)	-	-
10	*Carcharhinus macloti* (Hardnose Shark, টুইট্টা)	Inconsistent. However, many fishers could identify as a different species		NT (2003)	-	I
11	*Carcharhinus dussumieri* (Widemouth Blackspot Shark, লতা)	Inconsistent. However, many fishers could identify as a different species	Slender large to medium carcharhinid sharks	EN (2018)	-	I
12	*Rhizoprionodon acutus* (Milk Shark, লতা)	Inconsistent. Frequently identified as spadenose shark or pups of larger carcharhinid sharks		VU (2020)	-	I
13	*Rhizoprionodon oligolinx* (Grey sharpnose shark, লতা/ সোনালী লতা)	Several fishers could identify as a different species		LC (2003)	-	-
14	*Carcharhinus sorrah* (Spot-tail Shark, লতা/ দাড়ি)	Frequently identified as a separate species due to the presence of black markings on caudal fin		NT (2007)	-	I
15	*Chaenogaleus macrostoma* (Hooktooth	Inconsistent, frequently identified as spadenose shark	Small carcharhinid sharks	VU (2008)	-	-

	Shark, খলা/কালা হাঙর)					
16	*Loxodon macrorhinus* (Sliteye Shark, খলা/কালা হাঙর)	Inconsistent, frequently identified as spadenose shark		LC (2003)	-	-
17	*Scoliodon laticaudus* (Spadenose Shark, খলা/কালা হাঙর)	Frequently identified as a separate species due to the abundance of the species; however, confused with *Scoliodon macrorhynchos*		NT (2005)	-	-
18	*Chiloscyllium griseum* (Grey Bamboo Shark, বৈদ্য)	Frequently identified as a separate taxon as bamboo sharks, however, species-specific identification capacity was inconsistent	Bamboo sharks	VU (2020)	-	I
19	*Chiloscyllium indicum* (Slender bambooshark, বাঘা/ বৈদ্য)			VU (2020)	-	-
20	*Galeocerdo cuvier* (Tiger Shark, বোতা, বাঘা)	Frequently identified as a separate species	Tiger shark	NT (2018)	-	I
21	*Eusphyra blochii* (Winghead Shark, কাউন্না, হাতুড়ি হাঙ্গর)	Frequently identified as a separate taxon as hammerhead sharks, however, species-specific identification capacity was inconsistent	Hammerhead sharks	EN (2015)	-	I
22	*Sphyrna lewini* (Scalloped Hammerhead Shark, কাউন্না)			CR (2018)	II	I
23	*Sphyrna mokarran* (Great hammerhead Shark, কাউন্না, হাতুড়ি হাঙ্গর)			CR (2018)	II	-
24	*Sphyrna zygaena* (Smooth			VU (2018)	II	I

	Hammerhead Shark, কাউন্না, হাতুড়ি হাঙ্গর)					
25	*Rhincodon typus* (Whale Shark, ফড়া, পাইন্না, ব্যাঙ*)*	Frequently identified as a separate species	Whale shark	EN (2016)	II	I
26	*Stegostoma fasciatum* (Zebra Shark, চিতা হাঙ্গর/ বাঘা হাঙ্গর)	Frequently identified as a separate species	Zebra shark	EN (2015)	II	I
			Rhinopristiformes rays			
27	*Pristis pristis* (Largetooth Sawfish, সাদা আইশ্যা, খরখোর, করাত মাছ/ করাতি বাইল্লা/ করাত)	Frequently identified as a separate taxon as sawfishes, however, species-specific identification capacity was absent	Sawfishes	CR (2013)	I	I
28	*Pristis zijsron* (Green Sawfish, আইশ্যা, খরখোর, করাত মাছ/ করাতি বাইল্লা/ করাত)			CR (2012)	I	I
29	*Anoxypristis cuspidata* (Narrow Sawfish, আইশ্যা, খরখোর, করাত মাছ/ করাতি বাইল্লা/ করাত*)*			EN (2012)	I	I
30	*Glaucostegus granulatus* (Sharpnose Guitarfish, নাগলা, নাঙলা, গেরেঞ্জা, পীতাম্বরি)	Frequently identified as a separate taxon as guitarfishes, however, species-specific identification capacity of	Guitarfishes	CR (2018)	II	I

32	*Rhinobatos annandalei* (Annandale's Guitarfish, নাগলা, নাঙলা, গেরেঞ্জা, পীতাম্বরি)	giant guitarfishes and guitarfishes was absent		DD (2008)	-	-
33	*Glaucostegus typus* (Giant Shovelnose Ray, নাগলা, নাঙলা, গেরেঞ্জা, পীতাম্বরি)			CR (2018)	II	-
34	*Glaucostegus thouin* (Thouin Ray, পীতাম্বরি)			CR (2018)	II	-
35	*Glaucostegus obtusus* (Widenose Guitarfish, ভোতা পীতাম্বরি)	Frequently identified as a separate species		CR (2018)	II	-
36	*Rhina ancylostoma* (Bowmouth Guitarfish, ব্যাঙ মাছ, ভোতা পীতাম্বরি)	Frequently identified as a separate species	Bowmouth guitarfish	CR (2018)	II	-
37	*Rhynchobatus djiddensis* (Giant Guitarfish, ফুলআইশ্যা)	Frequently identified as a separate taxon, however, species-specific identification capacity was absent for different white-spotted wedgefishes	Wedgefishes	CR (2018)	II	I
38	*Rhynchobatus laevis* (Smoothnose Wedgefish, ফুলআইশ্যা)			CR (2018)	II	-
39	*Rhynchobatus australiae* (Bottlenose			CR (2018)	II	

	Wedgefish, ফুলআইশ্যা)					
	Rays					
40	*Aetobatus flagellum* (Longheaded Eagle Ray, সোয়াইন)	Frequently identified as a separate taxon, but identification capacity was absent for different eagle rays as separate species	Eagle rays	EN (2006)	-	-
41	*Aetobatus narinari* (Spotted Eagle Ray, ফুল সোয়াইন)			NT (2006)	-	II
42	*Aetomylaeus maculatus* (Mottled Eagle Ray, সোয়াইন)			EN (2020)	-	-
43	*Aetomylaeus nichofii* (Banded Eagle Ray, সোয়াইন)			VU (2015)	-	II
44	*Rhinoptera spp.* (Cownose Ray, সোয়াইন)	Frequently identified as a separate taxon, however, species-specific identification capacity was absent for all cownose rays	Cownose rays	NA	-	-
45	*Rhinoptera javanica* (Javan Cownose Ray, সোয়াইন)			VU (2006)	-	-
46	*Hemitrygon bennetti* (Bennett's stingray, মুন্ডুন)	Inconsistent, frequently identified as different species of whiprays and sting rays	Small to medium dasyatid rays	VU (2020)	-	II
47	*Pateobatis fai* (Pink whip ray, মুন্ডুর)			VU (2015)	-	-
48	*Pastinachus sephen/ Pastinachus* spp.			NT (2017)	-	-

	(Cowtail Stingray, রাম্মি, শিলর, মন্ডুর)					
49	*Pateobatis bleekeri* (Bleeker's Whipray, পাইন্না)			EN (2020)	-	-
50	*Maculabatis gerrardi* (Whitespotted Whipray, মন্ডুর)			EN (2020)	-	-
51	*Brevitrygon walga* (Dwarf Whipray, মন্ডুর)			NT (2017)	-	-
52	*Telatrygon zugei* (Pale-edged Stingray, রাম্মি)			NT (2006)	-	-
53	*Taeniura lymma* (Ribbontailed Stingray, শিলের থাক্কুয়াইশ)	Inconsistent	Spotted rays	NT (2005)	-	-
54	*Taeniurops meyeni* (Blotched fantail ray, শিলের থাক্কুয়াইশ)			VU (2015)	-	-
55	*Neotrygon kuhlii* (Blue-spotted Maskray, তাইন, থানকুইশ)			DD (2017)	-	II
56	*Gymnura japonica* (Japanese butterfly ray, নামেনি/পদনি/পদুনী)	Frequently identified as a separate taxon, however, species-specific identification capacity was absent	Butterfly rays	DD (2007)	-	-
57	*Gymnura micrura* (Smooth			DD (2006)	-	-

	Butterfly Ray, পদনি/পদুনী)					
58	*Gymnura poecilura* (Long-tailed Butterfly Ray, পদনি/পদুনী)			NT (2006)	-	II
59	*Himantura undulata* (Leopard Whipray, বাঘা/চিতা শাপলাপাতা)	Frequently identified as a separate taxon, sometimes as different species depending on the skin pattern	Large dasyatid rays	EN (2020)	-	-
60	*Himantura uarnak* (Honeycomb Stingray, বাঘা/ চিতা শাপলাপাতা)			VU (2015)	-	-
61	*Himantura leoparda* (Leopard Whipray, বাঘা/ চিতা শাপলাপাতা চিতা শাপলাপাতা)			VU (2015)	-	-
62	*Mobula mobular* (Giant Devil Ray, শিংচুয়াইন)	Frequently identified as a separate taxon, however, species-specific identification capacity was absent as all devil rays were identified as a single species; sometimes were identified as different species from Manta rays	Devil rays	EN (2018)	II	II
63	*Mobula kuhlii* (Kuhl's devil ray, শিংচুয়াইন)			EN (2020)	II	-
64	*Urogymnus asperrimus* (Porcupine Ray, খাটোইল্লা)	Frequently identified as a separate species	Large dasyatid rays	VU (2015)	-	-

65	*Urogymnus polylepis* (Giant Freshwater Stingray, হাউস)	Frequently identified as a separate species	EN (2016)	-	-

Table S3.9. Selected quotes of interviewed fishers on the status of shark fisheries and trade in Bangladesh

Interviewee	Theme	Quote
Artisanal fisher bycatching sharks	Habitat changes	*I used to see sharks closer to the shore when I started fishing 25 years ago. However, now all have moved to deeper waters.*
	Habitat changes	*There was a time when we did not have to go far to catch fish, but now we have to fish far away from the coast in deep waters to increase our catches.*
	Habitat changes	*Large sharks (6-10 m) have disappeared from nearshore waters. They have moved to deeper waters due to high fishing pressure in coastal areas.*
	Historic abundance	*Sharks and rays were easily caught in the early 2000s closer to the shores, and in some cases, the catch was so large that we couldn't take all the specimens to the landing sites.*
	Historic shark finning	*There used to be a time before 1990s when I couldn't take all the sharks caught in my net. The number was so high, that I used to cut the fins and discard the carcasses.*
	Population decline	*Larger sharks have declined by 60-70% in the past 15-20 years.*
	Population decline	*I started fishing more than 40 years ago. Since then, sharks have decreased by 80%.*
	Population decline	*Many species of sharks are rarely found. Many have gone extinct.*
	Population decline of sawfish	*I haven't seen sawfish in the past 20 years*
	Population decline of sawfish	*Sawfish have gone extinct from our waters.*
	Trade	*There have always been shark businesses in Cox's Bazar and Chattogram. Chinese buyers used to come and make orders.*

	Price and value	*One large shark can be sold at US$ 400-500 hence it is an important bycatch.*
	Consumption	*We don't eat sharks as it is prohibited by the Quran (Islamic scripture). However, tribal people in the Hill Tracts and Teknaf eat sharks.*
	Effects of regulation	*80% of all fishers will suffer if shark fishing is banned.*
	Knowledge on laws	*No one ever provided us with details on fishing laws and protected species.*
	Frustration of researchers and management officials	*Researchers come, collect their information and go. Nothing has changed for us. Officials come, and some charge bribes, and we bribe them in fear of punishment for something we clearly don't know what to do about.*
Ray fisher	Population decline of sawfish	*In 2015-16 I caught one sawfish. Since then I have never seen or caught one.*
	Population decline of *Rynchobatus* spp.	*Even eight to nine years ago, during the fishing season, there used to be regular landings of Fullaissha (local name of* Rynchobatus spp.*), at least two to three every day. But I have not seen or caught one since 2009.*
	Population decline of rays	*In the 1990s, we had to come back to shore after every daily fishing trip as we caught more than 2.000 rays in just less than 24 hours and had no storage capacity left. Even ten years ago, a seven-day fishing trip used to be enough for an entire month's subsistence for 10-12 fishers. Now there are days we don't even catch a single individual in a week.*
Elderly fisher once targeting rays	Conservation	*How can we get our shark stocks back like it used to be, 30-40 years ago?*
Elasmobranch trader	Population decline of *Rynchobatus* spp.	*I remember exporting fins of hundreds of Fullaissha between 2000-2005. They were landed in abundance. I haven't seen one in the past 10 years.*

Table S3.10. Results for the Poisson GLM (generalised linear models; family=quasipoisson)

Outcome: Timeline since a decrease in elasmobranch population size was observed				
Independent variable	Estimate	Std. Error	Statistics	p-value
Age	0.016652	0.003981	4.183	7.56e-05 ***
Fishing experience	0.007454	0.004225	1.764	0.0817 .
Model fit: $\chi^2(2) = 114.08$, $p = 0.00$; Nagelkerke's $R^2 = 0.84$				

We also fitted a generalized linear model (GLM, Poisson regression) to identify whether different age groups (A: <25 yrs, B: 26-35 yrs, C: 36-50 yrs, D: >50) noticed the decrease in population size in different timelines in comparison to each other				
Age group B	0.5212	0.1529	3.41	0.00104 **
Age group C	0.8583	0.1219	7.04	7.37e-10 ***
Age group D	1.1585	0.1196	9.69 *	6.44e-15 **

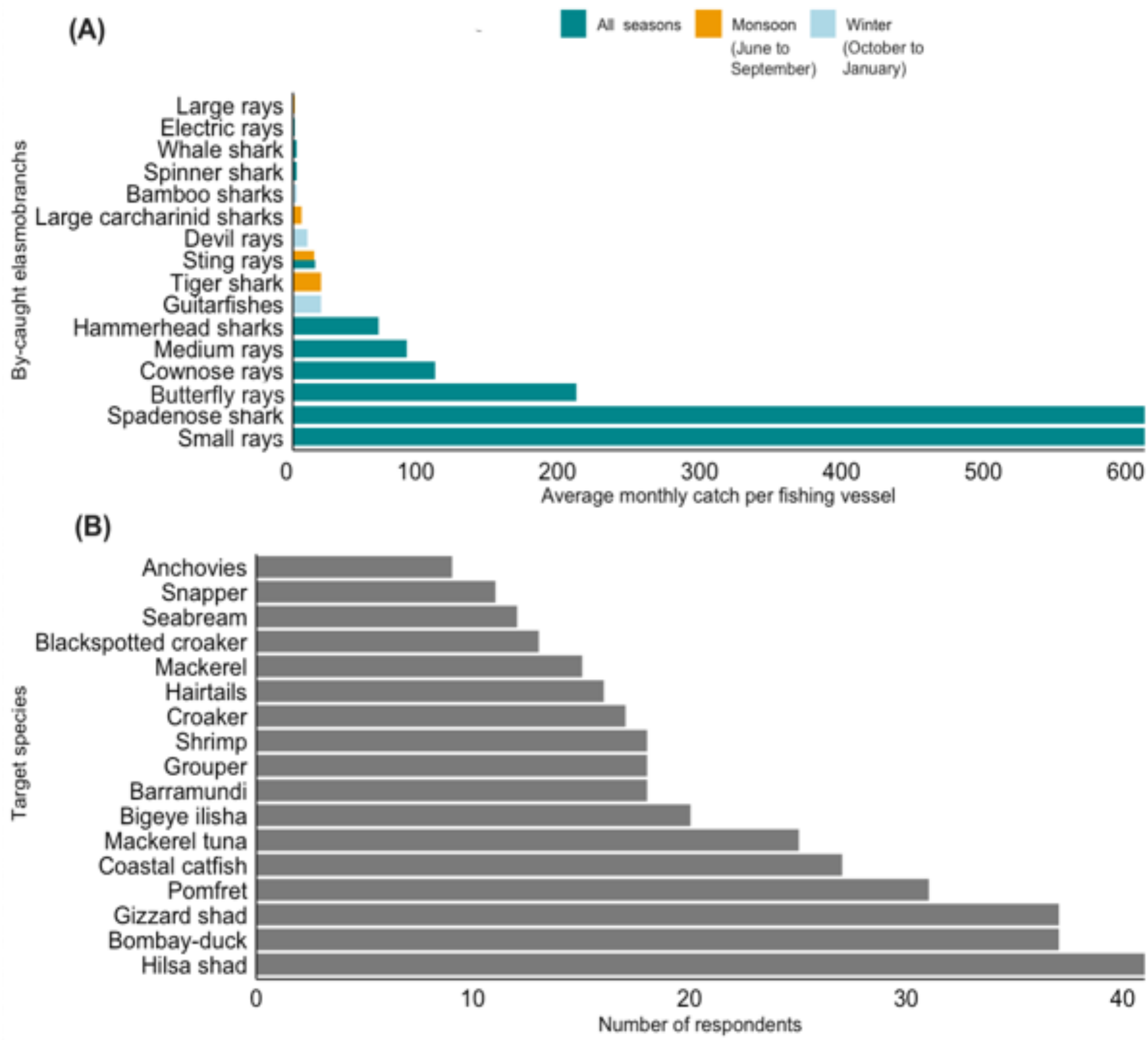


Figure S3.1. Targeted and bycaught elasmobranchs in Bangladeshi artisanal fisheries by season (total number of respondents= 66). **(A)** Bycaught elasmobranch species based on interviews with fishers and **(B)** Target species of fisheries that retained elasmobranch bycatch.

Figure S3.2. Ray fisheries in Bangladesh. (A) Graphical representation of submerged long line hooks, (B) hooks and lines used, (C) artisanal fishing boats at St. Martin's Island, (D) artisanal fishing boats in Cox's Bazar, (E) Selected rays caught in targeted ray fisheries and (F) elasmobranchs caught in bycatch fisheries.

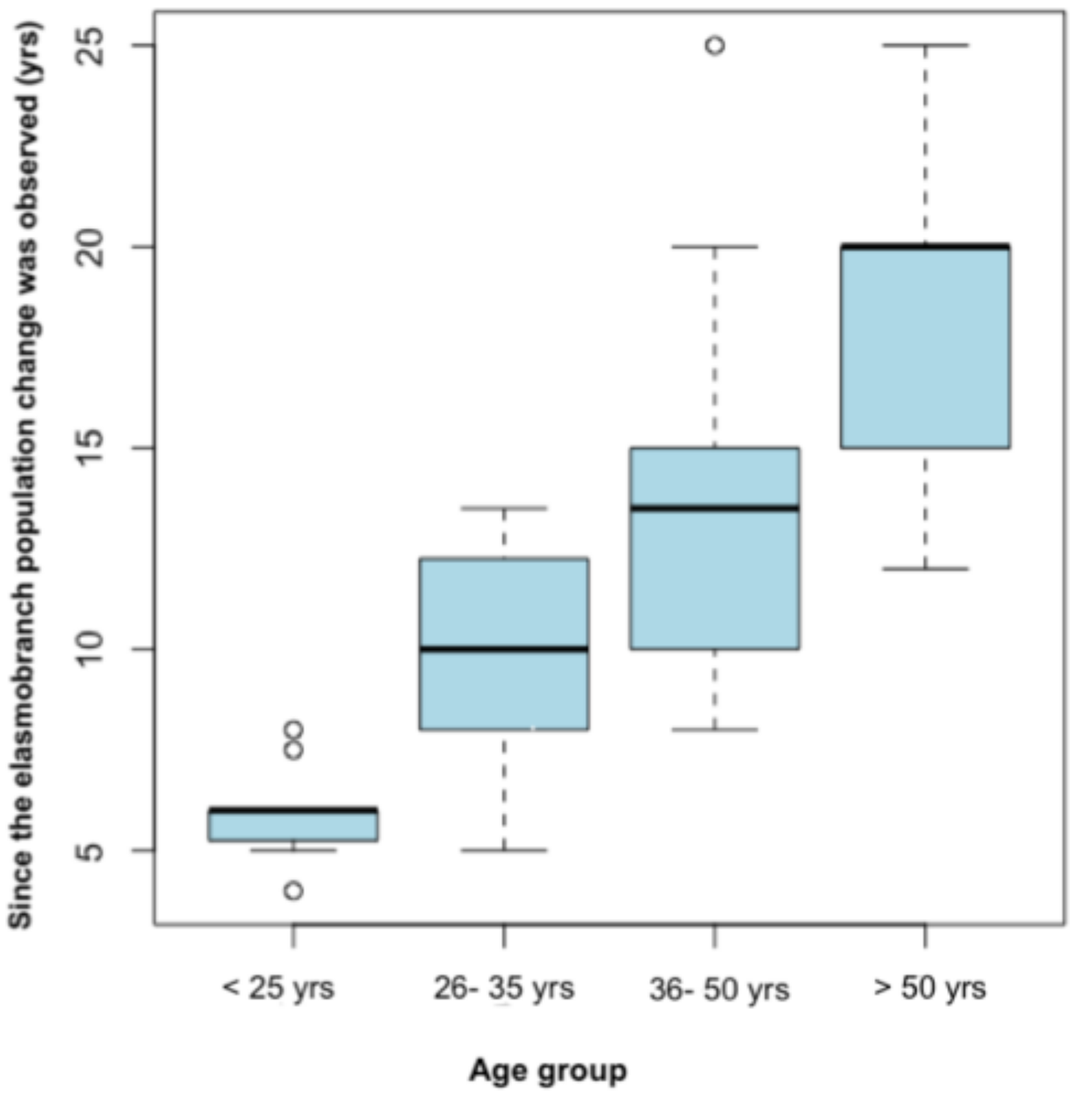


Figure S3.3. Observation on the timeline since the elasmobranch population change was detected by different age groups of fishers**.**

APPENDIX 3: SUPPLEMENTARY MATERIAL FOR CHAPTER FOUR

Table S4.1. Shark product HS (Harmonized Commodity Description and Coding Systems) codes used in trade, 1990–2019 (UN Comtrade). *Fin specific codes available only from 2012.

HS CODE	Meat	HS CODE	Fin
030265	Dogfish & other sharks, fresh/chilled (excluding fillets, other fish meat of 0304, livers & roes)	**030292**	Fish; fresh or chilled, shark fins
030281	Fish; fresh or chilled, dogfish & other sharks, (excl. fillets, livers, roes, & other fish meat of 0304)	**030392**	Fish; frozen, shark fins
030375	Dogfish & other sharks, frozen (excl. fillets, other fish meat of 0304, livers & roes)	**030571**	Fish; edible offal, shark fins
030381	Fish; frozen, dogfish & other sharks (excl. fillets, livers, roes, and other fish meat of 0304)	**0160418**	Fish preparations; shark fins, prepared or preserved, whole or in pieces (but not minced)
030447	Fish fillets; fresh or chilled, dogfish and other sharks		
030456	Fish meat; excluding fillets, whether or not minced; fresh or chilled, dogfish & other sharks		
030488	Fish fillets; frozen, dogfish, other sharks, rays and skates (Rajidae)		
030496	Fish meat, excluding fillets, whether or not minced; frozen, dogfish and other sharks		

Table S4.2. Semi-structured questionnaires targeted at a) traders, b) fish feed owner/worker, c) Alligator farm manager

a)

পণ্য এবং প্রক্রিয়াজাতকরণঃ Products and Processing:

1. হাঙরের কোন অংশটি তারা কেনেন? What Part of the Shark do they buy?
2. তারা কীভাবে মৎস্যজীবীদের হাঙর অথবা এর অংশ বিক্রয় সম্পর্কে খোঁজ রাখেন? How do they keep track of the fishers selling the shark products?
3. তারা নিজেরা কীভাবে প্রক্রিয়াজাত করেন? What kind of processing do they do themselves?

Supply Chain Structure:

1. উত্তরদাতাকে ছবি অথবা ম্যাপ আঁকতে বলা যেখানে হাঙর ধরা থেকে শুরু করে তার ক্রেতা পর্যন্ত যা যা ঘটে, পরিবহন, জায়গাগুলির নাম, কিভাবে পরিবহন করা হয়, কী কী পরিবহন ব্যবহার করা হয়, সংশ্লিষ্ট লোকজন ইত্যাদি সম্পর্কিত তথ্য থাকবে। Can they make a map or picture of what happens to the fins and other shark products (Where the shark products come from, who they buy from, from where e.g. villages, transport routes, names of places, how they are transported, who they sell the shark products to, where is the final destination of the shark products?
2. তাদের গ্রাহক এক না একাধিক? একজন হলে কেন?Do they sell to one buyer? More? If one why?
3. তারা কি সরাসরি মতস্যজীবীদের কাছ থেকে কেনেন নাকি অন্য সংগ্রাহকদের কাছ থেকে?Do you buys straight from the fishermen or from other collectors?
4. সেসব সংগ্রাহক কারা? Who are the collectors?
5. তাদের ধারণা অনুযায়ী এই এলাকাতে কতজন সংগ্রাহক আছে? How many collectors do you think in these areas are?
6. পুরো প্রক্রিয়াটি কীভাবে কাজ করে কোন ধারণা দিতে পারবেন? Can you explain how it works?
7. মোটামুটিভাবে কত কেজি পাখনা পাওয়া যায় সপ্তাহে, মাসে, ট্রিপে (সর্বনিম্ন থেকে সর্বোচ্চ) Roughly how many KG's of shark product do you buy each week/Month? Season?
8. প্রতি সপ্তাহে কত কেজি পাখনার শুটকি স্থানান্তর করেন? How many kg's of dried shark fins do you transport each week?
9. হাঙরজাত পণ্য সংগ্রহ করতে তাদের কত খরচ হয়? How much does it cost to collect these shark products?
10. হাঙরজাত পণ্য বাজার পর্যন্ত পরিবহনে তাদের কত খরচ হয়? How much does it cost to transport the shark products to the market or the nest buyer?

Other information:

1. তারা কেন এই পেশায় এসেছেন? Why did they start?
2. কখন এসেছেন? When did they start?
3. কীভাবে? How?

4. ব্যবসার উন্নতি বা মন্দা বিষয়ক কোন সময়সূচি দিতে পারবেন? Can they make a timeline with how good/bad was the business?
5. তারা কি মৎস্যজীবীদের কোন ধরণের উপকরণ সরবরাহ করে থাকেন? Do they supply any fishing gear to the fishermen?
6. দিয়ে থাকলে, কোন ধরণের? কয়জন/ কয়টি দল? If so, what kind of gears? Hoe many fishermen/teams have they given the gear to?
7. তার মূল্য কত? What is the cost of the gear?
8. কয়জন মৎস্যজীবী তার খরচ শোধ করেন? How do fishermen pay them back?
9. যদি কোন জেলে তার নিকট ঋণী থাকেন, তাহলে কি তিনি পাখনার মূল্য কমিয়ে পরিশোধ করেন? Do they reduce the price of fins paid to fishermen if the fishermen owe them money?

Most valuable/Target Species:

1. কোন প্রজাতিগুলো সবচেয়ে মুল্যবান এবং কেন? Which species are most valuable to you and why?
2. কোনগুলো সবচেয়ে কম মুল্যবান, কেন? Which species are least valuable to you and why?
3. তারা কি ছবির গাইড দেখে মাছের একটি তালিকা তৈরী করতে পারবেন? Can they make a list of species given the pictorial guide?
4. তারা যখন পণ্য সংগ্রহ করেন, প্রতি ট্রিপে তাদের গড়ে কত খরচ পড়ে? When you collect the shark products, how much does an average trip cost.
5. ট্রিপগুলো গড়ে কয়দিনের হয়? How long is an average collection trip for shark products?
6. বছরের কোন কোন মাসে মাছ সংগ্রহ করেন? নির্দিষ্ট কোন মাস আছে কি? What months of the year do you collect? Is there a favored season?

Prices:

1. পাখনার কি কোন মানগত পার্থক্য আছে? থাকলে কিসের ভিত্তিতে করা হয়? Can they tell you how the fins are graded and what are the qualities?
2. বিভিন্ন মানের পাখনার জন্য জেলে বা সংগ্রাহকদের কত মূল্য পরিশোধ করতে হয়?What are the prices paid to fishermen or collectors of these different qualities?
3. কোন ধরণের পাখনার মূল্য সবচেয়ে চড়া?What type of fins fetch the heights price?
4. হাঙরের অন্যান্য অংশ তারা কী পরিমানে ক্রয় করেন? How much do they buy the others parts of the sharks?

5. হাঙরের অন্যান্য অংশ তারা কী পরিমানে বিক্রয় করেন? How much do they sell the others parts of the sharks parts of?

নিয়মনীতি/ আইনকানুন/laws

1. কোন আইন অথবা অনুমতি নেয়ার প্রয়োজন আছে কি?Are there any laws or permits required?
2. তারা কি আইনগুলো সম্পর্কে বলতে পারবেন? Can you describe these laws?
3. তারা কি আইন এর প্রতি অনুগত? Do they respect them?
4. যেসব সংগ্রাহকের সাথে কাজ করেছেন তাদের নাম ঠিকানা দিতে পারবেন কিনা? অথবা আর যেকোন তথ্য। Can They give us the names and contact details of any collectors who work for them ?
5. তারা কি জানেন কয়জন সংগ্রাহক ওই এলাকায় আছেন? Do they know how many collectors work in this area?
6. তারা কি জানেন এই এলাকায় কয়জন জেলে শুধুমাত্র হাঙর ধরার কাজে নিয়োজিত আছেন? Do they know how many fishers is involved only in shark fishery in this area?
7. Do they know how many traders work in this area? Can they give us contact details?
8. পরবর্তী গ্রাহকেরা কোথা থেকে আসেন? Where do the next buyers come from?

b)

1. What are the different kinds feed that you produce?
2. What are the cultured fish for which the feeds are used?
3. What is the capacity of the company?
4. Which feeds are being produced in which quantity?
5. What are the raw materials that are being used?
6. Can you give a list?
7. Do you also buy liver oil of fish as a raw material of the feed?
8. Do you know which fish are being used for the liver oil?
9. Is it shark liver oil?
10. What proportion of the feed (per kg) is liver oil?

11. Source:

12. Where do you buy the liver oil from?

13. Can you tell me the process of buying the liver oil?
14. Who are your sources?
15. Where do they come from?
16. Do you have more than one source?
17. Do your source make the liver oil? Or they just collect and sell it to you?
18. How many collectors are there?
19. Can you give me the contact details?
20. How do you make the contacts?

21. Quantity

22. How much do you buy per month?
23. How do you buy it? Explain.
24. What proportion of the oil is being used in per kg of fish?
25. How much do you sell per month?
26. Make a chart of where and in which quantity your products go to?

27. Time:

1. When do you buy it?
2. How many times a month?
3. From when do this factory has started to use shark liver oil?

28. Price:

29. How much do you pay for the per kg of liver oil?
30. How much is the price of each of fish feed?

31. Consumers

32. Who are your buyers?
33. How many farmers buy from you?
34. Or do you sell to markets?
35. Which markets do you sell to?
36. How much demand is there?
37.

38. Others

39. How important is the Shark liver oil ingredient for the feed?
40. What contribution does it make to the fish feed?
41. Have you ever tried any other oil?

42. Law

43. Are there any laws or permits required?
44. Can they describe these laws?
45. Do they respect them?

c)

1. When did the farm start?
2. How many crocodiles are there at present?
3. What do you feed them?
4. Can you make a list?
5. Do you feed them bamboo/cat sharks or any other shark or rays?
6. Can you identify which species?
7. Can you make a list?
8. What proportion of the feed is sharks?
9. How do you feed them sharks?
10. Do you discard any part of it? Which part?
11. Do you use it as an ingredient in a mix of many items? or singly?
12. How much do you need per month?
13. How do you collect it?
14. How do you know when these sharks have landed?
15. What is the price you pay?
16. How much you spend to collect it?
17. What contribution this makes to the feed?
18. Is it a mandatory food item for the crocodiles?

Table S4.3. Number and type of interviews conducted by study site and respondent groups.

	Chattogram	Cox's Bazar	Teknaf	St. Martin's Island	Dhaka	Total	Type of interview

Respondent groups/ Study sites	Number of interviews						
Exclusive shark traders	4 (~10)	14 (~31)	5 (~13)	2 (4)	-	25	semi-structured
Alligator farm manager	-	1	-	-	-	1	semi-structured
Liver oil factory owner	-	4 (~6)	-	-	-	4	unstructured
Fish feed owner/ worker	-	-	-	-	10	10	semi-structured
Dry fish retailer	6 (~10)	15 (~31)	1	5	-	27	unstructured

Table S4.4. Demographics of traders: Role in the trade business, number of interviewees in each group and percentage of total interviewees, age group (years) and experience (years)

Role in trade	n (%)	Age group	Experience
Exclusive shark traders	25 (37)	25-72	5-50
Alligator farm manager*	1 (1.5)	28	2
Liver oil factory owner	4 (6)	35-40	10-20
Fish feed owner/worker	10 (15)	30-62	10-15
Dry fish retailer	27 (40)	26-55	10-30

*One alligator farm manager was opportunistically interviewed upon encountering buying smaller sharks in bulks

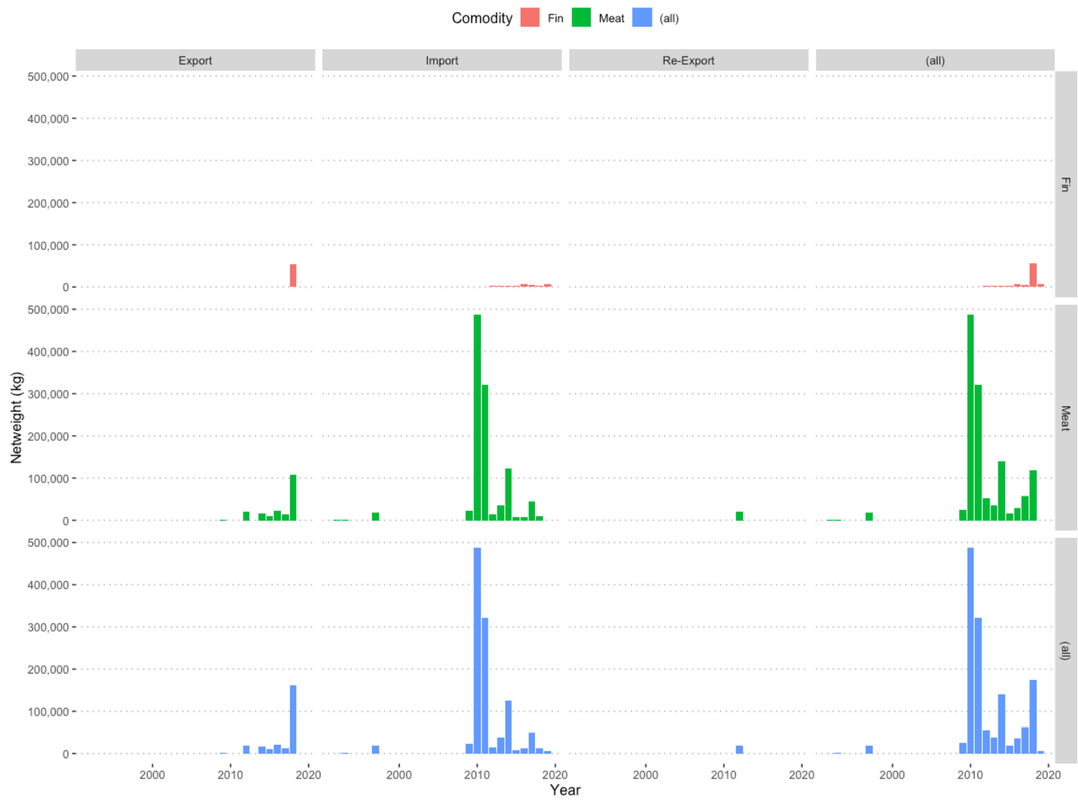


Figure S4.1. UN Comtrade data (1990-2020) for Bangladesh showing the reported amount of aggregate shark fins (green) and meat (blue).

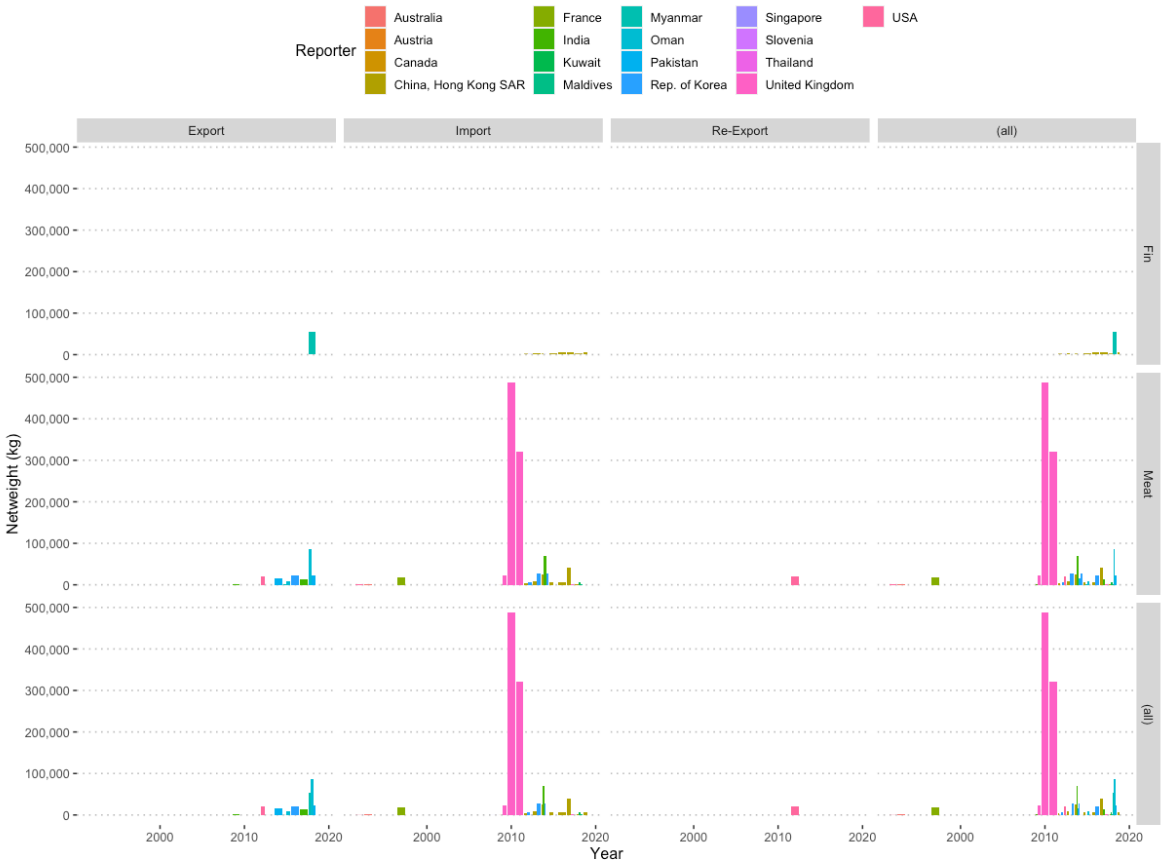


Figure S4.2. UN Comtrade data (1990-2020) showing the reported import from Bangladesh, export to Bangladesh and re-export into Bangladesh of aggregate shark products (meat and fins) (kg) in relation to various countries shown in different colours.

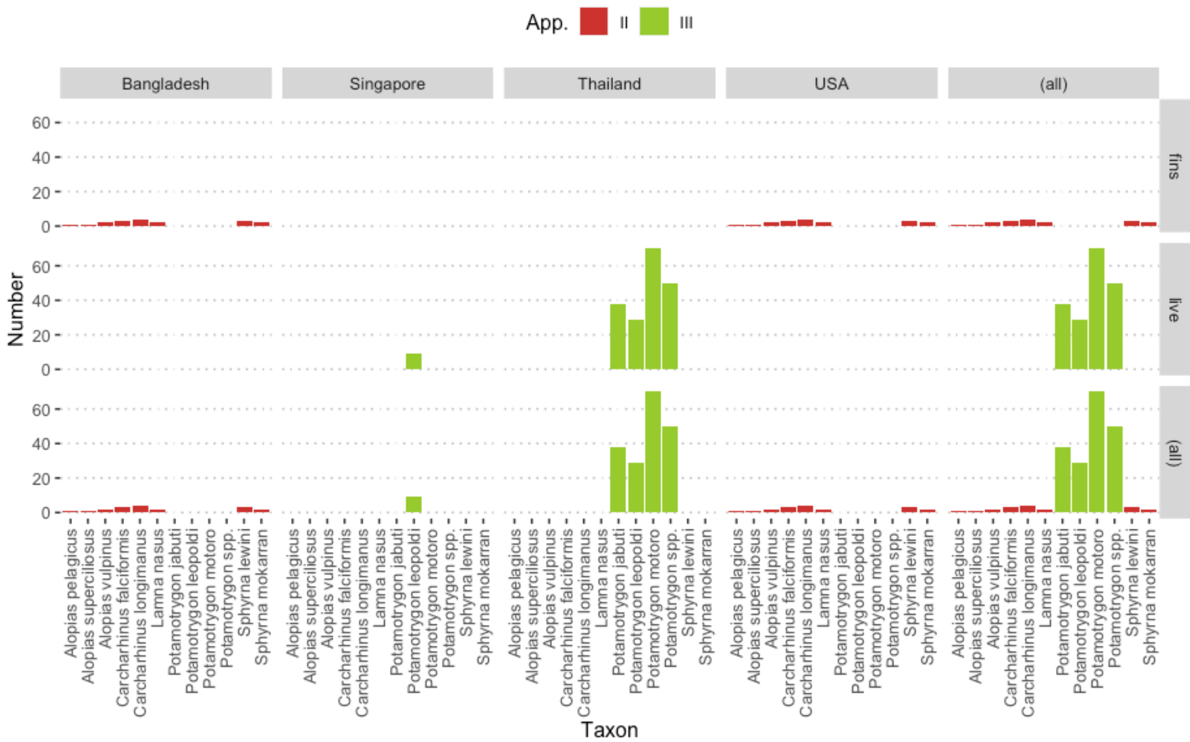


Figure S4.3. Number of exported and imported CITES listed species and fins (kg) by country. The CITES App. II species are shown in red and CITES App. III species are shown in green.

APPENDIX 4: SUPPLEMENTARY MATERIAL FOR CHAPTER FIVE

Table S5.1. Analytical levels of the framework for evaluating the market influencing unsustainable wildlife use (Adapted from Oyanedel et al. 2021a)

Analytical levels	Dimensions	Description/Definition	Possible interventions to mitigate unsustainable use
Actor level analysis	Access	To operate and collect benefits from a market, actors use various legal (e.g., property rights) and informal (e.g., social relationships, information about catch demand, political power) mechanisms referred to as access. Access to information, capital and power can improve or worsen the product's sustainability depending upon the motivation and the actor. Understanding the mechanisms of access permits tailored management actions to mitigate unsustainable wildlife trade (Oyanedel et al. 2021a).	If individuals lack the necessary skills, resources, or information, platforms for training, education, low-interest loans, equipment, and information can be offered or the governance responsible for providing such facilities can be strengthened. Depending on the need found, a variety of steps can be performed to improve sustainability through increasing access to facilities.
	Motivation	Motivations are the reasons behind an actor behaving or engaging in a market in a particular way. The underlying motivations are the real cause for an actor's behaviour. Motivations can be of different types. The instrumental motivation relates to calculating economic costs and benefits, such as catching more species for a higher price/value. The normative motivation relates to social and personal norms, such as catching more species for a social prejudice (cancer-curing properties of sawfish in Bangladesh; Haque et al. 2020). And when an actor is motivated to comply with a regulation due to the acceptance and its beneficial outcomes, it is called legitimacy-based motivation. Legitimacy can play a central role in achieving compliance and make governance efficient. For example, trust amongst the fishers and	Positive or negative incentives might be set based on the motivations of the actors driving the market's unsustainable nature. Improve enforcement, increase fines, or restrict revenue from unsustainable activities, for example, can assist counteract instrumental motivations. For pro-sustainable behaviour, performance-based rewards, alternatives, or remuneration can be recommended. Behavioural change through campaigns, education and creating positive examples for unsustainable social norms can be

		fishery officers (e.g., abiding by fishing ban as it can increase the catch in the future and compensations are provided as promised). Many methodologies can be used to evaluate motivation, such as surveys, key-informant interviews, and behavioural economic methodologies such as contingent valuation and choice experiments (Bova et al. 2018; Oyanedel et al. 2020b), risk profiles, cost-benefit analysis. By assessing specific reasons or constraints for a particular unsustainable behaviour, targeted solutions can be provided (Milner-Gulland, 1993; Damania et al. 2005; Jouffray et al. 2019; Oyanedel et al. 2020b).	recommended in case of normative motivations of actors.
Inter-actor level analysis	Supply-chain structure	Through repeated interactions and transactions, different actors create a supply-chain structure to trade products or information from suppliers to consumers. These interactions and the flow of information, capital and products can affect how markets operate and the sustainable use of the product in question (Milner-Gulland, 1993; Damania et al. 2005; McNamara et al. 2016).	When there isn't a direct communication/market link between suppliers and consumers, incentivising a short and direct link can help improve sustainability. Furthermore, if a small number of actors are supporting unsustainable behaviour, diversifying selling channels may be beneficial.
	Competition dynamics	This dimension assesses the way actors interact, compete and prevent new actors from entering the wildlife market. When several actors participate in a market, no particular actor has any disproportionate power of control on supply or demand; such a situation in a market is called perfect competition. When a few powerful actors control the market by reducing competition, such a situation in a market is called an oligopoly (Oyanedel et al. 2021a). When one actor supplies the product in question and has full control of the market, its monopoly (Oyanedel et al. 2021a).	Lower entry impediments if market participants are organised as an oligopoly, or monopoly. Focusing on the implementation of competition legislation can help actors get entry to the market while reducing power imbalances. Tenure rights can be introduced and improved to mitigate overexploitation.

Market level analysis	Supply-demand dynamic	This dimension assesses if the market in question is controlled by a supply- or demand-driven process. In a supply-driven market, the harvesters or suppliers participate in the market independently of price signals. In a demand-driven market, the harvesters or suppliers will respond to price signals (McNamara et al. 2016). Defining this will help design targeted interventions and actors, such as consumers (in demand-driven markets) or harvesters and traders (supply-driven markets).	Consumer behaviour can be changed in a demand-driven market by introducing alternative goods and providing information. In a supply-driven market, r educing harvesters' reliance on a specific product, imposing catch quotas, or enforcing catch restrictions can be beneficial.
	Quantity and price determinan ts	The variety of factors that influence product quantities provided and required within the market, along with product prices.	The demand for the product in question can be reduced by increasing the availability of competing/alternative products and influencing the price of legal products. For example, increasing the price to reduce consumption.
	Legal/ illegal interaction	Assessing the presence or supply of illegal products is essential to understand market dynamics fully. The legal/illegal interaction dimension assesses how products are integrated into the supply chain. Illegal products can be integrated into markets as legal products, making them harder to distinguish (Oyanedel et al. 2020b; Haque & Spaet, 2021). A clear picture of market dynamics can be gained after the extent of illegal products and their presence in supply chains is accurately ascertained.	Mechanisms to distinguish between legal and illegal products are critical in a market when they are indistinguishable. Improving law enforcement and monitoring, encouraging legal products with a premium price, and increasing consumer knowledge of legal products are all critical steps.

Table S5.2. Glossary

Phrase	**Definition/ Explanation**
Unsustainabl e wildlife trade	Unsustainable wildlife trade refers to the extent of WT which can cause overexploitation of the species in question. It can jeopardise th species survival. Historically such overexploitation has caused extinctions or severely threatened species.

Illegal wildlife trade	All prohibited activities (violation of national laws and regulations and international treaties) regarding the commercial exploitation and trade of wildlife species of specimens, including living or dead organisms or harvested parts (‘t Sas-Rolfes et al. 2018).
Trade	All activities including harvesting a resource/wildlife specimen or product, transportation, commercial exchange and the final use of the product locally or internationally (‘t Sas-Rolfes et al. 2018).
High value fin	The large-sized fins are the most priced product of the elasmobranch trade in Bangladesh. The value depends on the size of the fins and, in some cases, the species. At the same time, any small-sized fins (<2 cm) are not exported. For the study, any commercially (exported) viable sized fins are considered high-value fins.
Actors	Actors are individuals, groups or institutions that partake in a wildlife market. Generally, any wildlife products move through the supply chain through serval actors. From the individuals who collect/harvest them (harvesters, suppliers), facilitating the trade (intermediaries, traders) and finally, the end of chain actors who purchases or uses the final product (consumers).
Wildlife market	Combination of institutions, processes, infrastructure and social relations where actors participate in exchange or barter of wildlife species of products (‘t Sas-Rolfes et al. 2018).
Market forces	The factors (e.g. economic, enforcement, law) which can affect the price, demand or supply of the product in question.
The competition dynamics	This dimension assesses the way actors interact, compete and prevent new actors from entering the wildlife market.
Perfect competition	When several actors participate in a market, no particular actor has any disproportionate power of control on supply or demand; such a situation in a market is called perfect competition.
Oligopoly	When a few powerful actors control the market by reducing competition, such a situation in a market is called an oligopoly.
Monopoly	When one actor supplies the product in question and has full control of the market.
Motivation	Motivations are the reasons behind an actor behaving or engaging in a market in a particular way. The underlying motivations are the real cause for an actor's behaviour. Many methodologies can be used to evaluate motivation, such as surveys, key-informant interviews, and behavioural economic methodologies such as contingent valuation and choice experiments (Bova et al. 2018; Oyanedel et al. 2020b), risk profiles, cost-benefit analysis. By assessing specific reasons or constraints for a particular unsustainable behaviour, targeted solutions can be provided (Milner-Gulland, 1993; Damania et al. 2005; Jouffray et al. 2019; Oyanedel et al. 2020b).

Instrumental motivation	The instrumental motivation relates to calculating economic costs and benefits such as catching more species for a higher price/value.
Non-instrumental motivation	Normative or legitimacy-based motivation
Normative motivation	The normative motivation relates to social and personal norms, such as catching more species for a social prejudice (cancer-curing properties of sawfish in Bangladesh; Haque et al., 2020).
Legitimacy-based motivation	It would be a Legitimacy-based motivation when an actor is motivated to comply with a regulation due to the acceptance and its beneficial outcomes. For example, trust amongst the fishers and fishery officers (e.g., abiding by fishing ban as it can increase the catch in the future and compensations are provided as promised). Legitimacy can play a central role in achieving compliance and make governance efficient.
Mixed motivation	When an actor has more than one type of motivation
Access	To operate and collect benefits from a market, actors use various legal (e.g., property rights) and informal (e.g., social relationships, information about catch demand, political power) mechanisms referred to as access. Access to information, capital and power can improve or worsen the product's sustainability depending upon the motivation and the actor. Understanding the mechanisms of access permits tailored management actions to mitigate unsustainable WT.
Artisanal fishing	Comparatively small-scale, low-capital and low-technology fishing; however, differs from subsistence fishing owing to commercial scope and interest
Harvesters	Refers to those actors who directly interact with wildlife and extract it from nature through various mechanisms (e.g., fishing, hunting, logging)—fishers and boat owners in our case study.
Intermediari es	Connectors (those who transform and transport wildlife) of the products from the harvest point to the selling point- middlemen, landing site traders and opportunistic traders in our case study
Vendors/trad ers	Individuals involved in selling the products to the consumers- exclusive traders in our case study
Consumers	Refer to the end-users of wildlife products- international buyers in our case study.

Exclusive traders	Traders who exclusively trade on shark and ray products and have the financial and logistic access to export high-value fins from Bangladesh
Social relations	Relationships shared by different actors through different legal or illegal transactions or personal ties
Supply-chain structure	Through repeated interactions and transactions, different actors create a supply-chain structure to trade products or information. These interactions and the flow of information, capital and products can affect how markets operate and the sustainable use of the product in question (Milner-Gulland, 1992; Damania et al., 2005; McNamara et al., 2016).
Typology	Typologies refer to the systematic construction of types - which are unique combinations of attributes that influence the relevant outcome.
The market-level analysis	The market economic properties (e.g., quantities of products supplied and demanded by the market and product prices) resulted from actors' behaviours, and interactions are assessed at this level. Econometric analysis and regression models can be used to assess how different factors affect these economic properties (McNamara et al., 2019).
The supply-demand dynamics	This dimension assesses if the market in question is controlled by a supply- or demand-driven process. In a supply-driven market, the harvesters or suppliers participate in the market independently of price signals. In a demand-driven market, the harvesters or suppliers will respond to price signals (McNamara et al., 2016). Defining this will help design targeted interventions and actors, such as consumers (in demand-driven markets) or harvesters and traders (supply-driven markets).
The legal/illegal interaction	Assessing the presence or supply of illegal products is essential to understand market dynamics fully. The legal/illegal interaction dimension assesses how products are integrated into the supply chain. Illegal products can be integrated into markets as legal products, making them harder to distinguish (Haque & Spaet, 2021; Oyanedel et al., 2020b). A clear picture of market dynamics can be gained after the extent of illegal products and their presence in supply chains is accurately ascertained.
Unstructured interviews	Unstructured interviews rely on the researcher and informant interacting socially. They are a method of understanding people's complicated behaviour without imposing any a priori category, which may restrict the scope of the investigation. Because they frequently occur as part of continuous participant observation fieldwork, they are a natural extension of participant observation. They are entirely dependent on the spontaneous development of questions in the natural flow.

Table S5.3. Detailed methodology for data collection

Relevant literature on elasmobranch trade in Bangladesh

To provide information for the framework's price and quantity dimension, and legal/illegal interaction dimension, we collated quantitative and qualitative data from seven studies reporting trade on different elasmobranchs in Bangladesh (i.e., Hoq et al., 2011; Hasan et al., 2017; Haque et al., 2019; Haque et al., 2020; Haque et al., 2021a; Haque et al., 2021b; Haque & Spaet, 2021). We conducted a rapid review to collate all published data. Google Scholar and the ISI Web of Science databases were searched using the keywords Bangladesh* Shark trade, Bangladesh* Elasmobranch trade or Bangladesh* Chondrichthyan trade for 1990 – 2019. In addition, reports on trade and trade products were acquired through the Bay of Bengal Large Marine Ecosystem Project website (BOBLME), Bangladesh Fisheries Research Institute (BFRI), Bangladesh Fisheries Development Corporation (BFD(and the Department of Fisheries (DoF), under the administrative control of the Ministry of Fisheries and Livestock. Studies were selected only if any elasmobranch trade was reported (in numbers, weight or any qualitative information) (Table S5.4).

Field surveys

Between October 2016 and January 2020, 398 individual surveys were conducted in coastal Bangladesh at fishery landing sites and major elasmobran(processing centres (n=12) (Figure 5.1) as part of a wider study (Haque et al. 2021; Haque & Spaet, 2021d; Haque et al., 2022a). Elasmobranch landings the sites and trade at the processing centres were observed and documented. This included identifying actors (Table S5.4), inter-actor relationships an(transactions (buying and selling of elasmobranch products), supply-chain structure, price, amount of trade, mechanisms of the trade and product-processing. Several informal unstructured interviews were taken in this timeline.

Key informant interviews

During the field surveys, leaders in elasmobranch catch and trade within the study sites (Figure 11) were identified and later approached for detailed ke informant interviews (KIIs). These KIIs were spontaneous and unstructured to allow participants to formulate their own opinions and explanations without influence from the researcher (Zhang & Wildemuth, 2009; see definition in Table S5.2). Between December 2019 and January 2020, 19 unstructured KIIs were conducted. The KIIs were traders (n=6), fishers (n=6), intermediaries (n=5) and fishery official, landing site facilitator (n=2). Although 19 questions were prepared (Table S5.5) these were not used in a way that would restrict the natural flow of the discussions, rather they were used as a guide for the interviewer to discuss relevant topics or as discussion starters. These topics broadly followed Oyanedel et al. (2021a) and were designed to explore: i. Access, ii. Motivation, iii. Market characteristics and mechanisms of fin trade, iv. Financial mechanisms, v. Social ties, vi. Willingness to report trade and vii. Price determinants. The responses are summarised in Table A6. Prior and informed consent was obtained verbally from all participants to take part in the interviews. Each interview lasted for 30 minutes to 4.0 hours. None of the interviews were recorded upon the request of the interviewees. The responses were documented in a table and informal field notes. The human ethical approval was granted by the Ethical review committee of the Faculty of Biological Sciences, University of Dhaka (reference number- 59/Biol.scs.).

Table S5.4. Information collated from selected literature for selected aspects pertaining to Bangladeshi shark fin trade.

Aspects related to	**Summarised information**
Elasmobranch landing	To evaluate if the landing of other important target fishery (hilsa, rays, large pelagic fish-predictor variables) have any influence on the amount of annual elasmobranch landing (outcome), we performed a multiple linear regression model (for rays and large pelagic fish as they showed a linear relationship with elasmobranch landings) and polynomial regression model (for hilsa as it showed a non-linear relationship with elasmobranch landings). Multiple linear regression model (Sea Around US dataset) showed that, the annual amount of shark landing (outcome) was positively related to large pelagic fish landing (beta = 7.34, 95% CI [6.31, 8.37], $t(64) = 14.24$, $p < .001$) and large ray landing (beta = 18.89, 95% CI [5.84, 31.93], $t(64) = 2.89$, $p < .01$). 86% of the variation in the outcome was explained by the covariate ($R2 = 0.86$, $F (2, 64) = 204.58$, $p < .001$, adj. $R2 = 0.86$). With hilsa annual landing, elasmobranch landing showed a significant polynomial relationship ($p < 2.2e-16$, R-squared: 0.7434) (Unpublished data from Haque & Spaet, 2021). Patchy annual data on the traded number of fins (aggregated with fish maw) are available (DoF, 2019).
Trade	Review results showed, Bangladesh has been a market and exporter of shark-related products for more than four decades (Haque & Spaet, 2021). The trade in high-value fins is most prevalent in the southeast (SE) coastal region (e.g. Cox's Bazar and Chattogram) (Haque & Spaet, 2021) due to the presence of exclusive shark traders within active processing centres,

	opportunistic fish trading activities and several online platforms (Haque et al., 2018; Haque & Spaet, 2021). Almost all fins have been internationally traded through this region since 2014 (Haque & Spaet, 2021). At least 12 processing centres in the SE region of Bangladesh and several actors participate in the existing markets (e.g., fishers, traders, intermediaries, consumers) directly and indirectly, and are dependent on this trade (Haque et al., 2021b; Haque et al., 2021a). All catches are either landed in the formal landing sites or on the dispersedly distributed beaches, except for very valuable catches like sawfish, which in many cases would land at the exclusive shark traders' processing centres. However, a sizable landing occurs in the Southeast (SE) coastal region due to the presence of a better market and vicinity of the international trade route (Haque et al., 2021 a). Bangladesh has been a market and exporter of shark-related products for more than four decades (Haque et al., 2022a; Haque & Spaet, 2021), and all parts of a shark, including unconventional products, are processed to meet local and international demands. According to a recent study, one trader alone exported shark products worth USD 250,494, indicating the massive scale of the business (Haque et al. 2018). However, all these trade remains unreported (Haque & Spaet, 2021d). In 2010, the Bay of Bengal Large Marine Ecosystem (BOBLME) Sharks Working Group identified Bangladesh as "very data-poor" in terms of catch effort, trade data and monitoring (Fischer et al., 2012). Between 1992 and 2019, zero to 2,134 tonnes (mean= 215± 429 SD) of aggregated shark fins and fish maw were exported from Bangladesh according to the DoF dataset (DoF, 2019). The value earned from these trades is up to 3,680,104 USD (mean 987,028 ± 1,180,656 SD, n= 27 yrs.) (DoF, 2019); where data from each year were unavailable. However, the actual amount of non-aggregated high-value fin trade was 86-335% higher than reported that particular year (details in Haque & Spaet, 2021). Between 9,000 and 33,000 kg (avg. 23,000 kg) of rhinopristiformes rays (guitarfishes, giant guitarfishes and wedgefishes) were bought annually by each trader during 2015–2018 (Haque et al., 2021b). Furthermore, an estimated 180,904 kg of devil rays were bought between 2015 and 2018, approximately 60,000 kg per year by traders (Haque et al., 2021c). However, none of this trade in threatened species was formally reported in any national (DoF) or international databases (CITES, Food and Agriculture Organization of the United Nations (FAO), Sea Around Us).
Threats	In the Bay of Bengal, Bangladesh region, thousands of elasmobranchs (sharks and rays) are caught per trip (5-12 days) mostly within the artisanal fishery. However, elasmobranchs can either be caught as bycatch or target (especially rays) in the

	subsistence, artisanal and industrial fishing in the coastal and marine waters of Bangladesh. Almost all gears deployed catch some elasmobranchs. A good number of fishers are dependent on the earnings from such catch, especially the target ray fishers. A sizable proportion of elasmobranchs caught in Bangladesh are threatened with extinction according to the IUCN Red List of threatened species (IUCN Red List). All unreported bycatches consist of at least 85 species, including 10 Critically Endangered and 22 Endangered species, for example, several requiem sharks, hammerhead sharks, giant guitarfish, guitarfish, sawfish (Haque et al., 2021a; Haque & Spaet, 2021). An average of 8,000- 20,000 tonnes of annual shark landing and an 80-335% unreported trade (Haque & Spaet, 2021) including protected species heading to unnoticed extinction due to their low resilience to fisheries pressure (Haque et al., 2021a). The high catch rates are due to either targeted or unintentional fishing interaction with these species in the fishing grounds and high retention rate due to the high price attained from at easily accessible markets. Fishers vouched for a steep decline in catch size, number and composition of elasmobranchs over their career, especially in the last decade (Haque unpubl. data).
Financial mechanism in fishing	Coastal fishers in Bangladesh are poverty prone due to debt-driven fishing practices. Most of them do not own boats and nets, a secondary source of income, or have any facilitation to adhere to regulations regarding elasmobranchs. An efficient market is also lacking. Financial vulnerabilities of fishers are exacerbated by limited access to information and technology, lack of safety at sea, or basic amenities like education, healthcare, and social security (Haque et al., 2021b, c; Haque unpunbl. data).
Law and enforcement	There is no size, season closure or quota in place for the sustainable use of these populations or marine protected area for the critical habitats (till 2021). However, 29 species were protected under the national law, the Wildlife (Conservation and Security) Act, 2012 until 2021 which was amended to protect 49 species. Bangladesh is also a signatory of CITES and committed to adhering to CITES mandates for listed species (at least 18 species are listed in CITES that frequently occurs in Bangladesh). Furthermore, some species may have refuge in the sanctuaries in the Sundarbans, the marine protected area in the Swatch of No Ground and Nijhum Dwip within the Bay of Bengal. Enforcement of the law is lacking or sporadic. The law at its current form imposes an umbrella ban without any species-specific regulations in place and with limited market understanding for the regulations to be effective. It is globally common that, the shark product trade is predominantly managed by umbrella regulations for trade ban and has proven ineffective in many countries. As a result, for a better understanding of what restrictions might be effective and how they can be implemented, in-depth knowledge of the market is crucial. This is highly

	relevant given the unsustainable and unmonitored elasmobranch trade driving unsustainable fisheries (Haque, unpubl. datas) in Bangladesh.
Awareness about the law and regulations	Awareness about national law and regulations are low amongst the fishers, one of the reasons resulting in non-compliance towards the existing catch and trade regulations (Haque et al., 2021b; Haque et al., 2021c). Most fishers (78% to 87%) unaware of specific regulation regarding guitarfishes and devil rays (Haque et al., 2021b; Haque et al., 2021c).
Data paucity and underestimation in existing records	Although all studies focusing on elasmobranchs in Bangladesh mentioned the existing trade, none of these studies objectively elaborated its extent to help monitor or for evidence-based conservation strategies. Two focused studies on shark trade (Hoq et al., 2011; Hasan et al., 2017) shed some light on the existing trade. However, they over-simplified the countrywide trade dynamics. Hoq et al. (2011), through the FAO, BOBLME (Food and Agriculture Organization of the United Nations- The Bay of Bengal Large Marine Ecosystem project) report summarised the trade of products and prices and reported the existing international trade on protected species. Hasan et al. (2017) reported illegal trade and that Bangladesh earned US$ 10655 by exporting 1 MT shark fin during 2012-2013. They also reported no shark products export from 2010-11 to 2011-12. This information was grossly simplified and under-estimated. The underestimation was evident, as Haque et al. (2018) found existing data scarcity on shark trade and reported trade on several CITES listed and protected species in those same years (Haque & Spaet, 2021).

Table S5.5. Unstructured key informant interview questionnaire

1. Can you describe how the elasmobranch fin trade is operated here?
2. Who are the main actors participating in fin trade?
3. Who earns more from the elasmobranch fins trade more?
4. How do they access the benefits?
5. Who has the decisive power and financial capacity to buy high value fins?
6. Do you think any group has excessive benefits from this market?
7. Who has more power to control the supply?
8. Do fishers negotiate the price or it is pre-fixed?
9. Who set the price for fins/whole-bodied sharks?
10. Do traders have pre-existing relationships with fishers?
11. Do traders finances the fishers to catch elasmobranchs?
12. Are there fishers or traders who left the business? Why?
13. Do you know anything about the legal status of elasmobranchs?
14. Are the legal and illegal products differentiated at the landing sites of processing centres?
15. Do fishers or traders need any permit for fin trade?
16. Is there any checking for illegal products at the ports?
17. Has there been any enforcement activity?
18. What determines the price of the fins?
19. Is price affected by the quantity of landing?

Table S5.6. Detailed description of the identified actors in shark and ray catch, trade originating from Bangladesh, documented through field surveys between October 2016 and January 2020.

Actor identified	Assigned code	Broad categories	Description/definition
Artisanal fishers in south-west region	FSW	Harvester	Fishers operating from coastal Bangladesh in medium to large sized boats (mechanised). Artisanal fishers harvest sharks and rays either as a bycatch or target (Haque et al. 2021c, d). Fishers land their catch in the formal landing sites or in the processing centres depending upon the species.
Artisanal Fishers in south-central region	FSC		
Artisanal Fishers in south-east region	FSE		
Subsistence fishers	SF	Harvester	Fishers operating in smaller boats (non-mechanised) within the shallow coastal waters and catches sharks or rays as bycatch.
Industrial fishers/vessel owners	IF	Harvester	Fishers operating in large-scale industrial vessels from Chattogram (south-east) and Khulna (south-west). They use bottom and mid-water mechanised trawl nets catch sharks or rays as bycatch.
Large artisanal boat owners	BAB	Harvester	Owners of medium to large artisanal boats. They provide financial resources to the fishers to harvest the fish and thus owns the catch.
Fish traders in south-west region	FTSW	Trader	Traders trading on any species of fish in coastal Bangladesh.
Fish traders in south-central region	FTSC		
Fish traders in south-east region	FTSE		
Shark trader in south-west region	TSW	Trader	Traders exclusively trading on shark and ray products.
Shark trader in south-central region	TSC		
Shark trader in south-east region	TSE		
Opportunistic shark buyers from landing sites	OSB	Trader	Buyers buy shark and rays depending upon the size and opportunity. However, they also trade on other fish species or products.
Buyers using online platforms	OP	Trader	Buyers offering shark fin and meat using online platforms. These buyers mostly trade on several different fish products.

Processing centre owners/workers in Chattogram	PCC	Trader	Owners of exclusive shark and ray processing centres.
Processing centre owners/workers in Cox's Bazar	PCCx		
Small collector boat fishers	SCB	Intermediary	Often smaller boats transport the catch from the large boats and land the catch in the landing sites.
Middleman (shark collectors in the landing sites)	M	Intermediary	Middlemen/intermediaries are in operation in each landing sites who collects the shark and ray catch and sell it to the traders. Seldom appointed by the processing centre owners.
Agents with access in the port in Teknaf	PT	Intermediary	Agents (Bangladeshi nationals) who connect the national shark traders to the international buyers and have access to the port authorities, connections to both nation and international sellers and buyers, and financial resources needed to trade on shark and ray products.
Collectors of non-conventional products	CNC	Intermediary	Collectors (mostly from the north-west Bangladesh) collect cartilage, teeth, jaws from traders or processing centres in the south-east region.
Liver oil factory owners	LOF	Intermediary	Four liver oil factories collect the livers of sharks and rays from processing centres in the south-east region and produce liver oil to supply to fish and poultry farms.
Fish/poultry feed industry owners	FPF	Intermediary	Fish/poultry feed factories buy liver oil from the liver oil factories in the south-east region.
Dried fish retailers (Najirtek)	DFRN	Intermediary	Dried fish retailers collect small-sized sharks and rays and sun-dried them to sell to national consumers in south-east region. They buy the sharks and rays from the landing sites or from boats.
Dried fish retailers (Chattogram)	DFRC	Intermediary	Dried fish retailers in Chattogram buy dried small-sized sharks and rays from the dried fish retailers in south-east region and sometimes from other regions.
Buyers in Myanmar	BM	Vendor	Buyers in Myanmar who buy shark and ray products either through agents or national shark traders.

Buyers in India	BI	Vendor	Buyers in India who buy the shark and ray products through agents or national shark traders. Mostly buy non-conventional shark products (Haque & Spaet, 2021d)
Crocodile farm business	CF	Vendor	One crocodile farm collects small-sized sharks from the landing sites in the south-east region.
Village medicinal practitioners	VMP	Vendor	Village medicinal practitioners collect cartilages, teeth, jaws, rostrum of sharks and rays to sell to the coastal village consumers as medicine of a suite of diseases.
Buyers in other product destination countries	DC	Vendor	Buyers in different destination countries.
Local consumers in tribal villages	LC	Consumers	A suite of different species of small to medium-sized sharks and rays' fresh and dried meat and liver are consumed by tribal people in the coastal and hill-tract region.
International consumers	IC	Consumer	Consumers of the end products in different destination countries
Landing site workers/operators in south-west region	LSSW	Facilitator	Landing site officials (mostly appointed by BFDC- Bangladesh Fisheries Development Corporation) looks after and accounts for all the marine fish catch (including sharks and ray) and landing in the formal landing sites.
Landing site workers/operators in south-central region	LSSC		
Landing site workers/operators in south-east region	LSSE		

Table S5.7. Respondents (KI) and their summarised answers to selected themes pertaining to Bangladeshi elasmobranch fin trade and market characterisation along with insights from field observations and informal interviews

Respondent /Questions related to	**Summary description of KI interviews**				
	Traders	**Fishers**	**Intermediaries**	**Fishery official, landing site facilitator**	**Insights from field observations, informal interviews, in-depth KI and field notes (between 2016-2021)**
Earns more from the elasmobranch fin trade	Traders mentioned that boat owners (and not the actual fishers) are the price takers at the landing sites of the whole catch. Intermediaries and fishers earn very less. End of chain traders/exporters are the highest price takers.	Exclusive traders in the SE region by exporting them.	Traders (with capacity of exporting)	People who own the processing centres (exclusive traders), the wages are minimal for the workers and fishers and intermediaries	At the landing site the high price is taken by the boat owners for either the whole bodies fish or the fins separately and the end of chain traders take the highest price of the fins by exporting them. In most cases the fishers do not get any price beyond the salary and the intermediaries earns very little as well from fins. Fishers motivations were guided by less earnings, social and financial inequality, no training on more effective livelihoods. Repeated mentions of corruptions were documented where fishers felt helpless and exploited.

Reasons for trading on high value fin trade	Profit like any other fish related business	Profit as the price is very high for large sized fins; disease curing properties of some (sawfish meat can cure cancer)	Profit	Earning high profit for the traders and fishers	For large-bodied sharks the price is set depending on the size of the fins. The price is higher for such sharks. Except for some normative believes of disease-curing properties, all actors were mainly involved for the profits
Mechanisms of accessing the benefits	Traders (with capacity to export) having financial capacity, ties with exports and buyers, back accounts where Letter of Credit can be issued, international export licence for fishery products, syndicate, relationships with others, ties with in country and Myanmar buyers and agents, information about international market and price	Relationship with intermediaries	Ties with international buyers, financial capacity, international price information	Traders have a syndicate and maintain access to the fin market through the power exercise and ties with other actors; they also create barrier for new entries	Fishers only had connections to boat owners with limited participation in the fin trade. The intermediaries maintained a relationship with trader and sometimes were employed by them. The same intermediaries were at the landing sites with limited observation of new entries in five years. Even if the shark was bought by an array of traders the fins would end up with a group of traders with the capacity to export them. The syndicate of traders remained the same within this trade and was maintain the market by constantly keeping in touch with intermediaries, buyers, and information about international price. The traders could buy bulks of fins and store it having

					the financial and infrastructural capacity. Moreover, the few fishers' cooperative has no influential power of decision making limited by lack of cooperation and finances
Decisive power and financial capacity to buy high value fins from markets	Traders and sometimes boat owners	Traders and intermediaries; some mentioned boat owners	Traders and opportunistic traders	Exclusive traders and sometimes boat owners	Boat owners and exclusive traders had the decision-making power regarding fin trade; however, for all elasmobranch products the market was more disperse with more actors involved.
Group having excessive benefits from the market	Boat owners and exporters (traders)	Traders	The fin traders have very high profit from these products whereas others either have profit or loss depending on the size of the landing or prise set	Do not know	Traders with capacity to export (specific to fin trade).
Control the supply	Not possible, traders buy what is available at the market. However, during national ban period the supply diminishes significantly.	None; luck, cannot say what is going to be caught	No	Seasonal harvest (winter), as other species supply decrease at that time some fishers change to line	Supply diminished during national ban period (June, July and October). Although the demand is there, the supply is not controlled by that. Traders buy whatever is available at the market. The demand is higher for

				hooks and target more sharks	guitarfishes and large sized sharks. The supply is higher for guitarfishes between November and May due to seasonal target catch
Willingness to report on catch and trade	In there is a mechanism present then, traders may report but recent seizures and corruption may lead them not to report. Traders believe the reporting is a responsibility of the port authorities as they are already paying taxes for exporting fishery products	If facilitations are given for on-board monitoring then, fishers were interested to report but this may be biased as fishers were also not happy with more regulations	Unwilling as they are not the end of supply-chain traders and believes the traders/exporters should report if needed	The fishery official believes, there will be unwillingness from the traders to report on trade	There was an observed evolution of perceptions observed regarding the willingness to report trade. In January 2017, one trader mentioned "*we are more than happy to report our trade if the govt. asks us";* whereas in 2021 another trade stated "*there are a lot of corruption regarding regulations and no facilities are given to us, we may not be able to report if there is not a mechanism in place and we are losing business; however, we are open to help the govt*." The willingness to cooperate with fishery managers are low due to to-down management, no processes of loss-incurred and no technical or financial facilitations present to adhere to regulations

Negotiate the price or it is pre-fixed	Negotiated between boat owners and intermediaries advised by traders depending on the international rate at that current time	Either all catch is already sold to the boat owners or auction at landing site; price is mostly negotiated by the intermediaries, advised by traders	Negotiation between seller and trader and set by the current international price. However, the price of fins has decreases two to three-folds since 2007-2008	The traders have information about the international price and the price is set according to a negotiation amongst the traders, buyers and landing site sellers	The price remains quite similar for small bodied sharks. However, higher prices were frequently asked by the boat owners for large-bodied sharks. The price was then set according to the international fin price which is set by a negotiation between intermediaries and the boat owners.
Who set the price for fins/whole-bodied sharks	Negotiated but the price is set mostly by the intermediaries	Intermediaries through auction or pre-fixed price	Whole bodied shark price is set by the intermediaries, fisher cannot fix price	Boat owners and intermediaries	Intermediaries advised by the traders
Traders pre-existing relationships with fishers	No (fishers) to limited) boat owners)	No to limited; mostly with intermediaries	Some may have some ties to some boat owners where the money needs to be paid before the catch	Boat owners give loan and buys the whole catch beforehand; some traders do have mobile phone connection for large bodied species and lands separately in the	Two traders had pre-existing relationships with fishers and in several cases the landing was done at the processing centre for guitarfishes and large bodied sharks. However, this is not the common practice.

				processing centres.	
Traders financing the fishers to catch elasmobranchs	No	No	Mostly no	May be some but not a common practice	No such observations were made. However, almost all fishers were constrained by a debt-driven mechanism with the boat owners
Traders who left the business	A few since 2014 due to market saturation, less profit earned, more difficulties to export	No, one fisher mentioned two traders from Teknaf changed business	There are some in Chattagam as there are increasing administrative problems and chance of detection and fear of having bad reputation if any fines or case is lodged. The number of targeted boats has decreased.	One or two between 2014 due to decreasing number of catch and not profitable	Several traders (n=6) left the business or retired between 2016-2021.
Legal status of elasmobranchs	Awareness is low but according to two to traders they follow all rules and regulations	Limited knowledge; No clarity present	Not much clarity	Limited knowledge amongst all actors in 2014 when the interviewee conducted research	The succession of knowledge regarding the legal status was observed between 2016 and 2021. While between 2016 and 2018 no knowledge about legal status was observed amongst actors; after 2018 due to sporadic enforcement and

					some awareness meetings, a subset of the actors had some knowledge. However, no clarity regarding species- specific regulations were documented.
Legal and illegal products differentiated at the landing sites	No.	No	No	No	No such technical facilities were available in the landing sites. All landings were accounted in bulks.
Willingness to report	There is no reporting mechanism in place currently. However, recent enforcement activities made traders more careful and unwilling to report on fin trade in the future in fear of detection and penalties	If boat owners agree then fishers are bound to use log-books or any other reporting mechanisms	No reporting mechanisms in place particularly for fins or any other products. Not willing to report	Fishers maybe willing to report catch if proper mechanism and incentives are in place however, traders might not	
Traders need any permit for fin trade	Need fishery product permit to export but nothing specific to elasmobranch fins	No	No, permit to trade on any fishery product will do	No permit was needed (not sure)	No such observations were made. Anyone could trade on fins without a permit and could buy any part of the shark's body.
Checking for illegal products at the ports	No separate permit is needed to trade on fins, it is mostly traded with fish maw and sometimes	Couldn't answer clearly but two fishers mentioned that there are boats	Do not know	For hilsa the checks are there but for	N/A

	separately in the consignment is large enough. No experience of port authorly checking for legality of fin trade	which can bypass custom ports		sharks/fins not known	
Enforcement activity	Some since 2016-17	Since 2017 sporadic catch confiscation has been reported	Sporadically; but since 2019 the raids have increased by Dept. of Forest.	Not seen but in 2013 there was a confiscation of a larger bodied shark and that made the traders very careful	Between 2016 and 2017 18 sporadic enforcement activity were observed which included- confiscation and burying of catch; random monitoring visits and verbal warnings
Determinants of price of the fins	Size of fins and species. value attained from the international markets for high-value fins is significantly greater than any other fishery product	Size of fins and species	Size of fins and species (e.g. sawfish)	Size of the fins; depends on buyer specification (salted or unsalted)	Size was documented to be the primary determinant of the price; however, for guitarfishes and sawfishes the price was high even if the size is medium or small.
Price affected by the quantity of landing or not	If the landing is too low (2 to 3 sharks) the price is low as the profit from these do not suffice all cost related to export, hence trader wait to buy in bulks and the fishers sell it with low price just to get rid of it. If the landing is	Mostly no for whole bodied elasmobranch. Price remains almost same. But sometimes if the quantity for smaller sharks are too high	If the landing is too high then the price may decrease but it also depends on the buyers' demand. Fishers do not catch as a response to price signal.	Like any other fish; quantity of landing may be a factor as well	Not consistently.

	higher for large-bodied sharks then the price is high as well as a larger consignment to export may bring better profits.	price may fluctuate. One fisher mentioned, if the landing of hilsa is higher it may affect price	They desired a high catch but wat is caught on a particular fishing trip couldn't be fixed.

Table S5.8. Methodology for **t**ypology construction

The typology construction process was divided into four steps following (Kluge, 2000):
a) Development of relevant analysis dimensions
Three motivations types- instrumental, mixed and non-instrumental/normative and two access attributes (Limited/low Access and Varied/high access) were used as the analytical dimensions to construct typologies.
b) Grouping the cases and analysis of empirical regularities
Field observations and interviews allowed us to categorise actors into empirical regularities (Table A3). We identified the different combinations of the attributes (from motivation and access dimensions) which were either present or absent within the actors partaking in the fin trade.
c) Analysis of meaningful relationships and type construction
We identified 8 different empirically founded groups that share combination of the selected attributes. Each type was named according to the attribute that distinguished them from the others. Although, the exact attributes for the consumers could not be described (beyond the capacity of the study).
d) Characterization of the constructed types
The detailed characteristics of the types are described in Table 1 of the main text.

Table S5.9. Analysis of empirical regularities (present/absent) to construct typologies at the actor-level analysis; each type was named according to its differentiating attributes and their activities for clarity.

Types of actors*	Motivation	Type of Access

Actor categories		Only Instrumental	Mixed	Non-instrumental/ Normative	
Harvester	*Bycatch and opportunistic fishers*	*x*	*Present*	*x*	Limited/low access
	Target ray-fisher	*x*	*Present*	*x*	Varied access
	Boat owners	*Present*	*x*	*x*	Varied/high access
Intermediaries	*Permanent landing site middlemen*	*Present*	*x*	*x*	Varied/high access
	Opportunistic landing site middlemen	*Present*	*x*	*x*	Limited/low access
Traders	*Exclusive elasmobranch traders (fins and meat) and Online traders (fins)*	*Present*	*x*	*x*	Varied/high access
	Opportunistic elasmobranch traders (fins)	*x*	*Present*	*x*	Varied/high access

*Beyond the capacity of the study to interview international consumers or vendors in regards to fin use.

Table S5.10. Detailed description on the characterization of the constructed actor-types for high-value fin trade in Bangladesh

Actor level	Actor type	Characterization	Access to benefits
Harvester	***Type I*** *"Bycatch and opportunistic fishers"*	Target an array of finfishes, catching elasmobranchs as non-discarded by- catch.	Mixed motivations with limited/low access. Most are on a payroll from boat owners so access to benefits from these catches is low. Sometimes they get a share of the profit but that's true for the captains of the boats

			in the majority of the cases. However, in many cases subsistence fishers get the whole price from the landing site intermediaries if the boat is owned by the fisher hence can have high access but that is rare due to negligible elasmobranch catch in comparison to all artisanal fishers (see Table A6. for the definition of artisanal fishers).
	Type II *"Target ray-fisher"*	Target all rays using bottom set non-baited long lines, mainly in winter and summer.	The primary mechanism of benefits is the price of rays sold to intermediaries at the landing sites or to the exclusive traders at the processing centers. The access is varied. The access is low generally but can be high due to the seasonal catch of high-priced guitarfishes and wedgefishes. This is a debt-driven operation whereby the fishers get a sum of money from the boat owners and the major share of the profit goes to the boat owners.
	Type III *"Boat owners"*	Those with the financial capacity to operate multiple boats and hire several fishers and through a debt-driven mechanism.	They have the highest access to any catch from those boats and the power to make decisions, receiving between 50-75% of the profit.
Intermediaries	***Type IV*** *"Permanent landing site middlemen"*	Appointed by exclusive elasmobranch traders (exporting elasmobranch products) at the landing sites or independent middlemen to source the catch and transport it to the processing centers.	They have the permanent access to the benefits. These intermediaries have several mechanisms of access to the benefits of the fishery including price information control and ties with exclusive traders and the BFDC (Bangladesh Fisheries Development Corporation controlling marine landing at landing sites) officials.
	Type V *"Opportunistic landing site middlemen"*	Buy elasmobranchs at landing sites for transport to tribal areas or to the retail fish driers. They	These intermediaries are dependent on specific conditions when they buy elasmobranchs and hence, do not have permanent access to the benefits from the fishery.

		occasionally trade in other fish depending on the profit margin. They are not employed by any trader but have ties with some of them.	
Traders	***Type VI*** *"Exclusive elasmobranch traders (mainly fins, gill rakers and meat) and Online traders (fins)"*	Operate from main landing sites and in processing centres in the southeast region. These actors are well organized, work within a community. Online traders advertise elasmobranch products (mainly fins) on their sites with other fishery products to export. They source orders from the exclusive or opportunistic traders.	*Exclusive traders* have diverse mechanisms for accessing benefits knowledge of demand, ties with boat owners, relationship with national and international buyers, financial capacity to buy bulk products, process and store and infrastructure. They control the market by buying the majority share of the catch and being the leaders who influence compliance of other actors towards any fishery-related decision making. Online traders maintain their access by information shared by the locals and relationships with international buyers.
	Type VII *"Opportunistic elasmobranch traders"*	Trade in all fishery products including fish maw (dried swim bladders). They opportunistically trade elasmobranch products, mainly fins and meat.	They maintain their access to benefits by regularly visiting the landing sites, relationships with intermediaries, landing site workers and international buyers. They have the financial capacity to trade large number of expensive products.

APPENDIX 5: SUPPLEMENTARY MATERIAL FOR CHAPTER SIX

Appendix 5.1. Study region and fishery contexts

Bangladesh has a continental shelf of up to 50 m depth and an area of about 37,000 km2. Bangladesh's coastal and marine ecosystems include rivers, floodplains, wetlands, mudflats, wetlands, rocky coastlines, coral reefs, and seagrass beds. Further offshore, lesser-known deep-water continental shelf habitats (up to 200 m depth) account for substantial proportions of the region's area. An additional area is unknown within continental slope habitats (200–1000 m) and deep oceanic waters. More than 110 species of sharks and rays were documented from Bangladesh subjected to a disproportionately high number of fishing operations (Haque et al., 2021 a).

Artisanal fisheries - Compared to industrial vessels, fishers use smaller (small to medium) boats. Artisanal fishing is practised in shallow water, often within 40 metres, with mechanical or nonmechanical boats. Fishers do, however, typically use waters deeper than 40 metres. It refers to low-tech, low-capital fishing operations carried out by individual fishing boat owners or businesses. Many of these enterprises are run by Bangladeshi nationals on the shore or islands. Artisanal fisheries can be subsistence or commercial, supplying local consumption or export. Although referred to as small-scale fisheries, the scale varies depending on the location, social context and activity (subsistence-non-mechanized vs artisanal-mechanised). A total of 67669 boats with 188707 gear units are in operation (FRSS, 2017; Shamsuzzaman et al., 2017) with substantial illegal, unregulated and unreported (IUU) catch in the form of under-reported commercial catch, discarded bycatch and subsistence catches (Ullah et al., 2014). Fishers mainly use an array of fishing gears (e.g. gillnet, set-bag nets, longline, hooks, trammel nets etc.) and fishing techniques targeting predominantly as a suite of finfish (FRSS, 2017). Whereas, Hilsa shad (*Tenualosa ilisha*) and Bombay duck *(Harpadon nehereus)* are the major single species contributors, no data on species specific sharks and rays was available until 2017 (FRSS, 2017).

Artisanal target ray fisheries- Target ray fishery is more than decades old practice in Bangladesh. The technique of fishing has been passed down to generations. For this operation, both mechanised and non-mechanized boats are employed. Motorised boats use engines rated between 33 and 100 horsepower. Each voyage spanned five to seven days, and the fishers fished from 4.8 and 36.5 metres deep water. One such boat usually had ten to fourteen fishers fishing for rays. They made two or three journeys every month (14-21 fishing days). Non-motorized boats are smaller, with 3-4 fishers going for day trips in near-shore waters (Haque et al., 2022a). The target ray fishery is active over Bangladesh's whole nearshore coastline, but particularly in the south central and southwestern regions. Fishermen claim more than 100 motorised boats in use in this region alone, putting an estimated 4000000 to 8000000 hooks on long lines (each one 15 km) per day of the fishing season throughout Bangladesh's whole nearshore coastal zones. Rays are collected as a non-discarded bycatch by practically all types of marine fisheries and gears and target fisheries (see supplementary information in Haque et al., 2022a).

Artisanal gillnet fisheries- A great variety of gillnets operate within Bangladesh's coastal and marine waters. They vary in mesh size, net length and width, and deployment techniques in response to different seasonality and target species. They can exploit various water depths. Fishers can also decide if the nets should reach the benthic waters depending upon the target species and use certain clay weights. They also can drift in the pelagic or demersal waters. The great variety of gillnets is challenging to characterise and needs further work. We have found various techniques used by fishers to modify the gillnets according to their needs, enhancing the catchability of the target and non-target species. For example, a group of fishers adds trap-like pockets at the end of the nets for bigger fish to get trapped, enhancing the catchability and decreasing the chance of escape. They can be used seasonally or year-round during the fishing season.

Artisanal set-bag net fishery- Set-bag nets are commonly used. These sedentary nets are set against the current as different mesh sizes along the conical-shaped nets. At the net mouth, the mesh size is the biggest, ascending toward a smaller mesh size at the end of the net. They can be highly seasonal in the southwestern region but can be used throughout the fishing season in other areas (e.g. SE- Teknaf).

Artisanal prawn net/trawl fishery- This highly seasonal gear is made by fishers and used during the season for catching tiger shrimps. Although the action mimics a trawl net, it perhaps is more a bag-like gillnet trawled using the mechanised fishing vessel. This is a seasonal fishing practice whereby many gillnet fishers modify their gillnets or use specialised nets to be used as prawn net/trawl fishery. The mesh size is the smallest found in Bangladesh and is highly specialized for catching shrimps.

Industrial fisheries- A commercial fishing vessel with advanced technology and investment intended to operate fishing trawlers for large-scale fishing. In marine areas, larger vessels such as trawlers (both wooden and metal bodies) fish beyond 40 metres of water depth. However, fishing in shallow seas has also been documented. Trawling is a fishing technique that includes dragging a fishing net through the water in middle and bottom waters. Along with that 253 industrial trawlers deploying 759 gear units are in operation in 2017-2018 (FRSS, 2018; Shamsuzzaman et al. 2017; Islam et al., 2017). The industrial scale fishery can be subdivided into shrimp trawlers, fish trawlers and tuna long-liners.

Apart from these categories, there are **subsistence fisheries** which are small in scale with daily fishing trips and some level of shark and ray bycatch from shallow waters. These fisheries use an array of gillnets, including monofilament gillnets, individual hooks, traps, smaller-scale longlines, beach seine nets, bottom-set gillnets, rock-set gillnets, nets set in tidal waters on the beach and coasts and so on.

Appendix 5.2. Tables and Figures

Table S5.2.6.1. Details of interviews and respondents classified by study region, study sites, types of gears, target species and fishing grounds.

Selected interviews for analysis in different regions (n=988)	South-eastern (n= 181)	South-central (n=599)		South-western (n= 208)
	Cattogram (n= 70), Cox's Bazar (n=111)	Alipur (n= 119), Ashakhali (n= 26), Komorpur (n= 11), Mohipur (213), Patharghata (n= 168), Monpura (n=24), Nijum Dwip (n=6), Char Fasson (n=32)		Dublar Char (n= 15), Khulna (n= 5), Bagerhat (n= 125), Sharakhola (n=63)
Gears used by fishers	Longlines - Baited longlines (n= 40, Unbaited longlines (n= 35)	Small-mesh gillnet (n= 644)	Medium-mesh gillnet (n= 90)	Large-mesh gillnet (n= 9)
	Prawn trawl net (n= 80)	Set-bag net (n= 67)	Industrial fishing trawler (n= 16)	Bamboo-set gillnet (n= 6)
Gear positions/ operation	Floating net (n= 375)	Floating and submerged net (n= 55)	Submerged net/hooks (n= 370)	Trawl net (n= 97)
Exploited water columns by the gears	Upper surface/Pelagic (n= 135)	Middle/ demersal (n= 169)	Bottom/benthic (n= 354)	Pelagic and demersal (n= 130)
	Demersal and benthic (n= 108)	Pelagic and benthic (n=13)	All water column (n= 17)	
Target species	*Tenualosa ilisha* (n= 666)	Sciaenidae (n= 36)	Penaeidae (n= 97)	*Harpadon nehereus* (n= 28)

	Mixed species/ Teleosts (n= 41)	Ariidae (n= 28)	Elasmobranchs (n= 41)	Others (n= 57)
Exploited fishing ground	All regions (n= 45)	South-eastern (n= 160)	South-central (n= 290)	South-western (n=300)
	South-western and South-central (n= 107)	South-western and South-eastern (n= 44)	South-central and South-eastern (n= 34)	

Table S5.2.6.2. Details on fisheries classification (information were collated from interviews, field observations, and literature review -Kumar et al., 2019; Mustafa, 2003; Roy et al., 2014; and DoF, 2019*). The green highlighted fisheries were analysed for risk assessment and the orange highlighted ones were not included due to lack of primary data on geographical extent of fishing operation. % of each category were calculated and only complete interviews (n= 988) were used to classify and characterise the sub-fishery types.

Family	Species	Common name	Comments on landing by artisanal fishery (Haque et al, 2021 a)	Selectivity to different gear types from published literature and field observation
Carcharhinidae	*Carcharhinus hemiodon*	Pondicherry shark	Fishbase and IUCN distribution map shows the range includes Bangladeshi waters. No confirmed landing was recorded	Species like *Glyphis* spp. (Family: Carcharhinidae) are prone to both riverine and coastal fisheries practices. However, it is less prone to shallow water, unbaited longlines and more catchable to all kinds of gillnets and set-bag nets. Adults have no way to escape the gillnets due to their larger body size. On the contrary, *Scoliodon* spp. or pups of larger species can escape the large mesh gillnets. Deep sea species have refugia at depth where the fishery does not overlap their distribution range.
	Carcharhinus longimanus	Oceanic whitetip shark	CITES trade database shows it was traded from Bangladesh; the IUCN range map includes Bangladesh. No confirmed landing was recorded	
	Glyphis gangeticus	Ganges shark	Rare	
Sphyrnidae	*Sphyrna lewini*	Scalloped hammerhead shark	Commonly caught and landed	Mostly caught in gillnets and setobag nets, also reported to be caught in baited longlines in small numbers. They have refuge in deeper waters.
	Sphyrna mokarran	Great hammerhead shark	Rare	
Dasyatidae	*Maculabatis arabica*	Arabic whipray	Commonly caught and landed	Targeted by unbaited longlines and prone to bottom-set nets and gillnets
	Maculabatis bineeshi	Short-tail whipray	Commonly caught and landed	

Gymnuridae	*Gymnura tentaculata*	Tentacled butterfly ray	No confirmed record but it is present within the Indian Sundarbans with possible range overlap in Bangladesh	that reaches to the sea bottom.
Pristidae	*Pristis pristis*	Largetooth sawfish	Rare	Extremely prone to any gear that reaches the sea bottom including longlines, set-bag nets and bottom-set gillnets.
	Pristis zijsron	Longcomb sawfish	Extremely rare. One confirmed record	
Rhinidae	*Rhina ancylostoma*	Bowmouth guitarfish	Caught and landed in little numbers	Prone to gillnets
	Rhynchobatus laevis	Smoothnose wedgefish	No confirmed record of catch over a decade	
	Rhynchobatus australiae	Bottlenose wedgefish	No confirmed record of catch over a decade	
Glaucostegidae	*Glaucostegus typus*	Giant shovelnose ray	Rare	Shallow water benthic elasmobranchs (<40 m) are prone to set-bag nets, unbaited long lines, and gillnets reaching the sea bottom. However, they are less prone to large-mesh gill nets that operate beyond 40 m depths and other gillnets that do not reach the sea bottom either due to being deployed at greater depths and smaller net widths. Additionally, comparatively deeper water (>40, <100 m) benthic elasmobranchs are not prone to set-bag nets, united longlines, or gillnets deployed for pelagic or demersal species. Here, considering the mesh size and fishing tactics are also important.
	Glaucostegus granulatus	Granulated guitarfish	Commonly caught and landed	
	Glaucostegus obtusus	Widenose guitarfish	Commonly caught and landed	
	Glaucostegus thouin	Thouin ray	Rare	
Rhinobatidae	*Rhinobatos annandalei*	Annandale's guitarfish	Rare	
	Rhinobatos lionotus	Smoothback guitarfish	Rare	

Table S5.2.6.3. Fishing footprint of each selected species in regards to the total number of cells, area and water volume occupied.

Species	Total no. of cells	Total area (m^2)	Total volume (m^3)
Carcharhinus hemiodon	57	49363448.02	44903417.19

Carcharhinus longimanus	126423	109485529622.64	49765712390795.70
Glyphis gangeticus	25942	22466431024.98	290566274269.06
Sphyrna lewini	103296	89456960109.32	27352095188946.00
Sphyrna mokarran	120394	104264262463.23	15623559405683.90
Maculabatis bineeshi	45410	39326213585.85	1119421088300.21
Maculabatis arabica	39458	34171630382.53	364792928101.88
Gymnura tentaculata	188	162812775.91	1078057290.14
Pristis pristis	47404	41053068241.00	322591751425.40
Pristis zijsron	47404	41053068241.00	1123079179605.79
Rhina ancylostoma	73029	63244969212.97	2349230413988.58
Rhynchobatus laevis	51425	44535356389.62	1408017121784.22
Rhynchobatus australiae	73029	63244969212.97	2112312394819.99
Glaucostegus typus	73029	63244969212.97	2840203587770.06
Glaucostegus granulatus	73029	63244969212.97	3045580708111.09
Glaucostegus obtusus	73029	63244969212.97	2112312394819.99
Glaucostegus thouin	73029	63244969212.97	2112312394819.99
Rhinobatos annandalei	26067	22574684200.45	437599339449.85
Rhinobatos lionotus	34252	29663102130.42	559764340823.41

Table S.5.2.6.4. Species wise percentage 3D overlap with different sub-fisheries.

Species	SGN	MGN	LGN	ULL	BLL	PTN	SBN
Carcharhinus hemiodon	100.00	0.00	0.00	0.00	0.00	0.00	97.30
Carcharhinus longimanus	5.08	3.22	1.21	0.11	0.21	0.16	0.19
Glaucostegus granulatus	57.37	52.14	19.77	1.74	3.36	2.68	3.12
Glaucostegus obtusus	82.72	61.38	22.82	2.51	4.84	3.87	4.51
Glaucostegus thouin	82.72	61.38	22.82	2.51	4.84	3.87	4.51
Glaucostegus typus	61.52	55.91	21.20	1.87	3.6	2.88	3.35
Glyphis gangeticus	85.05	42.29	18.41	8.81	9.9	12.48	16.18
Gymnura tentaculata	71.87	0.00	0.00	15.02	3.45	16.43	46.37
Maculabatis bineeshi	81.86	30.58	6.18	13.69	5.48	20.41	25.12
Pristis pristis	68.94	64.14	28.00	3.57	6.34	5.35	6.48
Pristis zijsron	75.04	4.89	0.00	5.70	6.03	17.01	15.17
Rhina ancylostoma	76.24	64.62	25.97	3.68	4.36	5.51	6.72
Rhinobatos annandalei	74.37	62.78	23.49	2.26	11.28	3.48	4.05
Rhinobatos lionotus	82.57	72.29	32.12	4.39	9.04	8.39	10.74
Rhynchobatus australiae	76.08	57.91	25.52	5.81	4.84	9.22	11.19
Rhynchobatus laevis	82.72	61.38	22.82	2.51	6.95	3.87	4.51
Sphyrna lewini	81.91	62.43	21.03	0.73	0.37	4.74	4.43
Sphyrna mokarran	9.24	5.86	2.21	0.19	0.65	0.30	0.35

Table S5.2.6.5. Quasi-Poisson (GLM) model output

Parameter	Coefficient	95% CI	t(126)	p	Std. Coef.	Std. Coef. 95% CI	Fit
(Intercept)	9.40	[9.09, 9.68]	62.46	< .001	9.40	[9.09, 9.68]	
fishery [LGN]	-0.06	[-0.49, 0.36]	-0.30	0.764	-0.06	[-0.49, 0.36]	
fishery [MGN]	1.04	[0.70, 1.39]	5.91	< .001	1.04	[0.70, 1.39]	
fishery [PTN]	0.16	[-0.24, 0.56]	0.76	0.446	0.16	[-0.24, 0.56]	
fishery [SBN]	0.28	[-0.11, 0.68]	1.40	0.161	0.28	[-0.11, 0.68]	
fishery [SGN]	1.50	[1.18, 1.84]	9.01	< .001	1.50	[1.18, 1.84]	
fishery [ULL]	0.33	[-0.06, 0.72]	1.67	0.096	0.33	[-0.06, 0.72]	
R2_Nagelkerke							1.00
Sigma							87.08

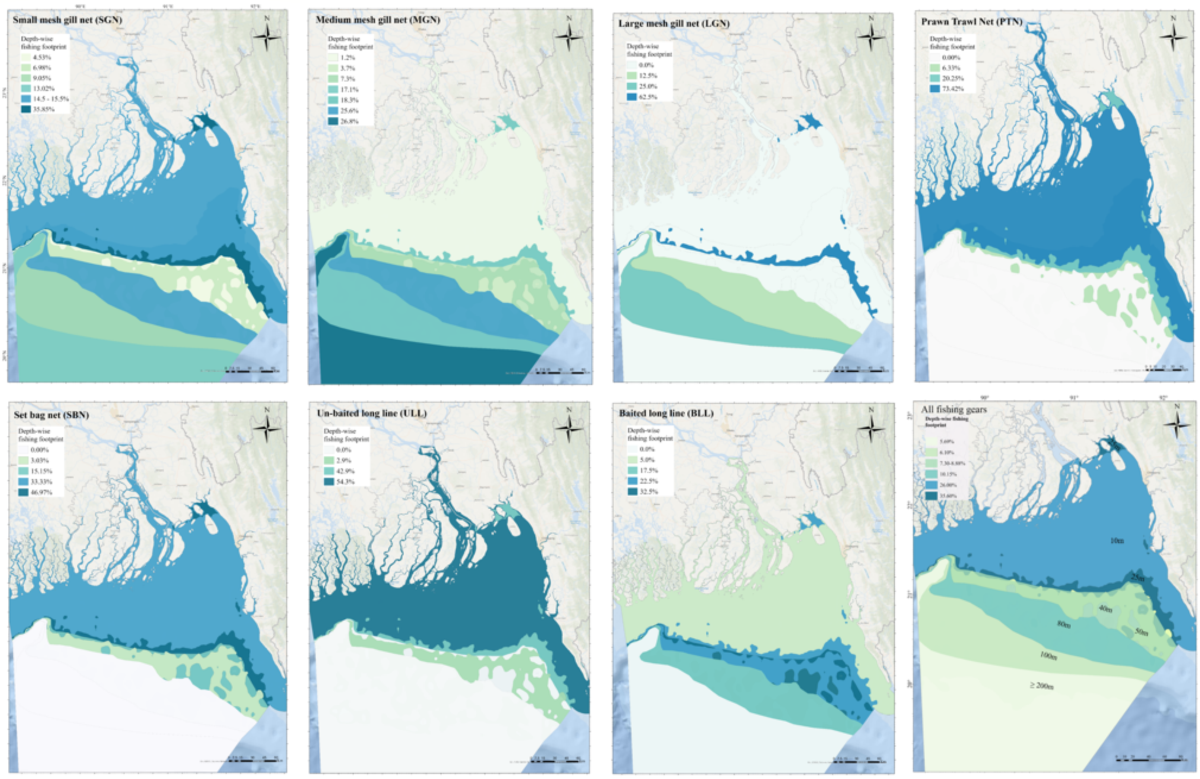


Figure S5.2.6.1. Map indicating the relative scale of fishing footprint at different depths of different sub-fisheries according to the fishers' interviews.

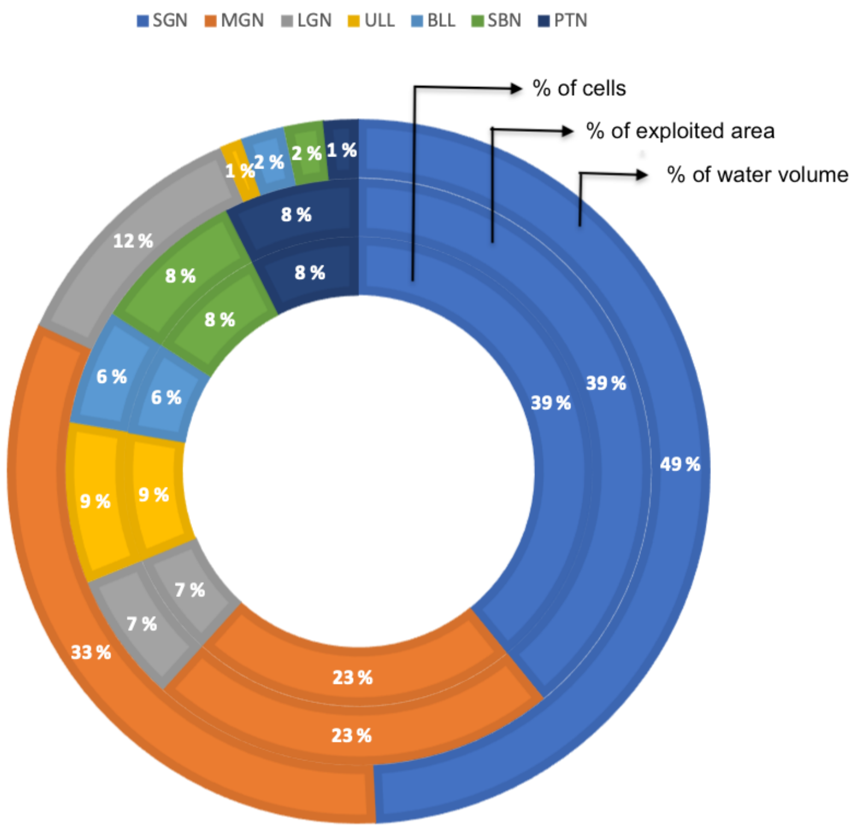


Figure S5.2.6.2. Size of the sub-fisheries: Percentage fishing footprint of each sub-fisheries in regards to the total number of cells, area and water volume occupied.

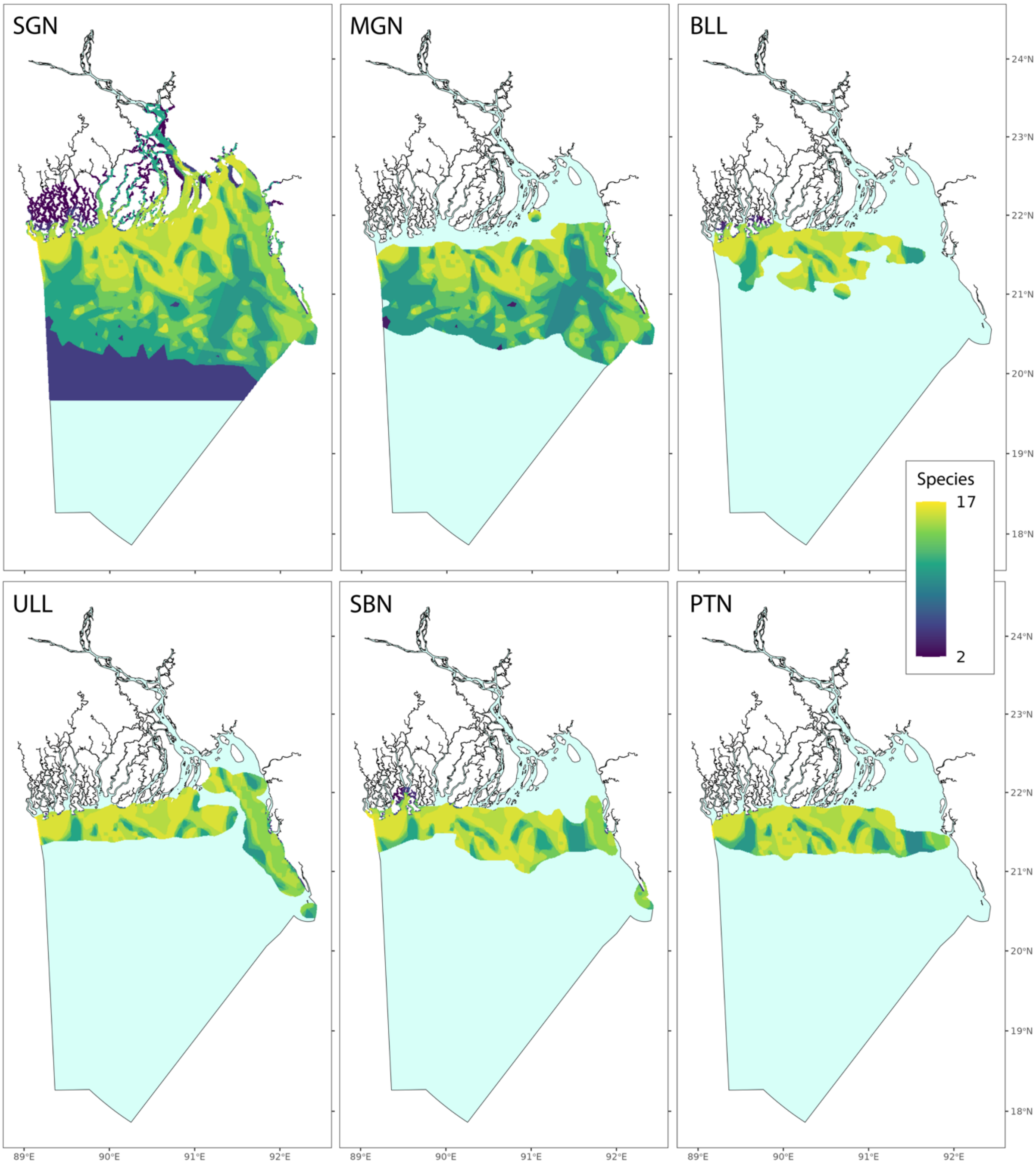
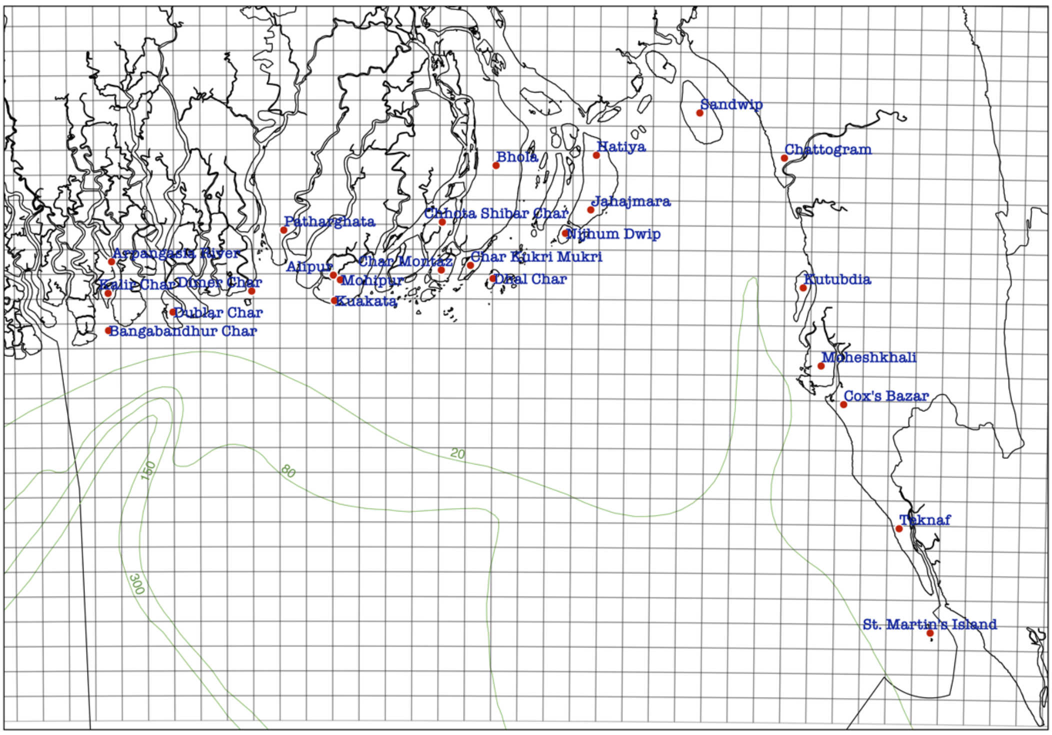


Figure S5.2.6.3. Maps showing the areas where each fishery intersects with the highest number of species' distributional range.

Appendix 5.3A. Variables selected for identifying the fishing grounds

1. Interview ID
2. Homeport- from where the fisher starts the fishing trip
3. No. trip per month- how many times he goes fishing every month Could be a range.
4. Fishing month- Number of months in a year they are active
5. Gear: what is the primary gear
6. Mesh size/ number of hooks- If hooks then number of hooks he uses per trip. And if net then mesh size of the net. Here, the unit is important.
7. Submerged/ floating /trawl- If the net is submerged gillnet or floating gillnet or a trawl net
8. Water Column-u/m/b- Here U means if the fish is caught from the upper column of water, M= middle water column and B= Bottom water column
9. Length of net/ line- the total of length of the net of line used
10. Depth/width of net/line- How wide the net within the water depth (how much water it can vertically cover)?
11. 1st target sp.- The main one species they go for fishing
12. Distance to fishing ground- The distance in KM from the homeport to fishing ground
13. Direction from homeport- Which direction they go from homeport? This is very important. Ask twice. Be sure- it can be South, North, East or West. Or SE, SW etc. Please write in Bangla if you are confused.
14. Travel time (hrs)- How many hours they travel before reaching the fishing grounds.
15. Nearest land location- What is the nearest land location from the place where they fish?
16. Depth rang- At which depth they fish? It has to be a range. Like- 50 to 60 bam or 01 to 50 bam.
17. Avg. shark catches per trip- How many sharks are caught per trip on average?
18. Avg. ray catches per trip- How many rays are caught per trip on average?
19. Avg. guitar per trip- How many guitarfish are caught per trip on average?

Appendix 5.3B. Map prepared for participatory mapping with landmarks



Appendix 5.4. Data collection and Data analysis

Interviews- Semi-structured questionnaire were prepared for fishers to evaluate: (1) Fishing practises; (2) Details of gear used and operational techniques; (3) Spatial range of fishing operation; (4) Bathymetric range of fishing operation; and (5) Average numbers of sharks and rays caught per fishing trip. The questionnaire was based in part on Haque et al. (2022a); Haque et al. (2021b) and Haque et al. (2021c). The semi-structured questionnaire included prepared questions to allow for comparison of responses and for unplanned questions. The latter allowed exploration of issues significant to individual responders on an informal level, which aided in qualitatively characterising the fisheries system (e.g., fishing techniques, gear deployment tactics). Interviews were conducted in ten fishing areas including villages, fish landing sites and shark processing centres in three coastal regions of Bangladesh- south-eastern (n= 342, 30%), south-central (n= 599, 52%) and south-western (n= 208, 18%).

All of the interviews took place in Bangla and then translated into English. Interviews lasted between 40 minutes and one hour. Further details on the interview process and interviewee selection processes are provided in Haque & Spaet (2021) and Haque et al. (2022 a). Ethical permission for the study was obtained from the Biological Sciences Faculty, University of Dhaka.

Data analysis- Due to their small catch sizes and low adverse effects on sharks and rays, non-motorized subsistence level fisheries were not included in our selection of vessels. The information gathered from interviews was used to categorise and characterise sub-fisheries within artisanal fishery practices, then validated using a fishers' workshop and published literature (e.g., DoF, 2019; Fanning et al., 2019; Haque et al., 2021 a, b, c, d; Haque et al., 2022 a). Because the artisanal fishery is divided into sub-fisheries based on the species targeted and the gear utilised, the risk was assessed independently for each sub-fishery. The risk assessment considered the risks of both the target and bycaught shark and ray species. Where complete information was not available for commercial/industrial fisheries through interviews, published literature was used to characterise them, however risks from industrial fisheries were not included in the analysis.

Interview data was also utilised in various exposure attributes, including spatial overlap, vertical overlap, fisheries assemblages (fishing footprint), seasonality of the fishery, fishery size and characteristics of gear impacting capture.

Fishing footprint: Different heatmaps were created to show the most exploited fishing locations at each sub-fishery level (fisheries' spatial footprint) using the point fishing locations identified by the fishers. Heatmap is a spatial analyst tool in ArcGIS used to interpolate a continuous density surface from discrete point data. A heatmap is a valuable visualisation tool for displaying the density or frequency of events (here, catch locations/fishing footprint) along with the extent of spatial influence around each data point. As a result, we can see how the concentration of event occurrences are distributed spatially using a heatmap. Heatmap is a spatial analyst tool in ArcGIS used to interpolate a continuous density surface from discrete point data. Here, the heatmaps were created using the KDE method which stands for Kernel Density Estimation. KDE uses a Probability Density Function (PDF) to estimate a point value. Estimation is the process of forecasting an unknown value at a given place based on a set of reference locations. We interpolate the value from known points when estimating an unknown value.

Heat mapping was used to determine fishing density within a particular search bandwidth or radius. The radius of influence around each fishing site over which the impact of that fishing is perceived is referred to as the search bandwidth or kernel bandwidth. Smaller bandwidth defines finer details, whereas bigger bandwidth specifies a broader and smoother region. For this investigation, a search bandwidth or radius of 30 km was set. The bandwidth is derived from a quantitative understanding that each gear type has an average length and may exploit a specific area of water in a fishing site using an array of gears. A map was also created to identify Bangladesh's most probable fishing sites for each sub-fishery level. Spatial distribution of fishing footprint was graphically analysed.

The current study utilised ArcGIS for analysis, which is a geospatial software and online Geographic Information System service developed and maintained by Esri. The digitised map of Bangladesh and the EEZ were obtained from open-source data imported into ArcGIS and overlaid onto the "Ocean Basemap" of Esri. The catch locations from each grid of the interview reference map were geocoded by giving X and Y coordinates to each location. For every geocoded point, an Identity (ID) in the form of a whole number is automatically created in ArcGIS. Every fishing location identified by each fisher on the grid map was also attributed with detailed information such as sub-fishery type, region, depth range, nearest land location, gear type, and gear length and depth (individual gear footprint both horizontally and vertically) where the data was available.

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