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Socio-ecological approach on the fishing and trade of rhino rays (Elasmobranchii: Rhinopristiformes) for their biological conservation in the Bay of Bengal, Bangladesh

Alifa Bintha Haque [a,*,1], Mahi Washim [b,1], Nidhi Gloria D'Costa [b,1], Amit Robert Baroi [b], Nazia Hossain [a], Rifah Nanjiba [b], Shanur Jahedul Hasan [c], Nazmul Ahsan Khan [b]

[a] Department of Zoology, University of Dhaka, Dhaka, 1000, Bangladesh
[b] North South University, Dhaka, Bangladesh
[c] Bangladesh Fisheries Research Institute, Marine Fisheries and Technology Station, Cox's Bazar, 4700, Bangladesh

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ABSTRACT

Rhinopristioid rays are among the most globally threatened cartilaginous fishes, almost all of which are Critically Endangered. Fishery pressure and lack of knowledge, especially where these elasmobranch fish overlap their habitats off developing countries in the Indo-West Pacific, impede their biological conservation which in turns result in unnoticed population depletion. Rhino rays are an important component of the Bangladeshi artisanal fishery; however, an understanding of these fisheries and their trade is limited. Fishers and traders were interviewed between June 2018 and June 2019 in four areas of southeast Bangladesh to characterize rhino ray fishing, trade and fishers' perception of population trends. All interviewed fishers reported life-long rhino ray catch in sizable numbers and noted a steep decline in the catch over time, especially for *Rhynchobatus* spp. Seven species were documented- not only targeted by un-baited longlines but also by-caught in gillnets and set-bag nets. Unregulated and undocumented catch fuelled by substantial international trade to Myanmar on high-quality skin, meat and fins; and national usages of meat, liver, cartilages and intestines. Between 9000 and 33000 kg (avg. 23000 kg) of rhino rays were bought annually by each trader during 2015–2018. Southcentral shallow-water char (sand island) areas are perceived as essential habitats, hence providing important fishing grounds. The predominant threats are overexploitation by unselective gear use, bottom trawling, target catch, international trade and source of protein and income. Compliance with international trade control treaties or the Bangladeshi law was low, with most fishers (78%) unaware of specific regulation regarding rhino rays. It is crucial to adopt precautionary principles to prevent further rhino ray population declines. We propose a combination of actions rooted in sustainability and inclusiveness in this regard; e.g. a) trade mitigation, monitoring and enforcement, b) need for sustainable fisheries management regimes, c) need for habitat protection; finally, d) the importance of fishers' inclusiveness in conservation decision making.

1. Introduction

Coastal fishing levels, fuelled by high demands of an increasing human population (Merino et al., 2012) has negatively impacted the marine ecosystems (Audzijonyte and Pecl, 2018) by depleting production (Hiddink et al., 2011) and destructing biomass, thus affecting biodiversity (de Macedo KLAUTAU et al., 2018). Increasing global pressure by fishing and trade on cartilaginous fish (Chondrichthyans), including sharks, rays, skates (Elasmobranchii) is pushing stocks close to critical limits (Duly et al., 2017). Multiple Chondrichthyan stocks worldwide have depleted (Haque et al., 2018; Jabado, 2018; Moore, 2017; Dulvy et al., 2000; De Oliveira et al., 2013; Sguotti et al., 2016; Jabado et al., 2018; Kyne et al., 2020). Recent studies have documented that these depletions are most acute for Rhinopristiformes rays (Yan et al., 2021; Moore, 2017; Kyne et al., 2020). The Order Rhinopristiformes include wedgefishes (Rhinidae), giant guitarfishes (Glaucostegidae), guitarfishes (Rhinobatidae) and sawfishes (Pristidae) (Last et al., 2016; Kyne et al., 2020) (rhino rays henceforth; sawfishes were not

* Corresponding author.
E-mail address: alifa.haque@du.ac.bd (A.B. Haque).
[1] authors have equal contribution to this manuscript.

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added in this study).

The habitats for these shallow-water rays are cross-national, especially in the tropical latitudes. The Indo-West pacific is the hotspot for rhino rays due to great diversity and habitat (Kyne et al., 2020; Last et al., 2016; Seret and Naylor, 2016), which are utilized by an array of fishing practices and gears (Moore, 2017). In this region, the Bay of Bengal, surrounded by several developing countries, supports numerous productive Chondrichthyan fisheries and includes amongst the top shark fishing countries globally, e.g. India, Sri Lanka, Malaysia (Lack and Sant, 2011). While supporting millions of livelihoods, extreme fishing pressure in the region impacts Chondrichthyan stocks (Stewart et al., 2010; Ullah et al., 2014). Shark and ray, including rhino ray landings, have declined significantly since the last decades, most likely due to stock collapse (Davidson et al., 2016; Kyne et al., 2020). However, rhino rays are important components of artisanal fisheries (Haque in review).

Rhino rays add to regional economies through artisanal, commercial and industrial fishing and international trade on the fin, meat and skin (Stewart et al., 2010; Bonfil and Abdallah, 2004; Jabado, 2018; Moore, 2017; Dunlop et al., 2013; Haque et al., 2018). Thus, these species are a component of a much-complicated socio-economic complex (Moore, 2017). Exploited throughout their range (Kyne et al., 2020) for the high market value of 'white' fins in the Asian shark fin trade (Moore, 2017; Dulvy et al., 2016), the fin trade is therefore prevalent throughout the rhino ray population range (Chen, 1996; Diop and Dossa, 2011; Jabado et al., 2017; Belhabib et al., 2012; Cooke, 1997; Bruckner et al., 2011; Jabado et al., 2017, 2017; Zynudheen et al., 2004). The rising demand for rhino ray products (especially meat and fins) suggest that more specimens will continue to be landed and traded throughout the region if management is not in place. Compounding threats (e.g., fishing, trade, habitat degradation and fishers' economic dependency, which is leading to overexploitation) aided by limited conservation efforts in developing and less developed nations that span their geographical range (Moore, 2017; Moore et al., 2019) substantially impacted populations of rhino rays. The application of IUCN Red List Categories and Criteria to rhino rays has shown an extremely high likelihood of global extinction for most species (Kyne et al., 2020) without immediate action. Populations have declined by up to 99% in some regions (Kyne et al., 2020). Furthermore, 70% of rhino ray species are categorized as Threatened or Data Deficient by the International Union for Conservation of Nature (IUCN Red List, 2019). They were added in Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) to control trade. However, catch and trade on these species are prevalent in Bangladesh for a long time (Haque et al., 2018).

Artisanal fisheries in Bangladesh are supported by the highly productive and shallow coastal waters (DoF, 2016) inhabited by rhino rays (Haque in review). These fisheries in coastal Bangladesh (see section 2.1.) catches rhino rays in both target and by-catch fisheries. Bangladesh's Wildlife (Conservation and Security) Act, 2012 (WCSA) is currently the only regulatory tool providing limited national protection. While WCSA prohibits catch and trade of 29 species of elasmobranchs, it only includes two rhino ray species often recorded (Hoq and Haroon, 2014; Haque et al., 2018; Haque in review). The two protected rhino rays are *Glaucostegus granulatus* (previously *Rhinobatos granulatus*) and *Rhynchobatus djiddensis* (misidentified for either *R. australiae or R. laevis* as *R. djiddensis* doesn't occur in Bangladesh; Last et al., 2016; Kyne et al., 2020). The enforcement of Bangladeshi law, awareness about these regulations and inclusion of stakeholders in conservation decision making for successful management is lacking (Haque et al., 2020a).

Furthermore, successful fisheries management, especially in developing countries in this region, is problematic due to various reasons, including data unavailability, lack of research and weak institutions (Bladon, 2016). Although many studies looked into biological and fisheries aspects of many of these species (Moore, 2017; Márquez-Farias, 2005), a holistic, sustainable model inclusive of social and economic aspects is lacking (Haque in review). Similarly, owing to no species-specific research on rhino rays, minimal knowledge exists about them in Bangladesh. Species-specific landing data is absent for rhino rays (DoF, 2016; Haque et al., 2018), though there is a significant indication of substantial shark and ray catch and trade in Bangladesh (DoF, 2018; Haque et al., 2018). The lack of quantitative data on rhino ray fisheries and trade (Fischer et al., 2012; Haque et al., 2018) is likely due, at least in part, to the high proportion of artisanal fishers (Ullah et al., 2014) and high level of illegal, unreported and unregulated (IUU) fishing in the region (Shamsuzzaman et al., 2017a) and lack of interest. This lack of knowledge prevents Bangladesh from fulfilling the national and international commitments towards WCSA, CITES and SDG 14 (Sustainable Development Goals). Bangladesh represents a conspicuous data gap in the global range of rhino rays. If not managed in national territories, international treaties fail to conserve species of global conservation concern. Therefore, the range countries of rhino rays, including Bangladesh, need to proactively take measures regarding research, fisheries management and conservation of these species before local extirpation occurs.

It is necessary to continue improving our understanding of species distributions, life histories, fisheries aspects, and monitoring threats and vulnerabilities for evidence-based management. This current study was initiated to address the data gap of this unrepresented marine megafauna from the Bay of Bengal Bangladesh region. This work aimed to document and compare fishers and traders' knowledge of the biological conservation and fishery status of rhino rays based on a socio-ecological approach in the Bay of Bengal, Bangladesh, to enhance conservation efforts and sustainable management of these species. In the absence of baseline quantitative data, a mixed-method approach was taken in this study to characterize rhino ray fisheries and their impact on these species from fishers' perspective.

Emphasis was given to acquiring local knowledge from experienced fishers targeting and by-catching rhino rays for years. Moreover, the aim was also mainstreaming this knowledge in science to answer critical questions regarding the conservation of rhino rays in this region. Fishers have extensive know-how and expertise of great value for fisheries and management, particularly in small-scale fishing in developing countries, where scientific data are often scarce (Fischer et al., 2015). Artisanal fishers can accumulate invaluable knowledge over their fishing careers (da Silva et al., 2019) and local pioneer-ship in conservation is the key to the effectiveness of any measures. A growing body of studies acknowledges the importance of fishers' ecological knowledge in characterizing fisheries, evaluating species abundance, assessing threat and extinction probability, and most importantly, effective fisheries management decision making (Leisher et al., 2012; Knowledge, 1999; Rehage et al., 2019; Berkström et al., 2019; Deshpande et al., 2019; Ayala et al., 2019) especially in data-poor regions (Lopes et al., 2019; Dey et al., 2020). This knowledge can be used to aid management efforts (Fischer et al., 2015). In particular, this could be used to gain information toward the rhino ray species assemblage and catch and trade in Bangladesh's territorial waters.

The aim of this work was to document aspects of the Rhino ray fishery based on the socio-ecological knowledge of local fishers and traders in Bangladesh and identify knowledge gaps in order to provide conservation strategies.

2. Materials and methods

2.1. Study region

The Bay of Bengal has been identified as a global hotspot for globally threatened marine megafauna. The Bay of Bengal Large Marine Ecosystem (BOBLME) includes a maritime zone of more than 6 million km2 among India and Indonesia, covering about 3,660,130 km2. The Ganges-Brahmaputra-Meghna (GBM) Basin influences this shallow embayment. Bangladesh extends across the northern coastal edge of the Bay of Bengal with 750 km of coastline. Fishing is operated from all three regions (South-west, south-central and southeast), overlapping the ideal rhino ray habitats. 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, 2017). The SRF lies within the Ganges-Brahmaputra delta in the Bay of Bengal, formed by the Ganges, Padma, Brahmaputra and Meghna rivers. It is the world's largest contiguous halophytic mangrove forest (Islam and 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 and Chauhan, 2006). Bangladesh's shallow coastal and marine landscapes endowed with a warm tropical climate and heavy rainfall loaded with land-based nutrients, producing one of the wealthiest high-productivity ecosystems (Hossain, 2001; Islam, 2003).

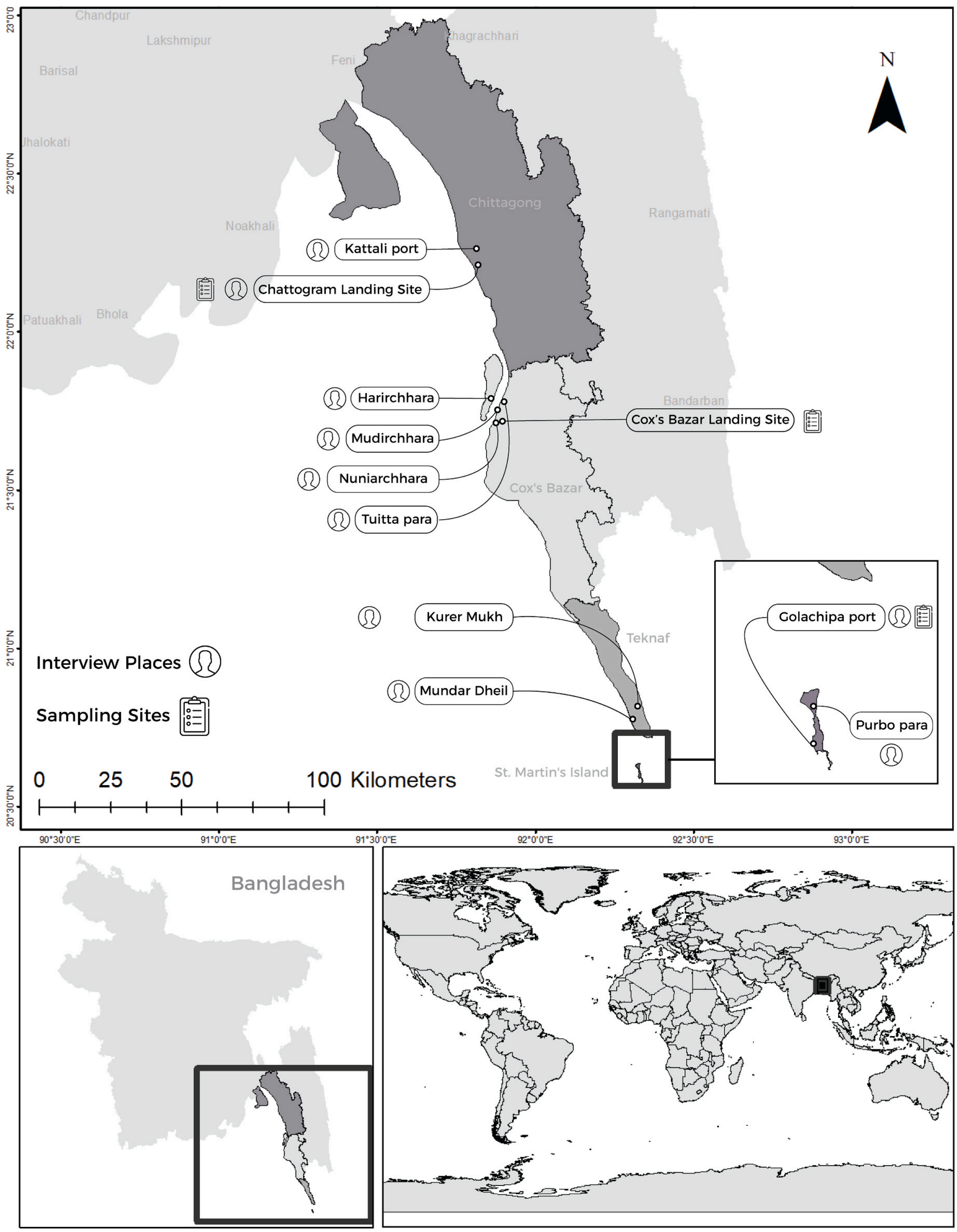


Fig. 1. Bay of Bengal within Indian Ocean (insets). Map of Bangladesh indicating locations where interviews and sampling at landing sites were done: Chattogram, Cox's Bazar, Teknaf and St. Martins.

This unique and dynamic environment creates a favourable niche for rhino rays (Kyne et al., 2020). This provides a productive ecosystem due to nutrient infusion and upwelling, supporting high species richness (Amaral et al., 2017), e.g. dolphins, whales, marine turtles, sharks and rays (Begum et al., 2020; Haque et al., 2018). Fishing pressure is substantially high in this region.

Bangladesh is largely dependent on its freshwater and marine fisheries, representing approximately 9% of its GDP (DoF, 2012). 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. A favourable geographical position of Bangladesh includes a large number of aquatic species and offers plenty of resources to support fisheries (Shamsuzzaman et al., 2017b; Ghose, 2014). A substantial number of fishing fleets are in operation throughout the fishing season, supporting many coastal people. The fishing efforts have increased tremendously in the last five decades (Ullah et al., 2014). It is, therefore, somewhat apparent that the increasing number of current mechanized, non-mechanized and industrial trawlers in the Bay of Bengal, Bangladesh, is the primary reason for over-fishing, which have caused several negative impacts on ocean health and biodiversity. In fact, through trawling and bycatch, substantial numbers of fishes are trapped even if they are not targeted (Haque et al., 2020a). Furthermore, with multiple countries exploiting the waters of the Bay of Bengal for decades, the impact of specific fisheries is somewhat unclear.

2.2. Socio-ecological method: interviews

Two separate questionnaires were made for two groups of stakeholders (fishers and traders) based on Haque et al. (2020a) and Haque et al. (2020b). The interviews were piloted on two key stakeholders representing both groups. Key informant interviews (KIIs) of two nationals, the chairman of one fishers' cooperative (Cox's Bazar fishing boat labourer union) and the then chairman of traders association, were conducted for piloting both the questionnaires. The informants were selected based on years of experience. Data from KIIs incorporated vital information about the extent of fishing pressure on rhino rays.

Interviews were conducted monthly over a year between June 2018 and June 2019 in the four major south-east coastal areas of Bangladesh, namely Cox's Bazar (n = 80), Teknaf (n = 40), Chattogram (n = 30) and St. Martins' Island (n = 50) (Fig. 1). In total, 230 semi-structured interviews were conducted. Amongst these, 200 were fishers, and 30 were traders. Standard, semi-structured questionnaire interviews with both qualitative and quantitative question patterns, including open-ended and closed-ended questions, were used, which took 1.5–4 h to complete. Verbal consent was taken from the interviewees. Fishers were chosen at random, and extensive trust-building and cultural blending sessions were required (methods for trust-building in Haque et al., 2020a). Each interviewee was provided with a pictorial guide following Last et al. (2016) for five species(e.g. Glaucostegus granulatus, G. obtusus, G. typus, Rhina ancylostoma and Rhinobatos annandalei). Rhinobatos lionotus and R. ranongensis were not added as the report of the species were confirmed after this study was completed. Knowledge on Rhynchobatus spp. was also evaluated as a genus. This exercise was conducted to assess species identification precision amongst fishers and obtain some species-specific fisheries data.

The study identified two main stakeholder groups, catching (fishers) and trading (traders) rhino rays, with a total of 8 stakeholder subclassifications. The classification was made based on their financial strata and actions regarding fishing and trading. Fishers were classified as follows: a. crew (fishers recruited by the boat owner), b. technicians (labourer responsible for the engine and helps in fishing), c. captains and d. boat owners. Traders were classified as: a. fish traders (fishers who trade all kinds of fish), b. opportunists (people who sell rhino rays if any opportunity arise), c. middlemen (negotiators among fish traders) and d. shark traders (traders whose business is solely based on shark and ray products) (Table S1). Fishers deploying gears to fish were interviewed at fishing boats, villages and fish drying sites, whereas traders were interviewed in the processing centres and landing sites and had separate interviews.

2.2.1. Fishers

The interview for fishers comprised ten sections and a total of 85 questions on (1) Fishers' demographics, (2) Common fishing activities (fishing practices, fishing frequency, depth and distance covered), (3) Fishing gear, (4) Fishing vessel/boat types, (5) Targeted species, (6) Rate of the rhino ray species sighting and catch, (7) General population trend (increasing/decreasing) about captured specimens, (8) Biological information of rhino ray species, (9) Fishers' perception of the species being studied and (10) Profit obtained from the selling of the species being studied.

A map of probable rhino rays catch areas in near-shore waters of Bangladesh was constructed from interview data of fishers' targeting benthic rays, about distance travelled from homeports, direction, depth at which they fish and the name of the adjacent area. Fishers who carried gill nets and caught incidental rhino rays as by-catch were not included in this map.

2.2.2. Traders

The questionnaire for traders included a total of 54 questions across five sections: (1) Traders' demographics, (2) Overall information on trade, (3) Market value of each product (e.g. fresh meat, dried meat, bones, intestine, fin and skin), (4) Fresh and dried meat processing and preservation, (5) Structure of supply chain. A map of the trade route, transport and hubs was created using data from traders' interviews.

2.3. Interview data analysis

The data gathered from the interviews were cleaned and sorted into five major sections: (i) demographics and fishing practices and distribution, (ii) targeted rhino ray fisheries, (iii) fishing pressure, (iv) fisher's perception on population trend and (v) trade and catch of rhino rays. The demographics of fishers and traders were classified based on age group, level of education, experience, position on the boat and local/settler status to understand their socioeconomic status. This was done (see Table S1) as socioeconomic status plays a vital role in conservation or management decision making. Similarly, characteristic of targeted rhino fisheries were tabulated based on several factors, which include: homeports, fishing characteristics, fishing grounds, habitats, among others, to characterize area specific fishing practices and identifying the most prevalent areas for rhino ray catch. Other than this, annual encounters for each species by the fishers were illustrated as a mean perceived annual catch and was compared with both annual sightings per fisher and actual landing sampled from the study areas.

Moreover, open-ended information from the interviews on fisher's perception of rhino rays, for example, population trend (increase, decrease, or no change observed) and reasons behind their perceptions, were grouped into broader categories and presented. These responses were presented under the following categories: (i) reason for the increasing trend, (b) reasons for the decreasing trend, (c) benefits of rhino rays, (d) and suggested solution for population recovery and conservation by fishers. In some instances, where an individual respondent gave multiple answers to the same question, each data was treated as individual responses.

In many cases, the interviewees were asked to discuss similar topics to confirm or refute the findings from one informant to another. Triangulation was applied by asking similar questions to test the reliability and validity of the data obtained. All the results were translated from Bangla to English, and data analysis were performed through a combination of tools which include: RStudio, Microsoft Excel 2013, Python, Pandas (0.24.2) and NumPy (1.16.4) packages, and plotted using Microsoft Excel 2013, Matplotlib (3.1.0) and Seaborn (0.9.0) packages, with the Scikit-learn (0.21.1) library used for inferential statistics and regression models. Maps were generated using ArcGIS 10.3.

2.4. Sampling at the landing sites

Rhino ray landing data were opportunistically collected to support and validate fisher's catch recorded in the interviews and create a preliminary species list of rhino rays predominantly caught in artisanal fisheries in Bangladesh. Only whole specimens and/or those with clear diagnostic characteristics were included, with identification based on Last et al. (2016) and Jabado (2019). Sex was determined by the presence (male) or absence (female) of claspers, where possible.

2.5. Vulnerability assessment

A threat assessment to examine the relative vulnerability of the studied species were conducted by adopting a method discussed by Nelms et al. (2021). The assessment was conducted by identifying the threat posing variable (Table S4), extinction risk, and protection status based on literature and observation-based evidence from target and by-catch fishery, national and international trade, habitat degradation presence or absence of refuge within habitats. If the species received some level of conservation support (national regulations or conservation actions) and trade control mandates by CITES, that was also considered a positive indicator. The abundance of the catch was used as a proxy for the species abundance, and it was corroborated by fishers' annual encounter rate. Each criterion was scored (Table S5) from low to high (Low score denoting some positive outcomes for conservation and the high score being negative). The scores from each criterion were multiplied to give an overall score of vulnerability (Table 4).

3. Results

3.1. Landing site sampling

A total of eleven species were listed in this study from literature and landing site observations. One species was presumably misidentified (Giant guitarfish *Rhynchobatus djiddensis*) in previous studies, and one needed further confirmation from Bangladesh (Bottlenose wedgefish *Rhynchobatus australiae*). During the study period, five species of rhino rays were documented from landing site sampling of artisanal catch. These species were identified from 336 specimens, which included Sharpnose guitarfish *Glaucostegus granulatus (71.13% of total specimens identified from the sampled specimens)*, widenose guitarfish *G. obtusus (23.21%), giant shovelnose ray/guitarfish G. typus (0.3%)*, bowmouth guitarfish *Rhina ancylostoma (2.38%)* and Bengal guitarfish *Rhinobatos annandalei (2.98%),* with few unidentified specimens. No *Rhynchobatus* spp. was recorded. Identification of Smoothback guitarfish *Rhinobatos lionotus and R. ranongensis* were confirmed after the study period (Table 1).

3.2. Interviews

The fishers and traders mainly were middle-aged, with a few retired from fishing and had many years of experience. The income and literacy levels were low, primarily in fishers. Although the income was comparatively higher, the literacy was low in traders as well. Socio-economic characteristics of fishers and traders are presented in Table S1 and Table 2.

3.3. Fisheries characterization

3.3.1. Fishing season and target species

Sixty percent of the fishers (n = 120) operate all year, including the highly desirable times in summer and pre-monsoon (February–May). Almost a quarter of fishers (24%, n = 48) preferred monsoon (June–September) season, 15% winter (October–January) (n = 30) and 1% both winter and monsoon (n = 2). Fishing significantly reduces during the ban period (June–July).

Amongst the interviewed fishers, 95.5% (n = 191) caught an array of other target fish. For example, Hilsa (*Tenualosa ilisha*), Rupchanda (*Pampus chinensis*), Shrimp (Caridea), Loitta (*Harpadon nehereus*) and Bailla (*Awaous guamensis*) among others, while catching rhino rays as a very desirable by-catch. However, 4.5% (n = 9) of the fishers mentioned catching rhino rays as a target. Many of them target an array of benthic rays, including rhino rays. Winter till pre-monsoon was claimed to be the best season for targeted rhino rays fishing. According to the fishers, the high catch rate was because of char formation (dynamic sand islands formed mainly by the accumulation of sand and soil from upstream rivers and tidal actions of coastal rivers), water clarity, and easily catchable in the water. The majority of the fishers mentioned a larger community in the south-central region targeting all benthic rays.

Table 1
List of rhino rays reported from Bangladesh (reference year: 2020). Sawfishes (Pristidae) were not added in this study. Here, CR= Critically Endangered, DD = Data Deficient.

	Family	Scientific name	Common name	CITES	IUCN status	Remarks
1	Rhinidae	*Rhina ancylostoma*	Bowmouth Guitarfish	App. II	CR	Recorded in the current study
2	Rhinidae	*Rhynchobatus djiddensis*	Giant Guitarfish	App. II	CR	Presumably misidentified in previous studies (Last et al., 2016; Kyne et al., 2020)
3	Rhinidae	*Rhynchobatus laevis*	Smoothnose Wedgefish	App. II	CR	Present in Bangladesh (Roy et al., 2014), however, not recorded in the current study
4	Rhinidae	*Rhynchobatus australiae*	Bottlenose Wedgefish	App. II	CR	Not recorded from Bangladesh, but presumably occurs in this region (Last et al., 2016; Kyne et al., 2020)
5	Glaucostegidae	*Glaucostegus typus*	Giant Shovelnose Ray	App. II	CR	Recorded in the current study
6	Glaucostegidae	*Glaucostegus granulatus*	Sharpnose Guitarfish	App. II	CR	Recorded in the current study
7	Glaucostegidae	*Glaucostegus obtusus*	Widenose Guitarfish	App. II	CR	Recorded in the current study
8	Glaucostegidae	*Glaucostegus thouin*	Thouin Ray	App. II	CR	Present in Bangladesh (Hoq et al., 2011), however, not recorded in the current study
9	Rhinobatidae	*Rhinobatos lionotus*	Smoothback Guitarfish	–	DD	Identification was confirmed after the current study was completed (Haque in review)
10	Rhinobatidae	*Rhinobatos ranongensis*	Ranong Guitarfish	–	DD	Identification was confirmed after the current study was completed (Haque in review)
11	Rhinobatidae	*Rhinobatos annandalei*	Annandale's Guitarfish	–	DD	Recoded in the current study

Table 2
Demographic data of fishers and traders involved in Rhino ray fisheries in Bangladesh (n = 230).

Groups	Demographic Characteristic									
Fishers	Age Group	n, %	Education	n, %	Experience	n, %	Role on boat	n, %	Local/ Settler	n, %
	14–23	26,13%	No education	68, 34%	<= 1	0, 0	Crew	124, 62%	Local	156, 78%
	24–33	58, 29%	Primary (1–5)	95, 47.5%	2–10	18, 9%	Captain	18, 9%	Settler	44, 22%
	34–43	59, 30%	Secondary (6–10)	37, 18,5%	11–20	116, 58%	Technician	6, 3%		
	44–53	35,17.5%			>20	66, 33%	Owner	52, 26%		
	54–63	20, 10%								
	64+	2, 1%								
Traders	Age Group	n, %	Education	n, %	Experience	n, %	Role on boat	n, %	Local/ Settler	n, %
	20–29	12, 40%	No education	15, 50%	2–10	13, 43.3%	Shark businessmen	6, 20%	Local	20, 66.7%
	30–39	8, 26.6%	Primary education (1–5)	9, 30%	11–20	11, 36.6%	Fish trader	13, 43.3%	Settler	10, 33.3%
	40–49	5, 16.7%	Secondary education (5–10)	5, 16.7%	>20	6, 20%	Opportunist	6, 20%		
	50–59	2, 6.7%	College education (11–12)	1, 3.3%			Middle man	5, 16.7%		
	60–69	2, 6.7%								
	70–79	1, 3.3%								

3.3.2. Gear characteristics

Majority of the respondents used gillnets (n = 105, 52.5%), followed by setbag nets (n = 60, 30%) and long lines (n = 35, 17.5%). **Gill nets** were used at all study sites: Chattogram (n = 44, 42% fishers using this gear), Teknaf (n = 40, 38%), Cox's Bazar (n = 18, 17.1%) and Saint Martin's Island (n = 3, 3%). Whereas **setbags** had only been reported in Cox's Bazar (n = 25, 11.5% fishers used this gear). Gillnets and set bags were further classified according to their stretched mesh size (small, medium and large) (Table S2). **Long lines** were used at each of Cox's Bazar, St. Martin's and Teknaf sites, generally for targeted fishing of rays, including rhino rays. The identified interviewed areas used long lines with an average length between 182.76 and 3046 (1583.92 ± 1432.59) m and an average depth of approximately between 9.14 and 15.23 (12.18 ± 3.05) m (Table S2). Longlines were left in the water for an average of 0.5–20 (8.7 ± 5.47) hours. The number of hooks in a long line is reported to be from 1000 to 1500 (9200 ± 5263.08). No **Individual hooks** were found to be used by the interview respondents as a primary gear, although 13% (n = 26) of fishers carried these as secondary gears.

3.3.3. Fishing frequency, depth and distance covered

Fishing frequency varied between 2 and 30 (mean = 11.8 ± 12.07SD) times per month for fishers in Chattogram, 1–30 (11.22 ± 8.08) times in St. Martin's, 2–29 (15.1 ± 7.9) for Cox's Bazar and 1–10 (9.27 ± 6.66) times in Teknaf depending on the boat size, fishing capacity and financial condition; fishing almost every day at sea except for the ban period. Bigger boats with greater storage and fishing capacity with more fishers onboard fished for more days (5-12d) per trip. Whereas smaller boats went for a lesser number of days (1-3d) per trip with a smaller number of fishers on board. Trip duration also varied according to the amount of fish caught. If enough fish is caught, the trip was usually cut short. However, that would not change the fishing days at sea as they would return to the sea after selling all fish at the ports.

Mean fishing distances varied among the regions of Cox's Bazar, Chattogram, Teknaf and St. Martin's; 10–90 km (41.57 ± 27.65), 1.53–289.14 km (72.61 ± 87.27), 1–90 km (12.45 ± 25.93) and 0.11–98.95 km (13.07 ± 23.04), respectively, as reported by the interviewed fishers from homeports (Table S2). Fishing depths are also measured with prompt differences among the studied areas accordingly: 3.05–254.34m (82.19 ± 84.86) for Chattogram, 3–5.60m (4.03 ± 0.50) for St. Martin's, 9.13–150.88m (67.85 ± 56.68) for Cox's Bazar and 7.62–33.50m (23.76 ± 8.56) for Teknaf.

3.4. Fishing grounds especially for rhino rays

Common fishing grounds indicated by 49% of the fishers (n = 98) included; Guliddhar, Shonarchar, Boddar, Shonadia, Dhalchar, Mongla, Kuakata, Teknaf, Hatiya, Lama, Bairpata, Charadar, Hejurkul, Harimur, Mohipur, and sometimes as far as to Myanmar and Indian borders. Grounds were identified on a map; however, due to local names used and no identifiable landmark, a few couldn't be located. These areas are predominantly in the south-central region of Bangladesh. Nine fishers carried long-line hooks (n = 4), gill nets (n = 3) and set bags (n = 2) target rhino rays within 3.54–24.37m depth range in Patharghata, Guliddhar, Mohipur, Alipur, Bakkhali, Chalnar boya and Shonarchar

Table 3
Characteristics of fishing activities on Rhino rays based on fisher interviews (N = 9) in Bangladesh.

Homeport	Cox's Bazar (n = 8), St. Martin's Island (n = 1)
Fishing frequency (times/month)	2-4 (mean = 2.9 ± 0.8 SD)
Fishing duration (days)	7-15 (mean = 10 ± 2.34 SD)
Fishing depth (m)	3.54–24.37
Engine power (hp)	10-82 (mean = 37 ± 28.6)
Boat size (m)	3-7 (5.22 ± 1.7)
Gear type used by the target fishers	Longlines (n = 4), Gillnets (n = 3), Setbag nets (n = 2)
Perceived gear types best suited to catch rhino rays	Bottom set nets with bamboo in south central region, shallow water long lines targeting rays, setbag nets and then submerged gill nets (by-catch)
Mesh size for nets (cm)	10.7–12.7 (mean = 11.7 ± 1.37)
Hook numbers for long lines	10,000–30,000 per 3–10 km line
Fishing season	Winter (n = 7) and Summer (n = 2)
General fishing ground	Coastal waters with 40 m depth in south central region (Mohipur, Alipur, Patharghata, Shonar char, Gulidhar), Near Sundarbans close to Indian boarder, South eastern region (Bakkhali river-mouth, West bound to Inani, Cox's Bazar)
Habitats for rhino rays in Bangladesh (Mostly caught from)	Char areas (coastal islands with freshwater influx) in the South-central Bangladesh (Shonar Char, Gulirdhar, Balur Char, Monkhali) within ~ 30 m depth
Last season (2017-18) catch per trip in target ray fishing season (mid-October to mid-April)	2-70 (mean = 19.9 ± 22.5 SD)
Benefits	Good business, expensive fin, export value, consumption by the tribal people, medicinal values
Action after catch	Bring to fishery landing sites, sell, dry the meat and fins, export abroad including Myanmar and India or sell to the tribal communities
Selling price per kg fresh meat at landing sites by fishers (US$)	1.8-3 (mean = 1.9 ± 1.23 SD)
Selling price of per kg dried guitarfish by traders to buyers (US $)	3–9.6 (mean = 6.15 ± 2.7 SD)

regions (Table 3). Several other fishers carried larger hooks to target other big fish, including sharks and rhino rays, in addition to their primary target. These areas have been explicitly identified for fishers who mentioned targeting rhino rays. A 20 km buffer has been used in fishing points as it is evident that no fishers fish only in one area (Fig. 2).

3.5. Fishers' knowledge on rhino rays

3.5.1. General understanding

The majority of fishers perceived one to five (mean 2.74 ± 1.18 SD) species of rhino rays present in the region, with ten fishers mentioning more than six species presence. Morphologically similar species are identified with different local names (e.g. *Glaucostegus* spp. and *Rhinobatos* spp. are locally called পতিাম্বরী- pitambori, নাঙলা-nangla or গরেনেজা- gerenja; *Rhina ancylostoma* - Bang hangor- ব্যাঙ হাঙ্গর; and *Rhynchobatus* spp., are called Fullaissha-ফুলাইশ্শা). They could identify the different species from morphological characteristics (colour, snout, fins, skin texture, n = 123, 61.5%) and the experience of handling rhino rays (n = 59, 29.5%).

To evaluate fishers' knowledge of breeding season and biology, they were asked about the breeding season and the number of pups given each season by rhino rays. Although half of the fishers could not answer the questions, the majority who answered the question (n = 96, 48%) identified from winter to monsoon (87.5% from who answered) as the breeding season. This could not be differentiated for different species. The fishers identified the breeding season by the phenomenon of a greater number of pups sighted and caught (n = 32, 33.33% of fishers who answered) and a greater number of gravid females' presence (n = 7). The clutch size was suggested to be more than six by a large proportion of the fishers (n = 57) who knew the answer (n = 124, 62%) followed by three to four (n = 47) and one to two (n = 20) (Table 3). Many fishers mentioned that rhino rays breed once (n = 53 fishers) or twice (n = 46 fishers) a year.

3.5.2. Annual sighting

Fishers were asked about the annual frequency of observations (observation on rhino rays at sea) when fishing and the number of rhino rays caught annually to triangulate both answers for correctness. Winter to pre-monsoon was identified to be the season best suited to catch rhino rays at sea according to the fishers (n = 146, 74.5%) (Table 3). Where identification capacity was very good for *Glaucostegus granulatus*, *Glaucostegus obtusus, Rhina ancylostoma, Rhinobatos annandalei* and *Rhynchobatus* spp., fishers couldn't confidently differentiate *Glaucostegus typus*, and *Rhinobatos lionotus (As R. lionotus* was identified for the first time from one specimen from Bangladesh by Haque in review, it was not added in this study). Identification capacity among different *Rhynchobatus* spp. was also low, although it was identified unmistakably as the genus.

The most frequently encountered rhino ray species was *G. granulatus*. 55.04% of fishers identified it with a greater number of observations between 1 and 1500 (mean 80.38 ± 159.5 SD annual sightings per fisher) followed by *G. obtusus* with mean observations between 1 and 260 (mean 25.07 ± 40.03 SD). *Glaucostegus typus, Rhinobatos annandalei and Rhina ancylostoma* had approximately equivalent proportion of annual mean observations 14.18 (1–365), 13.96 (1–625) and 12.31 (1–120) individuals respectively. Many fishers (26%, n = 52) also identified and presented knowledge on *Rhynchobatus* spp. with no sightings or catch in the last season (2017–18). They also mentioned no catch or observation in the last five years. Upon presenting the pictorial guide, fishers could not differentiate amongst different *Rhynchobatus* spp. However, they could differentiate between *Rhina ancylostoma* and *Rhynchobatus* spp.

This sighting frequency data coincides with the perceived mean annual catch and representative number of actual specimens sampled from the landing sites (Fig. 3), proving the authenticity of fishers' knowledge on sighting and catch rate. Regression models have shown significant positive relationships between the perceived annual catch (2017–18) last season and the sighting frequency of all five species of rhino rays (Table S3).

3.5.3. Catch

It was found through extensive interviewing that a community in Cox's Bazar is practising targeted rhino rays fishing for generations. However, fishers mentioned a greater community of fishers targeting them in the south-central region. Long lines and an estimated catch of rhino rays is reported to be 1–300 (46 ± 53.09) over the study period (2017–18), and 1–200 (47.28 ± 61.03) number of individuals were estimated to be caught on an average in a year (Table S2). The annual catch of the last season ranged between zero to 250 individuals (mean 27.14 ± 37.60 SD per fisher). Most species were sighted in the monsoon and winter seasons. All gears caught a substantial number of rhino rays; however, fishers from Cox's Bazar were found to catch relatively more of them (Fig. 4).

In regards to this classification of fishing nets, it is found that

Table 4
Responses of fishers' from interviews (n = 200) to selected questions pertaining to Bangladeshi rhino ray fisheries and important quotes by the respondents.

Question related to	Answers (no. of respondents)					
Number of rhino ray species present in Bangladesh	One (23)	Two (44)	Three-five (110)	>six (10)	Don't know (13)	
How could fishers identify different species	Experience of handling rays (59)	Colour (21)	Morphology (fin, size and shape, tail) (59)	Skin texture/spots (20)	Snout structure (23)	Don't know (19)
Probable breeding season	Pre-monsoon and monsoon (63)	Winter (21)	Summer (12)	Don't know (104)		
How the breeding season was identified	Greater number of pups sighted (32)	Experience (19)	Sightings of greater no. of gravid females (7)	Easily entangled pups (4)		
Breeding intervals	Once a year (53)	Twice a year (46)	>thrice (6)	Don't know (95)		
Perceived clutch size	1-2 (20)	3-4 (47)	>6 (57)	Don't know (76)		
Season of most sightings	Pre-monsoon and monsoon (89)	Winter (60)	Summer (15)	Spring/all seasons (3)	Don't know (33)	
Catch trend over the last five years	Decreasing (144)	Increasing (30)	Same (24)	Don't know (3)		
Size over the last five years	Decreasing (113)	Increasing (31)	Same (54)	Don't know (2)		
Respondents	Important quotes					
Fisher	The population of rhino rays (পতিাম্বরী) have declined tremendously in the last ten years at least by 50–60%					
Fisher	The last *Rhynchobatus* spp. (ফুলাইশ্শা) I caught was 20 years ago.					
Fisher	Khuta jal (Bamboo set nets at the bottom of the ocean floor in 5–10 m depth of southcentral coastal waters) catch a lot of rhino rays.					
Fisher	Rhino rays are predominantly found near the char areas in shallow waters in the southcentral and southwestern region.					
Trader	The fins of rhino rays are very expensive and the international demand is highest amongst all other elasmobranch species.					
Trader	Between 2005 and 2010 I traded on hundreds of *Rhynchobatus* spp. However, I haven't seen one in the last 9–10 years.					
Middleman	Even in 2008-09 at least 2–3 *Rhynchobatus* spp. would land in Cox's Bazar every month. The last one I saw was in 2009.					

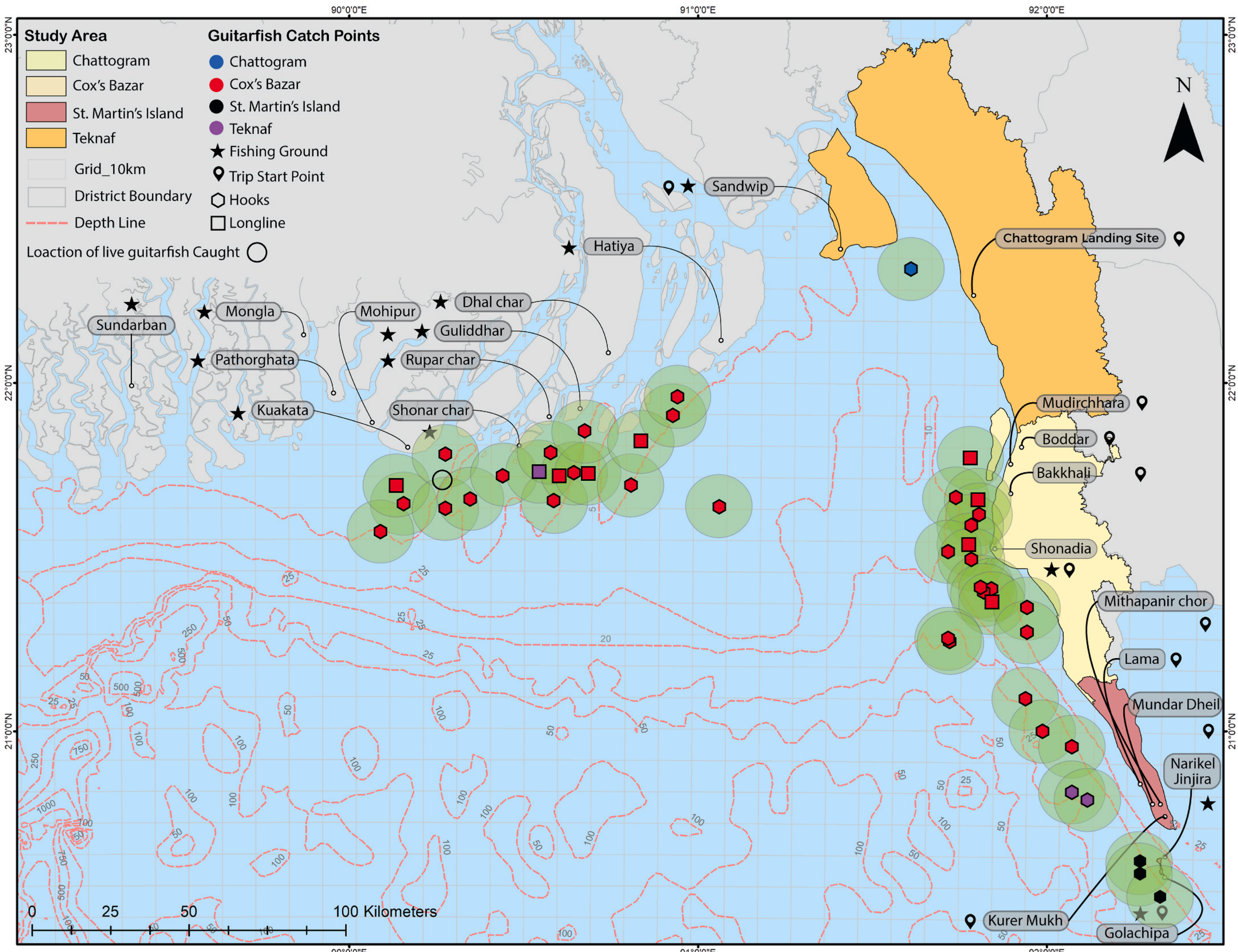


Fig. 2. Rhino ray fishing pressure within their habitats in the Bay of Bengal, Bangladesh and around the study regions of Chattogram, Cox's Bazar, St. Martin's and Teknaf.

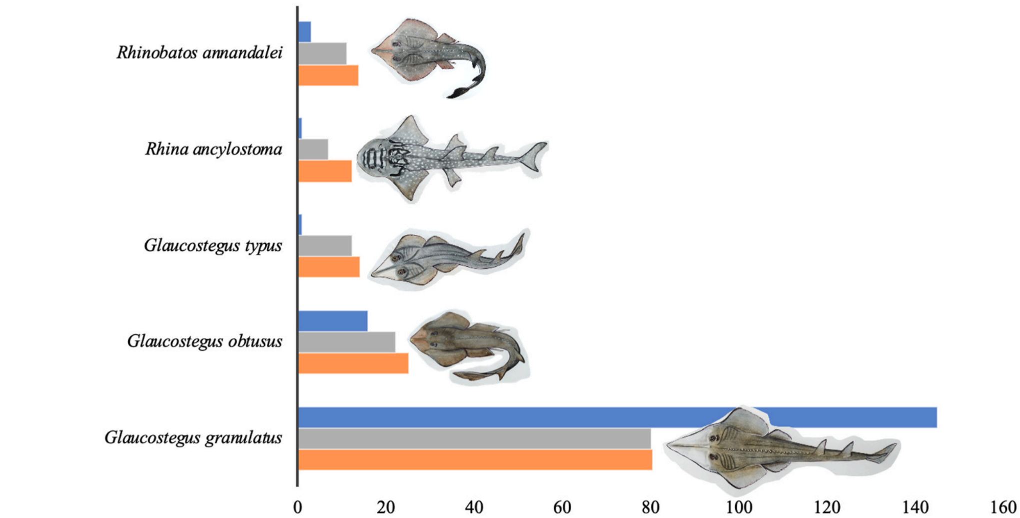
medium-mesh sized gillnets (mesh mean = 10.16–15.24, mean 11.12 ± 1.35 SD) cm caught the highest number of rhino rays during 2017-18 (1–300, mean 45.81 ± 65.48 SD) and as well as for average annual catch of the studied species which ranged between 2 and 500 (70.83 ± 94). However, for set bags, the results vary slightly as the number of rhino rays catches (both last season and avg. annual catch) increases with an increase in mesh size (Table S2). Regression models have shown no significant relationship between mesh size and average perceived species caught (Table S3), and they were caught almost at any mesh size.

The study found substantial target fisheries that catch rhino rays through a multi-species fishery targeting all species of benthic rays through the interviews. However, they were not represented in the study due to the smaller number of target fishers being interviewed. Almost 5% (n = 9) of the interviewed fishers reported that they mainly target rhino rays, of which 100% were using longline non-baited hooks. This is due to the high export demand for rhino rays' skin and fins.

3.6. Population trend

The majority of the fishers (n = 144, 72%) stated that rhino rays are decreasing over the last five to ten years. However, some claimed (n = 30, 15%) that their population is increasing with the disappearance of *Rhynchobatus* spp. from catch in the last decade. A few (n = 24, 13%) thought it was the same. Four of them could not enlighten the interviewers with any knowledge on the population trend. The majority of the fishers (n = 113, 56.5%) mentioned the reduction in the size of these species in catch as well in the last five years (Table 4).

Multiple answers as the reasons for both perceived increasing and decreasing trends were recorded and were classed under broad categories. For increasing trend, there was a total of 46 responses (Fig. 5a) from 30 fishers, and there were 210 responses (Fig. 5b) for decreasing trend from the sampled population who claimed rhino rays were observed to decrease in both in number and size. The majority of the fishers (n = 144, 72%) stated a decline in the rhino ray populations over the last five years. Two hundred ten responses were reported from 11 different reasons for the declines of rhino rays classed under four broad themes. They are as follows: (i) Consumption: food for indigenous community (n = 38, 18%) and medicinal use (n = 21, 10%) (ii) Unselective gear use: bottom-trawling (n = 35, 17%), longline & gill net use (n = 21, 10%) and by-catch (n = 17, 8%), juvenile catch (n = 20) (iii) Income generation: increasing targeted/by-catch (n = 18, 9%), extra income source (n = 28, 13%) and enhance artisanal fish catch (n = 4, 2%) (iv) Others: climate change (n = 5), and illegal fishing (n = 3, 1%).



	Glaucostegus granulatus	Glaucostegus obtusus	Glaucostegus typus	Rhina ancylostoma	Rhinobatos annandalei
Total number sampled	145	16	1	1	3
Perceived mean annual catch	80.17	22.35	12.43	7	11.11
Perceived mean annual sighting at sea	80.38	25.07	14.18	12.31	13.96

Fig. 3. Mean perceived annual catch, annual sightings per fisher with actual landing sampled from the study areas.

3.7. Trade

According to the traders, the rhino ray fins are one of the most desirable of all elasmobranch products, depending on the size of the fins. The weight (kg) of rhino rays bought by traders depended on the traders' financial capacity. It ranged from 13691 to 21788 kg in Cox's Bazar (n = 13), 4707–33089 kg in Chattogram (n = 9), 13060–32760 kg in St. Martin's (n = 5, mostly operating from Teknaf) and 13060–32760 kg in Teknaf (n = 3, 9013–27200 kg) per trader. On average, more than 23000 kg of rhino rays were bought annually from the landing sites per trader between 2015 and 2018. The amount was almost similar in the last twenty years except in 2005–2010 (Fig. S1).

The trade chain of rhino ray products spans national, regional, to international regimes stated by both traders and fishers. By both trader interviews and field observations it was evident that the landed rhino rays were bought by the shark processing centre owners or shark traders through middlemen or by their employers at the landing sites, and some bigger catches landed straight to the processing centres, e.g. in Cox's Bazar. At the processing centres, workers process the whole body to make different products (fin sets, meat, liver, skin, cartilages, intestines and snouts). The products are immediately dried on thatched roofs or frozen to be dried later. Consignments of dried meat, fins and skin are prepared for mainly international trade. According to all shark businessmen, the fins are the most valuable products, followed by the meat.

According to the traders, both dried meat and fresh meat along with cartilages were transported from Cox's Bazar to the local coastal villages and hilly area of Bandarban, Khagrachhari in Chattogram Hill Tracts (Fig. 6) to meet the nutritional demands of the tribal communities, but this practice was negligible in comparison to international export. Village medicinal practitioners were also encountered to use the cartilages for medicinal purposes. However, this was found to be negligible in comparison to international trade.

No direct global route for export to China was recorded from interviews during the study period (however, ties with China are present through Myanmar); or other countries previously reported to import shark products from Bangladesh. Trade occurred from the south-central and south-west region of Bangladesh via Myanmar and then transported to China via pickup trucks and buses to Chattogram and Cox's Bazar for international trade (Fig. 6).

According to the traders, all kinds of rhino ray products (meat, fins, skin and vertebrae) were transported via wooden fishing vessels, generally used for carrying all elasmobranch species' products. Some vessel/boat owners usually had their hubs in Bangladesh and Myanmar and worked as specific traders connecting the global markets to the local traders and fishers. Through traders or direct communication with Chinese buyers, orders were sent via Myanmar, as they had closer seaports to China. They have also exported to Thailand and India in recent times. There was also high demand for meat, both dried and fresh; skins and cartilage for consumption, medicinal purposes, manufacturing accessories, jewellery. Intestines were found to be sold at basic rates per kilograms for consumption (Fig. 7).

The traders stated different prices for different rhino ray products. The ranges in price for fresh meat from the local fishing boat was between US$0.59–2.37 per kg, and the selling price by the local traders were limited to within the range of US$2.13–14.19 per kg. Dry meat was usually bought by traders and sold at prices between US$1.18–4.73, which is both locally traded or exported for food consumption (n = 30). The selling price of skin was US$2.37–8.28 per kg and was only exported. Fins of rhino rays had the highest demand and were the most expensive, with selling prices ranging from US$4.73–18.92 (fin 15.24 cm) and US$ 8.28–23.65 (fin 20–26 cm) per kg. Intestines and cartilages were sold at a very cheap rate per kilograms, US$0.35–3.55 (Table 5).

All the information collected from traders' interviews were used to reconstruct a highly complex trade map denoting products, routes, transports and hubs for rhino rays. They significantly overlap with general shark product export (Haque in review). Most of the products reach the south-eastern region and the traders herein for further export towards Myanmar from across the coasts of Bangladesh.

3.8. Fishers' and traders' attitudes towards conservation

The awareness level about the existing international treaties (CITES) and national law on rhino ray species was limited. Almost 78% of the fishers (n = 156) and 43.3% traders (n = 13) did not know about any regulatory measures on rhino rays. The remainder of the fishers (22%) had minimal knowledge of the specifics of the law despite being

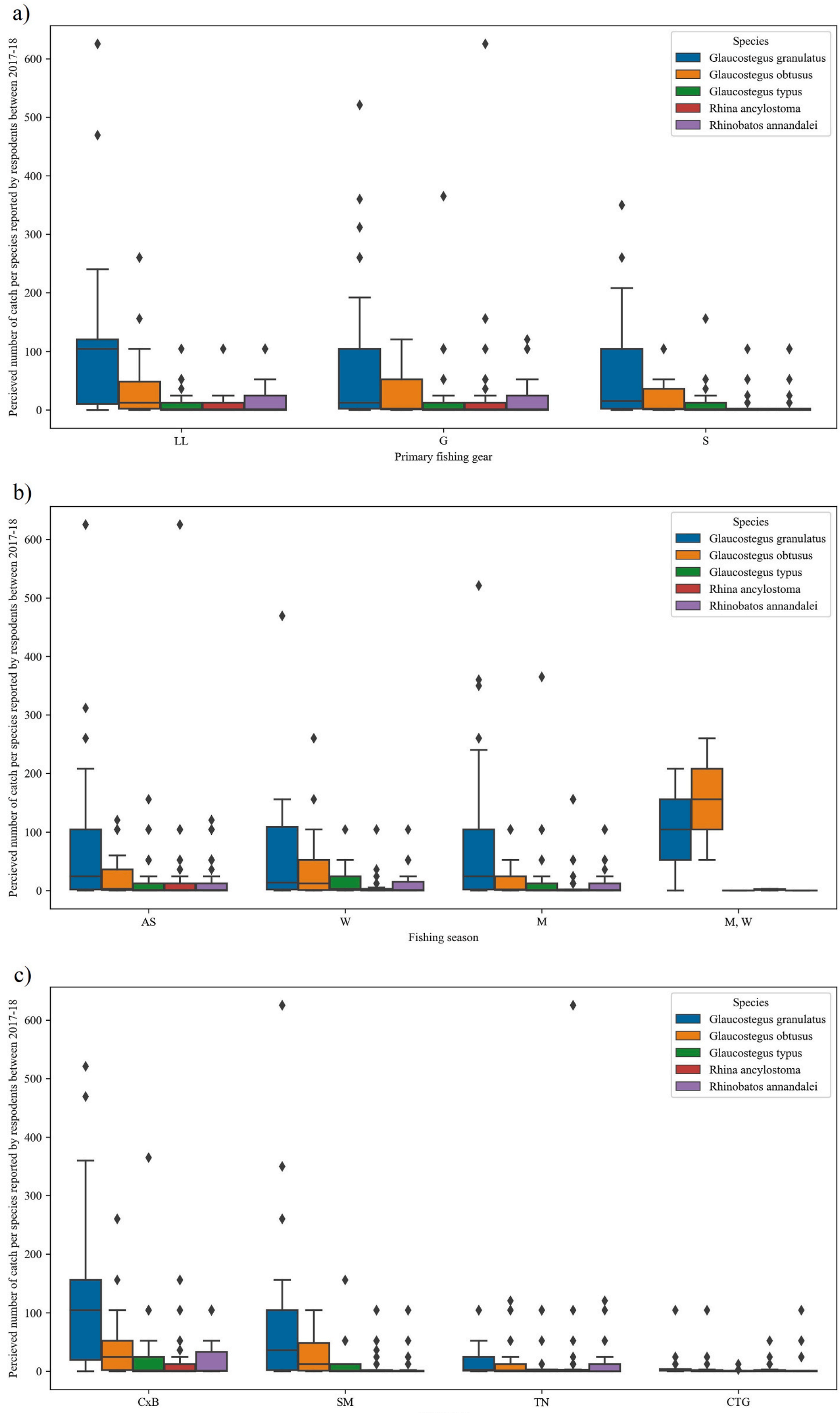


Fig. 4. Boxplots showing the perceived number of catch (2017–18) for primary different gear used (a), fishing season (b) and homeports from here fishing vessels are originated from (c). (LL = Long lines, G = Gillnets, S=Setbag nets, AS = All season, W=Winter, M = Monsoon, CxB = Cox's Bazar, SM=St. Martin's Island, TN = Teknaf and CTG=Chattogram).

generally aware of the restrictions. Limited and faulty knowledge prevented them fishers to take informed decisions in regards to rhino ray catch.

Almost, 73% of the fishers (n = 146) asserted on the ecological (n = 37, 24%), economic (n = 70, 46%), aesthetic (n = 11, 7%) and social benefits of rhino rays (Fig. 5c). In total 152 responses were reported. They are as follows: (i) Ecological: cleans ocean (n = 6, 4%), beneficial for ocean's health (n = 20, 13) and beneficial for other small fishes (n = 11, 7%), (ii) Economic: highly values fish (n = 45, 30%) and high export demand (n = 14, n = 9), (iii) Aesthetic: preserves ocean beauty (n = 11,

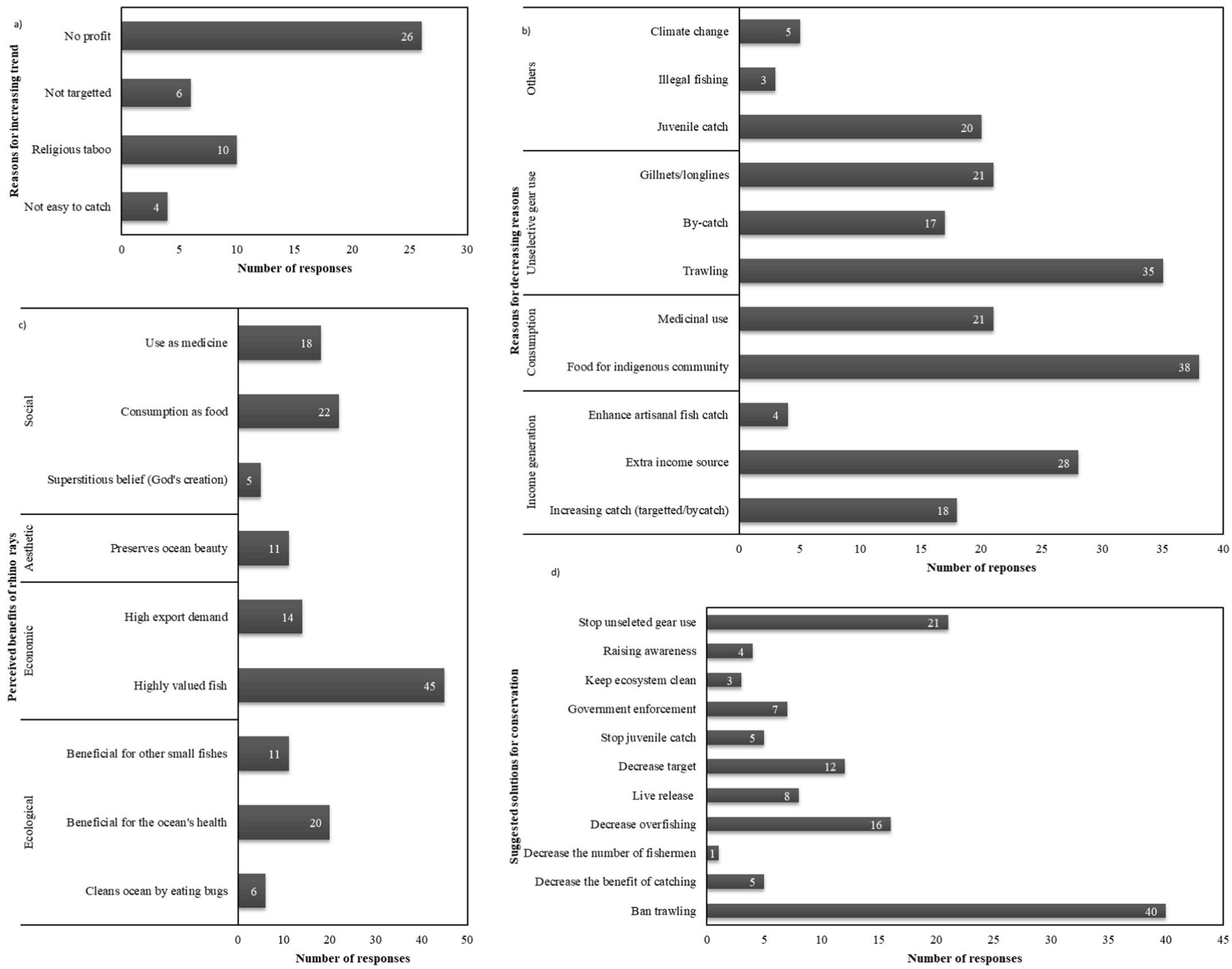


Fig. 5. Perceived population trend by fishers: reasons for increasing trend (n = 46 responses) (a) reason for increasing trend (n = 46), (b)reasons for decreasing trend (n = 210 responses) (c), benefits of rhino rays (n = 152) (d) and suggested solution for population recovery and conservation by fishers (n = 122 responses).

7%) and (iv) Social: religious belief (God's creation) (n = 5,3%), consumption as food (n = 18, 12%) and use as medicine (n = 18, 12%). However, 27% of the respondents (n = 54) were not aware of any benefits rhino ray species bring about.

Upon asking what could be done to preserve the population sustainably and mitigate by-catch, the fishers came up with an array of solutions. Some notable solutions presented in the study were to restrain overfishing (n = 16, 13%), bottom trawling (n = 40, 33%), targeted catch (n = 12, 10%), fishing in the breeding season (n = 5, 4%) and encouraging live release protocols (n = 8, 7%) among many other recommendations (Fig. 5d).

While most fishers sell the fish regardless of being targeted or by-catch (n = 106, 53%), 63 fishers (31%) claimed to release by-catch. This was mainly within the Muslim communities in Cox's Bazar and St. Martins Island since they believe eating them is prohibited. However, this information could not be corroborated with observation data.

3.9. Vulnerability assessment

The most vulnerable genus was *Rhynchobatus* sp. with the highest score. *Rhynchobatus* spp. *was assess as a group comprising of all Rhynchobatus* spp. recorded in Bangladesh, as the identification capacity of the fishers in differentiating among these species was low. *Rhynchobatus djiddensis* is protected under national law; this species does not occur in Bangladesh. Hence, the protection status has been designated herein as not protected for present *Rhynchobatus* spp. *(R. laevis or R. australiae)*. Although *Rhinobatos annandalei* has scored low and hence seems less threatened, it is because of the Data Deficient status of the species. It is relatively rare in landing and might gone through depletion without notice. The least vulnerable species is *Glaucostegus granulatus*, as the abundance is still high in landing and the national law protects it. The results of the threat assessment are described in Table S6, with further detail presented in Supp. Mat. Tables S4 and S5.

4. Discussion

Catch and trade on rhino rays in Bangladesh is common for decades (Fig. 7, Hoq et al., 2011; Hoq and Haroon, 2014; Roy et al., 2014; Haque et al., 2018). Results have shown that all of the near-shore shallow waters in Bangladesh are utilized by a fleet of vessels using an array of unselected gears. All these vessels exert substantial pressure on rhino ray populations in their habitats by-caught and target fishery. These specimens meet the increasing demand in the meat and fin industry. The populations have declined substantially for *G. typus, R. ancylostoma, R, Annandale*, and most importantly, *Rhynchobatus* spp. has been perceived to be extremely rare with no sighting in the last 8–9 y. As a result, the

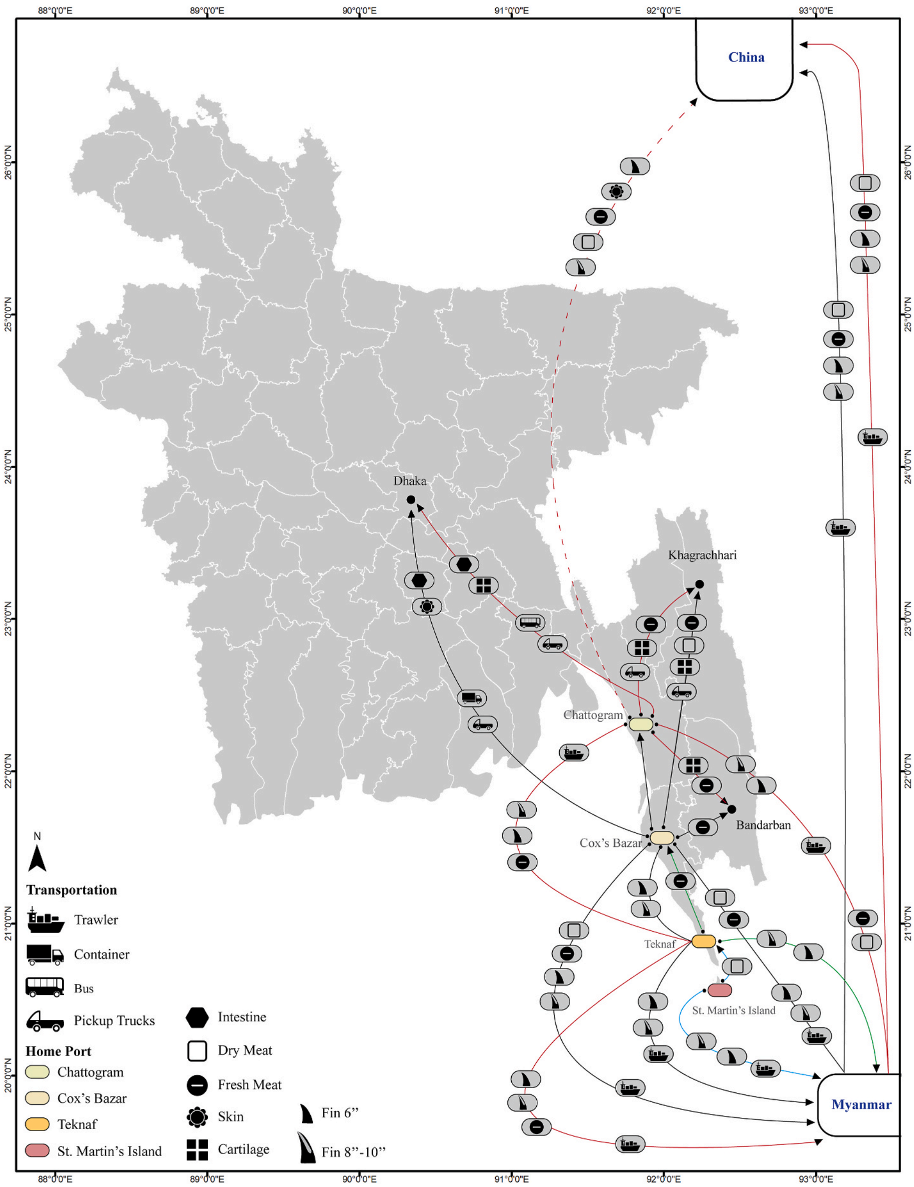


Fig. 6. Trade map showing the possible trade routes of rhino rays products as per the domestic and international market.

pressure from the fin trade has increased on other rhino rays, especially *Glaucostegus* spp., *resulting* in increasing the risk of local extirpation for these species. Where the continuing livelihoods generating from these fisheries are essential, this conflicts with the conservation of these species. This study elaborates on the fishing and trade of rhino rays in Bangladesh, filling the conspicuous data gap hindering timely conservation actions. We also propose several immediate actions which are essential to halt the stock collapse.

4.1. Current status of rhino rays in Bangladesh

Fishers' ecological knowledge is vital for understanding the historical status of fisheries, especially in a data-poor region (Frezza and Clem, 2015; Begum et al., 2020). Fishers' rhino ray knowledge was particularly impressive in Bangladesh compared to other elasmobranch fisheries (e.g. *Mobula* rays) (Haque pers. obs.). For example, all fishers could differentiate amongst wedgefishes (Rhinidae), giant guitarfishes (Glaucostegidae), guitarfishes (Rhinobatidae) and sawfishes (Pristidae). Although species-level identification was low for smaller species, they could quickly identify and differentiate between *Rhynchobatus* spp., *Glaucostegus* spp. *and Rhina ancylostoma*. Identification capacity for giant guitarfish and wedgefish were high, whereas, for smaller guitarfish, it was low. The most commonly identified specimen to the species level was *Glaucostegus* granulatus due to a pointed snout and abundant availability. Hence, genus level and, to some extent, species-level understanding could have been recorded with confidence.

Most of the fishers could identify at least three-five different species and presented some ideas about their ecology and breeding in the inshore waters as a group. A total of nine species have been reported from Bangladesh so far (e.g. *G. granulatus, G. obtusus, G. typus, G. thouin, Rhina ancylostoma, Rhinobatos annandalei, Rhinobatos lionotus, Rhinobatos ranongensis, Rhynchobatus laevis*) so far (Hoq et al., 2011; Roy et al., 2015; Hoq and Haroon, 2014, Haque in review). The most frequently sighted species was *G. gralulatus*. This may be because the population of *G. gralulatus* in the Bay of Bengal is still viable and as they are easily identifiable for their long snout. This has been corroborated by landing data where the highest number of landing was recorded for this species during the study period (Haque unpubl. data.). According to the fishers ' perception, the number of other *Glaucostegus* spp., *Rhinobatos annandalei* and *Rhina ancylostoma* were comparatively low. This information was

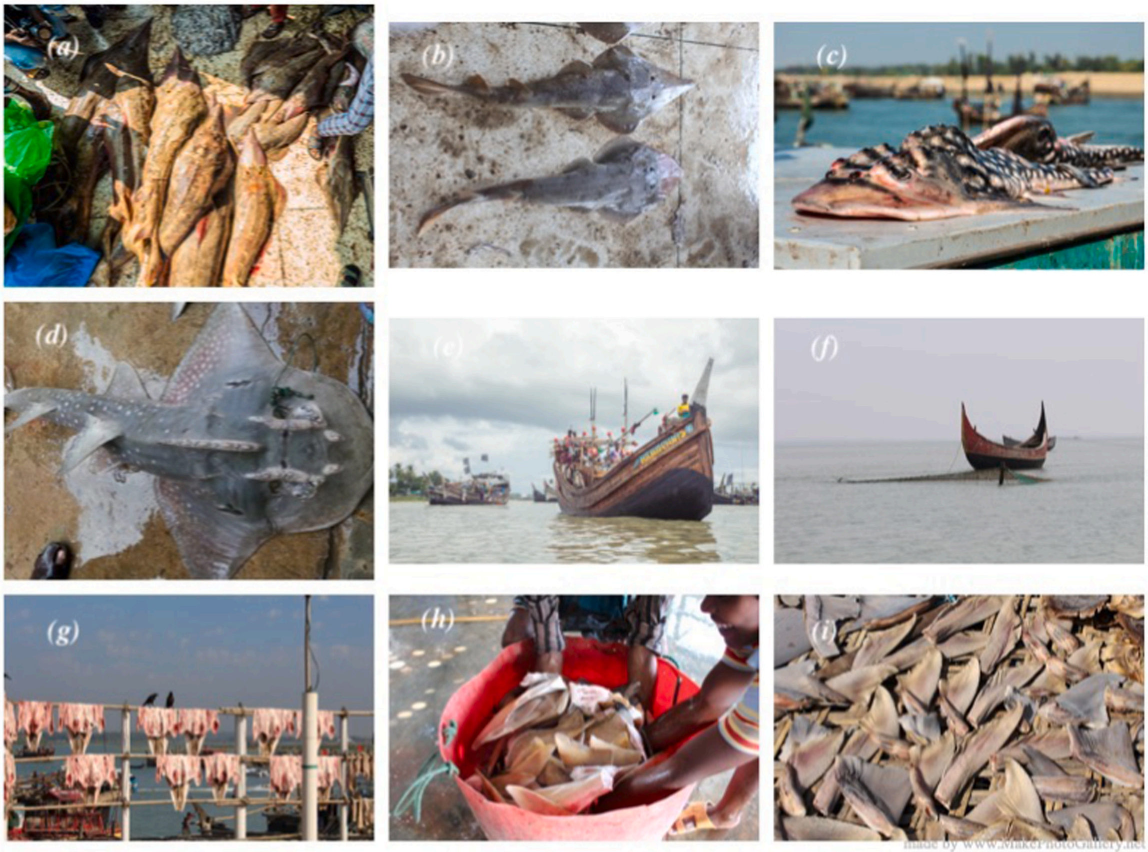


Fig. 7. (a–d) Landed *Glaucostegus granulatus, G. obtusus and Rhina ancylostoma;(e)* Large and (f) small boats in the coastal waters of Bangladesh; (g–i) different products at processing centres (skin and fins).

Table 5
Reported buying and selling price of rhino ray goods, trade and use.

Product	Buying price/kg (US$)	Selling price/ kg (US$)	Local or Exported	Uses
Fresh meat	0.59–2.37	2.13–14.19	L	Food (n = 24), Medicine (n = 6)
Dried meat	1.42	1.18–4.73	L, E	Don't Know (n = 22), Food (n = 8)
Skin	1.42	2.37–8.28	E	Don't Know (n = 4), Jewellery (n = 3), Shoe (n = 1)
Fin 6"	1.42	4.73–18.92	L, E	Food (n = 29)
Fin 8–10"	–	8.28–23.65	L, E	Food (n = 29)
Intestine	–	0.35–0.59	L, E	Don't Know (n = 7), Oil & Soap (n = 3), Liver Oil (n = 2), Soup (n = 2)
Cartilage	1.42	1.06–3.55	L, E	17 Don't Know, 7 Jewellery

also corroborated by landing data whereas less than 20 individuals were recorded for most of these species during the study period (except for *Glaucostegus obtusus*).

The local knowledge of fishers confirms a substantial decline in the catch of these species, especially *Rhynchobatus* spp. over the past decade. None of them caught a single individual between 2017 and 18. Furthermore, there were no sightings of the species in the last five years by these fishers. A fisher with 25 years of experience recalled: "*Even eight to nine years ago during the fishing season, there used to be regular landings of Fullaissha, at least two to three every day. However, I have not seen or caught one since 2009.*" This was echoed by landing site workers in Cox's Bazar involved in elasmobranch trade and transport who mentioned not having encountered them since 2008–2009. One shark trader with 30 years of experience from Cox's Bazar mentioned trading hundreds of "*Fullaissha*"- *Rhynchobatus* spp., between 2000 and 2005. However, in recent years he had not seen even one. Interestingly he informed that these species are prevalent in Oman and Saudi Arabia. It may be the case in light of the substantial decline in the Bay of Bengal (Bangladesh Region), the international demand from buyers has shifted to the Middle East.

According to national experts, *Rhynchobatus* spp. was last seen in 2012 (pers. comm. Jakia Hasan, Scientific Officer, Bangladesh Fisheries Research Institute, Cox's Bazar, Bangladesh 20 May 2020). Researching elasmobranchs since 2017, the Wildlife Conservation Society is yet to record any specimens of *Rhynchobatus* spp. (pers. comm. G.M. Masum Billah Project Coordinator of Marine Mega-Fauna and Fisheries at Wildlife Conservation Society, 17 May 2020).

Although much is not known about the resilience of these species against fisheries pressure in this geographic context, the relative population decline may have occurred due to their less rebound capacity. Their prolonged gestation period and very low reproductive potential make them more susceptible to bycatch, as well as opportunistic and targeted fisheries. Although several species have shown higher population productivity (e.g. *Rhynchobatus australiae*, *G. typus*, and *G. cemiculus*), *many* other sharks and rays, however, population will not be bouncing back if proper management is not in place (D'Alberto et al., 2019). The rate at which these rays are being depleted exceeds the population recovery time compared to any other elasmobranchs taxa, indicating that local extinction of such exotic species is common and rapid even with low levels of artisanal fisheries (i.e. mortality rate > birth rate).

In the absence of reliable historical data, these results could not be compared to discuss the change in composition or abundance. However, the landing was documented for three species between 2006 and 2013 (Roy et al., 2015), where *R. annandalei* and *R. ancylostoma, Glaucostegus* spp. *and Rhynchobatus* spp. were regularly landed (Roy et al., 2015; Zafaria et al., 2018). This reflected in historical overfishing. For instance, in 2011-12, 27.16 tonnes for *G. typus* was landed, and now the number has gone down tremendously. This is also the case for *Rhynchobatus* spp. which has been now replaced by *Glaucostegus* spp., both in catch and trade. Although landing data is not a suitable parameter for abundance at sea (Kyne et al., 2020), it can be used as a proxy to understand population trends and status. The total annual catch and catchability with different gear demonstrate knowledge of a very high perceived fishing pressure and declining species populations. Bangladeshi fishers' perception of a substantial decline in rhino rays is consistent with the global population of the rhino rays; wedgefish, and giant guitarfish, declining by between 81 and 99% and 87% in eastern India (Kyne et al., 2020). In fact, substantial numbers of fishes are trapped through trawling and bycatch, even if they are not targeted. The young individuals get caught in the nets, which inhibit their further growth and breeding, declining the population as a whole (Dulvy and Polunin, 2004). Given that pregnant and juveniles specimens were caught historically, this might have an irreversible impact on these populations in the Bay of Bengal even before it was noticed.

4.2. Causes of rhino ray population declines

Globally rhino rays are the most threatened group of marine fauna (Moore, 2017; Kyne et al., 2020). Unsustainable fisheries and international fin trade have fuelled population decline. Indo-West Pacific (Iran to Indonesia) has been reported as the centre of global rhino ray population declines (Kyne et al., 2020), with highly depleted stocks and localised extirpations reports (Dulvy et al., 2016; Jabado, 2018; Moore, 2017; Tous et al., 1998). It is likely that high rates of exploitation and the growing global trade have resulted in the declines, with wedgefish and guitarfish considered as threatened as sawfish (Haque et al., 2018; Jabado, 2018; Moore, 2017; Kyne et al., 2020). Given that rhino ray populations have low recovery rates (rmax; D'Alberto et al., 2019) and a high extinction rate (Kyne et al., 2020), this is alarming.

Fishers catch an average of at least 27 rhino rays annually, irrespective of gear in Bangladesh. Given that there are ~67669 artisanal boats operating in the coastal areas of Bangladesh (DoF, 2016), this catch rate translates to extremely high total number of rhino rays. Bangladesh fishing effort (kilowatt-hour) increased 1387 times between the 1950s and 2014 (Ullah et al., 2014) and has likely played a vital role in the decline of rhino ray populations over time. The retention of the by-caught species is driven by existing trade globally (Barrowclift et al., 2017; Diop and Dossa, 2011; IOTC, 2005; Jabado, 2018; Lteif, 2015; Moore, 2017; Newell, 2016; Seisay, 2005). Several thousand kilograms of rhino ray products were exported from Bangladesh through a port not monitored by the national customs authority. The exports were valued at USD 250,494 from just one of many processing centres in the south-east region between 2012 and 2014 (Haque et al., 2018). Hence, immediate, more effective management and monitoring is crucial.

Rhino rays have contributed a source of marine protein for coastal communities since the Bronze Age (Uerpmann and Uerpmann, 2005) and continue to be essential for local fisheries and communities. Moreover, rhino ray products have become highly valued in local and international markets, especially in Asia (Moore, 2017; Kyne et al., 2020; Jabado, 2018). The most valued product is the fins sold at a very high price in the international fin markets. Several other Asian countries are involved in the fin trade, including; Sri Lanka, India, Bangladesh, Indonesia, Malaysia, Maldives, Myanmar, and Thailand, with China the dominant importer and exporter (Clarke et al., 2006; Jabado et al., 2015; Dent and Clarke, 2015; Steinke et al., 2017; Spaet and Berumen, 2015; Cardeñosa et al., 2017; Haque et al., 2018, 2019; Fischer et al., 2012). In Bangladesh, highly desirable elasmobranch products, including those of rhino rays, have been traded after targeted fishing or by-catch for more than four decades. In contrast to other countries (Harry et al., 2011; White et al., 2013), in Bangladesh, almost every part of the rhino ray can be sold, not just their fins, making them a precious commodity. Bangladesh exports fresh meat, dried meat, fins, intestines, skin, fin and bones to China and Hong Kong via Myanmar maritime borders and local tribal markets (Haque et al., 2018). Most of the products from throughout the coasts of Bangladesh reach the south-eastern region and the traders herein for further export towards Myanmar. This route is non-custom (without any customs check); hence monitoring is absent. It is cardinal to enhance monitoring in this port and routes.

4.3. Sustainable fisheries and habitat management

Despite their threatened status (IUCN), there is no established system to monitor rhino rays catch and trade in Bangladesh (Haque et al., 2018, 2019). Effective fisheries monitoring and management are lacking in Bangladesh for several reasons; the absence of holistic national legislation, the impaired capacity of the authoritative bodies to implement management strategies, a lack of conservation education and awareness amongst fishers and traders, and few alternative livelihood options, which leads to poor compliance. For example, the implementation of CITES mandates which could safeguard the threatened species through controlled trade is also low.

Population declines and disproportionate catch of juveniles indicates ongoing unsustainable rhino ray fisheries (Crowder and Murawski, 1998; Diamond et al., 1999; Najmudeen and Sathiadhas, 2008). In the absence of fishing mortality and fishing effort data, management decision making is difficult. In this study, fisheries exploiting the rhino ray population has been characterized to inform improved conservation decisions.

The solution has to be within a sustainable fisheries model (Jabado et al., 2015). A logical first step to guide and prioritize actions for these species is a global conservation planning exercise. To conserve rhino ray populations, national, regional, and international measures are required in species protection, spatial management, by-catch mitigation, harvest and international trade management measures. Effective measures are required to be enforced on training sessions and capacity building by Government authority and concerned conservation organizations. Catch and critical habitat monitoring, especially in artisanal fisheries, is needed to help understand local population trends and inform management. The local fishing community needs to be involved, and fishermen's knowledge must be used to develop and implement conservation strategies. Awareness programs and training among them are necessary to be conducted.

Fishers showed some knowledge about sustainable management. This was evident by the array of solutions proposed by the fishers to mitigate overexploitation, for example, ban trawling, a fishing ban in the breeding season, awareness building, live release, banning destructive nets. Furthermore, these recommendations were in line with fisheries management recommendations given in Kyne et al. (2020); Jabado et al. (2018); Dulvy et al. (2014). These can be positively used for inclusive conservation management actions in the future with better chances of success as proposed by the fishers (Roe and Booker, 2019). In the absence of species-specific historic and time-series data (Kyne et al., 2020), LEK (local ecological knowledge) (Gilchrist et al., 2005) of fishers can prove to be tremendously helpful in prioritizing species-specific assessments and conservation actions.

In Bangladesh, the south-west and central region, the warm tropical waters and shallow soft-bottom habitats are important for rhino rays (Jabado, 2018; Moore, 2017). On one occasion, a live *G. granulatus* was observed to be caught near shore (depth 9–9.5m) from Kuakata (south-central region) using a specialized net locally called khuta jal (bamboo sticks are inserted at the sea bottom, and the net is deployed touching the bottom layer of the water column). This corroborated the confidence level about the fishers' knowledge on habitats for rhino rays mapped in this study.

This is evident from the research overview that; inshore coastal waters in the south-central region could be a potential critical habitat for rhino rays in Bangladesh. The fishing grounds for targeted rhino rays catch has been identified to drive more focused conservation actions. In light of this research, this information and map can help policymakers strategize species-specific habitat conservation measures.

To promote sustainable rhino ray fishery practices (Fig. 8) that will help stabilise population declines, we propose the following four steps be rapidly implemented in coastal regions of Bangladesh. They are **1.** enabling fishers to select gears in the nearshore habitats of rhino rays, ban the use of bamboo-set-bottom nets in the south-central region. Selective use of small mesh gill nets, set-bag nets and long lines are essential. **2.** Species-specific catch quotas based on biological sustainability (if possible, should not be done if proper monitoring cannot be ensured). No *Rhyncobatos* spp. should be caught and if caught needs to be released alive, whereas there can be a sustainable quota for more resilient rhino ray species. **3.** Size selection. Juveniles, year-of-pups and pregnant rays should be released (post-release mortality needs to be understood and research incorporating such a measure). And finally, **4.** Ban fishing in the breeding season, especially in nearshore soft-bottom areas. Further taxa-specific research is needed to understand if size selection in a catch for species with greater potential to support sustainable fisheries can be an option or not for these slow-growing elasmobranchs.

Furthermore, ensuring market efficiency and an equitable share of profits amongst the fishers from sustainable marine stocks (e.g. Hilsa in Bangladesh) may offset pressures on other species. To increase compliance, fishers need to be compensated through economic and basic amenities. To be willing to take potential management and conservation initiatives, proper direction, strong cooperation and communication between fisheries and biodiversity conservation agencies and a comprehensive approach to engaging various stakeholders, including fishers and traders, would be beneficial (Jabado and Spaet, 2017).

There have been advances in fisheries status and conservation researches that suggested measures embedded in sustainable fisheries management to conserve rhino rays (Kyne et al., 2020; Jabado, 2018; Moore, 2017). However, due to a lack of research and historical data, the unavailability of conservation actions have been subverted. The results in this study may substantially provide support in creating an evidence-based and holistic conservation model for not only Bangladesh but developing nations with similar fisheries contexts. These results also have significant regional implications on the Bay of Bengal rhino ray populations, contributing positively to conservation decision-making.

4.4. Fishers in conservation

In data-poor regions, fishers' knowledge can act as tremendous proxies for scientific information (Jabado et al., 2015; Bonfil et al., 2018; Liao et al., 2019; Patankar, 2019; Braulik et al., 2020). Perceived knowledge from fishers can provide valuable insights into the impacts of fishing communities on the marine ecosystem (Jabado et al., 2014). Age, education, years of experience, income, and occupation are critical parameters that helped this study identify potential target groups for conservation education programs. This can help build environmentally responsible and informed fishing communities (Bodin et al., 2017).

Most of the fishers in the interview population had around 20 years of experience and knowledge, both from their involvement and undoubtedly from being related to traditional fishing families. A wide range of information was sourced from the respondent interviews, confirming a targeted rhino ray fishery in the Bay of Bengal. While the lack of historical data precludes comparisons with the past status of the fishery, it helped to interpret the complex social, economic, and cultural aspects of this fishery as relating to the lives of these fishers to some extent.

The artisanal fishers who catch and retain rhino rays are some of the

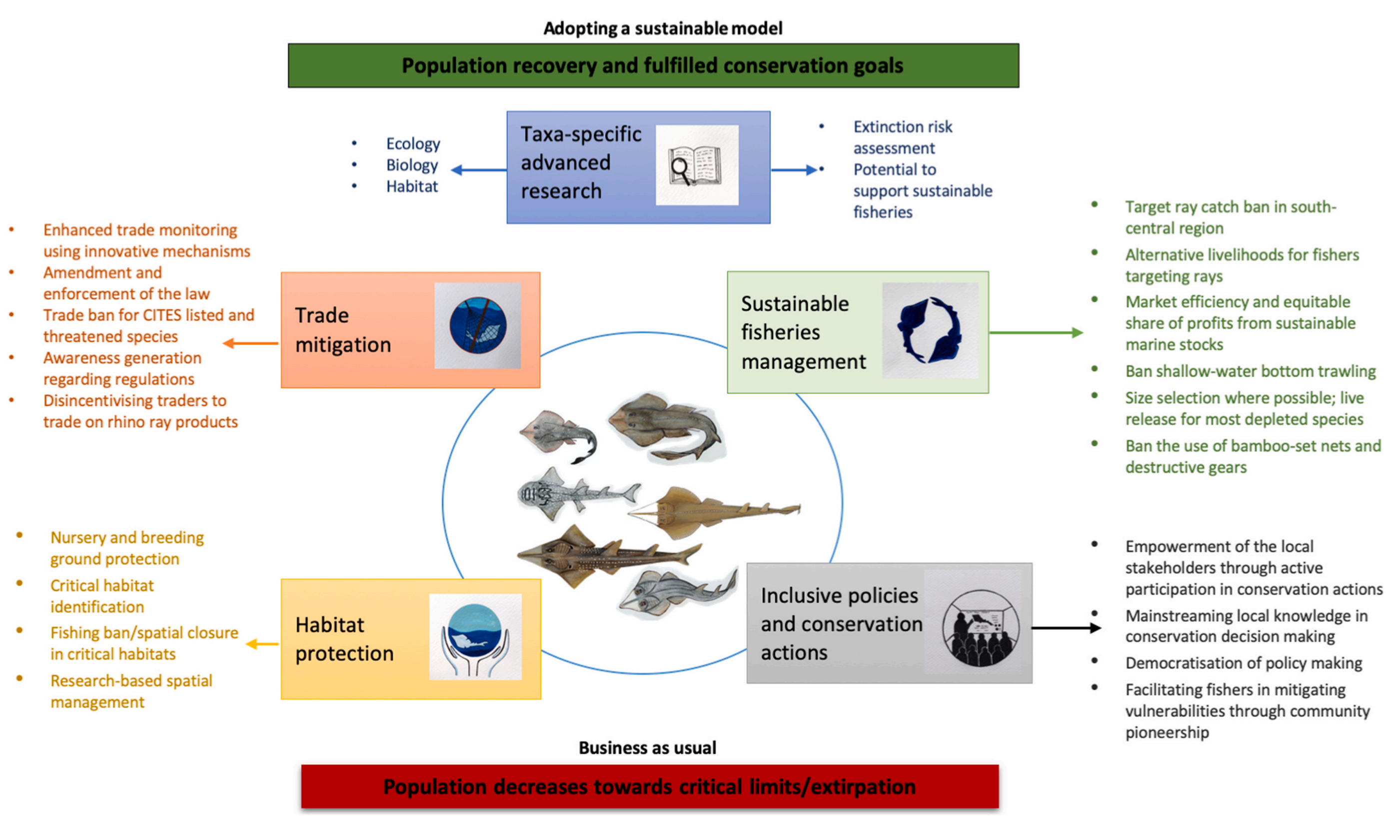


Fig. 8. A holistic conservation model for rhino ray fisheries management in Bangladesh with special emphasis on evidences from science and local pioneership.

most marginalised people with less income – hence stakeholder specific understanding will guide which group are most vulnerable and needs support. As a whole, these species are a component of a much-complicated socio-economic complex (Moore, 2017). Incorporating social aspects is essential in designing rhino ray conservation strategies for Bangladesh as any regulations limiting catch or trade of rhino ray products would likely impact local fishing communities and traders significantly.

Conservation decision making is complex for resource-poor communities without alternatives offered to them (Roe and Booker, 2019). The study showed that marginalised and financially deprived fishers in Bangladesh rely on the extra income from the rhino ray trade and subsistence. The education level is low, and the unequal distribution of profit amongst the boat owners and fishers makes it substantially difficult for them to abide by laws. Conservation compliance is challenged by limited knowledge about existing laws and primary stakeholders not being consulted on laws that directly affect their livelihoods. Successful marine conservation in developing countries requires local pioneer-ship (Jabado et al., 2013); without mitigating these problems, it will be increasingly difficult to implement conservation policies and management actions in this region.

5. Conclusion

The current study is the first focused research that provides a crucial and in-depth understanding of the inclusive conservation needs of several threatened rhinopristiformes rays in a critical coastal and marine ecosystem. We take a socio-ecological approach that extends our understanding further on the highly data-poor rhino ray fisheries and trade in the Bay of Bengal, Bangladesh. The high pressure from target and by-catch fisheries impacted these populations tremendously, leading to a near disappearance of *Rhynchobatus* spp. and number and size decrease for others. High-quality fin and meat from these species contribute to a large share of international elasmobranch trade violating national law and CITES mandates. Whereas precise knowledge on specific rhino ray regulations is unclear amongst fishers and traders, their specific knowledge of species diversity and its importance for the ocean was notable. Although these species are highly threatened, many fishers depend on the income generated from these fisheries, leading to non-compliance towards regulation. As a result, these fishers need further assistance for mitigating their vulnerabilities and for positive conservation decision making. These are valuable insights that can be effectively used for behavioural change amongst these primary stakeholders for adopting a sustainable model for rhino ray conservation in this developing region. We recommend actions such as including fishers' perceptions and evidence-based scientific management for more effective implementation of actions and the legislation based on insights gathered from this study. The results could also be used to amend the national legislation to incorporate the most exploited and threatened species and provide the highest protection. Furthermore, it is cardinal to initiate more taxa specific research on ecology, breeding and biology, critical habitats, by-catch mitigation strategies, trade control and monitoring mechanisms regarding rhino rays in this region.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ocecoaman.2021.105690.

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