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Fishing and trade of devil rays (*Mobula* spp.) in the Bay of Bengal, Bangladesh: Insights from fishers' knowledge

Alifa Bintha Haque[1,2] | **Nidhi Gloria D'Costa**[3] | **Mahi Washim**[3] | **Amit Robert Baroi**[3] | **Nazia Hossain**[1] | **Mashrur Hafiz**[3] | **Sumaiya Rahman**[3] | **Karabi Farhana Biswas**[3]

[1]Department of Zoology, University of Dhaka, Dhaka, Bangladesh

[2]Department of Zoology, University of Oxford, Oxford, UK

[3]Department of Environmental Science and Management, North South University, Dhaka, Bangladesh

Correspondence
Alifa Bintha Haque, Department of Zoology, University of Dhaka, Dhaka, Bangladesh.
Email: alifa.haque@du.ac.bd; alifa.haque@zoo.ox.ac.uk

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Abstract

1. Devil rays (*Mobula* spp.) are globally threatened cartilaginous fishes that have attracted global conservation concern owing to their high extinction risk and lack of protection in many countries. Limited resources and data on threatened marine species, including devil rays, impede conservation actions, particularly in developing countries, many of which have high biodiversity.
2. Devil ray catch is a component of artisanal fisheries in Bangladesh, but data on their fisheries and trade are limited. To characterize devil ray fishing practices, fishers' perception and trade, 230 fishers and traders were interviewed between 4 June 2018 and 22 June 2019, in four areas of south-east Bangladesh. Catch data were also opportunistically collected at landing sites.
3. Six devil ray species were documented, caught in an array of gill nets, set-bag nets and longlines. All interviewed fishers reported life-long devil ray bycatch in some numbers, and also noted a decline in catch over the last decade. Bottom trawling, increased bycatch levels, increased demand for devil ray products and, in some cases, ecosystem changes were identified by fishers as threats to devil ray populations.
4. Unregulated and undocumented trade and retained bycatch, especially by gill nets and set-bag nets, are fuelled by local consumption of devil ray meat and international trade in meat and gill rakers. Compliance with international trade control treaties for all *Mobula* spp. or the Bangladeshi law protecting *Mobula mobular* was low, with the majority of fishers (87%, n = 174) unaware of their existence.
5. To manage devil ray fisheries, and prevent possible population declines, we propose a combination of legally enforced gear modifications, and catch and trade control through community-owned implementation strategies. Additionally, we propose the simultaneous implementation of inclusive, community-based awareness and stewardship projects in conjunction with a coast-wide ray monitoring programme. Finally, we emphasize that more research and action rooted in a sustainable fishery model is urgently needed to protect Bangladeshi devil ray populations.

Alifa Bintha Haque and Nidhi Gloria D'Costa have equal contribution to the manuscript.

KEYWORDS
biodiversity, elasmobranchs, endangered species, sustainability, trade, trawling

1 | INTRODUCTION

Devil rays (order Myliobatiformes, family Mobulidae, genus *Mobula*) are the largest rays (Stevens, 2011) and amongst the most charismatic groups of cartilaginous fishes (Ward-Paige, Davis & Worm, 2013; White et al., 2017), inhabiting tropical, subtropical and temperate waters (Last & Stevens, 2009; Clark, 2010; Marshall & Bennett, 2010; Canese et al., 2011; Stewart et al., 2018; Lassauce et al., 2020). Globally, 11 devil ray species have previously been recognized; however, a recent phylogenetic study recategorized the genera *Manta* and *Mobula* into the single genus *Mobula* (White et al., 2017). Similarly, previously distinct species were found to be synonymous, including *Mobula japanica* and *M. mobular*, which are now both *M. mobular* (White et al., 2017; Notarbartolo di Sciara, Stevens & Fernando, 2020). Although *M. eregoodoo* has been synonymized with *M. kuhlii* (White et al., 2017), Notarbartolo di Sciara et al. (2020); Notarbartolo di Sciara, Stevens & Fernando (2020) concluded that they are different species. Therefore, there are nine species of devil rays according to the current knowledge (which is adopted throughout this paper). The majority of devil rays are categorized as Endangered by the IUCN Red list, and all fall under the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) Appendix II. Conservation actions and trade control on these species should therefore be a priority, but a lack of data, limited national protection and demand in international markets are hampering such efforts.

Devil rays are susceptible to both direct and indirect fishing effects, including targeted fishing, bycatch, boat strike and ghost fishing (Canese et al., 2011; Couturier et al., 2012; Pardo et al., 2016). Such fishing threats and their life history strategy of high mobility (trans-boundary stocks), slow reproductive rates (*k*-selected) and low rate of population increase, have led to a global need for conservation (Couturier et al., 2012; Dulvy et al., 2014; Croll et al., 2016; Alfaro-Cordova et al., 2017; Lawson et al., 2017; Stewart et al., 2018). These gentle giants are facing enormous fishing pressures from five countries with the largest targeted devil ray fisheries: Sri Lanka, India, Indonesia, Peru and China (over 95% of catch; Heinrichs et al., 2011).

Devil rays are particularly targeted for their high-priced gill rakers, used to make Asian medicinal soup and for meat consumption (Rajapackiam, Mohan & Rudramurthy, 2007; Fernando & Stevens, 2011; Ward-Paige, Davis & Worm, 2013; Acebes & Tull, 2016; Croll et al., 2016; O'Malley et al., 2016; Venables et al., 2016; Hosegood et al., 2018; Stewart et al., 2018; Mazzoldi et al., 2019). Devil ray products, both fresh and dry, are valuable (Fernando & Stevens, 2011; Croll et al., 2016), with the average price of a dry devil ray gill raker being US$ 95.63–228/kg in a Sri Lankan fish market (Fernando & Stevens, 2011; Croll et al., 2016). Owing to their value, a large number of devil rays are landed, especially where gill nets are used, such as in regions including Indonesia (White, Giles & Potter, 2006; White & Dharmadi, 2007), the Gulf of California (Bizzarro et al., 2009), India (Rajapackiam et al., 2007), western Africa (Essumang, 2010) and eastern Africa. As a result, dramatic declines in devil ray catch and landing counts have occurred in the Philippines, Indonesia, Mexico, India and Mozambique (Couturier et al., 2012).

The Bay of Bengal is one of the most ecologically active and unique ecosystems in the northern Indian Ocean (Somayajulu, Murty & Sarma, 2003; Smith et al., 2008; Amaral et al., 2017). Within the devil ray distribution range, the Bay of Bengal offers high nutrient content, high biological productivity and oceanographic mixing, owing to upwelling, providing an ideal habitat for the predominantly pelagic planktivorous filter feeders such as devil rays (Somayajulu, Murty & Sarma, 2003; Smith et al., 2008; Adnet et al., 2012; Amaral et al., 2017). Two devil ray species have been reported within the Bangladesh region of the Bay, namely *M. mobular* (including former *M. diabolus* and *M. japanica*) and *M. kuhlii* (Hoq, Haroon, & Hussain, 2011; Haque, Biswas & Latifa, 2018; Haque, Das & Biswas, 2019); *M. hypostoma* was also reported (presumably misidentified as this species only occurs in the Atlantic Ocean). Of these ray species, only *M. mobular* is protected in Bangladesh – under Schedule II of the Wildlife (Conservation and Security) Act, 2012 that protects 29 elasmobranch species under two schedules. The lack of protection may be, in part, due to a conspicuous data gap that has prevailed in Bangladesh, despite the long-standing practice of elasmobranch fishing and trading, including devil rays (Hoq, Haroon & Hussain, 2011; Roy, 2011; Roy et al., 2014; Roy et al., 2015a; Haque et al., 2018).

Bangladesh, located in the Indo-Malayan ecozone (Das & van Dijk, 2013), borders approximately 710 km of the Bay of Bengal, with coastal areas varying in depth range, from 0–10 m (24,000 km^2) to 0–40 m (37,000 km^2) and 40–100 m (20,700 km^2) (Khan, Alamgir & Sada, 1997; DoF, 2013) within the Exclusive Economic Zone. While only 242 registered industrial-scale fishing vessels are allowed to fish in the Exclusive Economic Zone (MoFA, 2014), in 2016 and 2017, an estimated 67,669 artisanal fishing vessels operated there, including an approximately even split between motorized and un-motorized boats (Islam et al., 2017; Shamsuzzaman et al., 2017). It is estimated that such an artisanal fishing fleet deployed 18,8707 sets of fishing gear (DoF, 2016), including drift gill nets, set-bag nets, purse seines, long-lines and trammel nets (DoF, 2014). Bangladesh's high fishing pressure dramatically increased in overall effort from 420 to 58,2670 kW between 1950 and 2014 (Ullah et al., 2014) and four-fold just between 2000 and 2014 (Pauly, Zeller & Palomares, 2020) with a high level of illegal, unreported and unregulated fishing (Shamsuzzaman et al., 2017).

Historical unmonitored shark and ray catch by Bangladesh's fishermen, and a failure to document shark and ray product trade

(DoF, 2017; Begum et al., 2020), led to an assumption that Bangladesh had no targeted elasmobranch fishery (Hoq, Haroon & Hussain, 2011). Targeted ray fisheries appear prevalent, however, with increasing global demand for ray products (Couturier et al., 2012; Dulvy et al., 2014; Croll et al., 2016; O'Malley et al., 2016; Stewart et al., 2018) and readily available local and international markets. Almost 3,974 metric tons of shark, skate and rays, including protected devil rays, were landed in Bangladesh during 2017–2018 (DoF, 2017; Begum et al., 2020), then sold to shark traders or local consumers. However, this is an underestimation by the Department of Fisheries as a reconstruction study showed that 1,247 t were landed from industrial fishing and at least 6,234 t from artisanal fishing alone (Ullah et al., 2014). The largest landing sites are on the south-eastern coast of Bangladesh (Ullah et al., 2014), close to elasmobranch trade hubs (Haque et al., 2018). Yet species-specific documentation of landings and trading (Haque et al., 2018), along with the biology and ecology of Bangladesh's devil rays, remain to be documented, hindering effective fisheries management and conservation actions (Stewart et al., 2018; McCallister et al., 2020).

Although the concepts of elasmobranch research and conservation are relatively new in this region (Haldar, 2010; Hussain & Hoq, 2010), fishers hold decades of local knowledge, which, in the absence of historical data, can serve as a tremendous source of long-term trends and patterns. In many cases, declines and regional extinctions of marine species often go undocumented, but can be inferred from local knowledge (Dulvy & Polunin, 2004; Jabado et al., 2015; Abudaya et al., 2018; Mason et al., 2020). Additionally, fishers are key stakeholders and can provide socio-ecological perception and knowledge on natural resource conservation needs (McNeill, Clifton & Harvey, 2018), existing legislation and trade, which are all essential for developing effective conservation strategies (Jabado et al., 2015; Liao, Huang & Lu, 2019; Patankar, 2019; Mason et al., 2020; Ward-Paige, Brunnschweiler & Sykes, 2020).

This study addresses the paucity of data on Bangladeshi devil ray fisheries and trade by utilizing fishers' perceptions and knowledge acquired through stakeholder interviews with the aim to (1) provide estimates of fishing pressure, (2) evaluate fishers' knowledge on these species, (3) assess the local and international demand driving the existing trade and trade dynamics and (4) suggest evidence-based, localized conservation and management strategies.

2 | METHODS

2.1 | Study area

The study was conducted at the four largest elasmobranch landing sites (including processing and trading centres), on the coast of the south-eastern region of Bangladesh. These centres included Cox's Bazar (21.58° N 92.02° E), with the fishing villages Harirchhara, Mudirchhara, Nuniarchhara and Tuitta para, Chattogram (Kattali port; 22°22′0″ N 91°48′0″ E), Saint Martin's Island (Golachipa port and Purbo para; 20°36′47″ N 92°19′36″ E) and Teknaf (20.8667° N 92.3000° E), in areas called Kurer Mukh and Mundar Dheil (Figure 1).

2.2 | Semi-structured interview

A total of 230 interviews were conducted amongst fishers and traders between June 2018 and June 2019 (Table S1). All interviews occurred at fish markets, landing sites, shark processing sites and fishing villages (Figure 1).

2.2.1 | Interviewee classification

Two stakeholder groups were identified: (1) artisanal fishers, who exploit marine resources and sell fish; and (2) traders involved in the supply chain of devil ray product trading (e.g. buying, selling, exporting and distribution). Fishers were categorized according to their roles on the vessels: (i) captain; (ii) crew; (iii) technician; and (iv) boat owner. Traders were subdivided according to the mode of trade: (i) fish traders (buy, sell and distribute all kinds of marine fish); (ii) middlemen (negotiators who connect the buyer to the sellers of elasmobranchs); (iii) opportunistic traders (trade in devil ray when available, but also have other jobs); and (iv) shark businessmen (exclusive shark traders with the capacity for exporting products – the main actors in the supply chain of elasmobranchs including devil rays in Bangladesh) (Table S1).

2.2.2 | Interview

Separate questionnaires were developed for fishers (Table S2) and traders (Table S3), and initially piloted through two key-informant interviews. After the pilot session, questionnaires were revised and re-tested with an experienced fisher and a trader to evaluate the strength of the method and exclude any redundancies. The final fisher's questionnaire had 80 questions across 10 sections: (1) demographic information; (2) general fishing practices; (3) information on fishing gears; (4) types of boats; (5) the targeted species; (6) frequency of sightings and catch of devil ray species; (7) perceived population trend (increasing/decreasing) of devil ray catch; (8) perceived biological and catch information; (9) fishers' perception about the studied species and (10) income generated from selling the studied species. Section 6 involved showing a photo-booklet of devil rays to evaluate the precision of species identification (Table S2). The trader's questionnaire had five sections: (1) demographic information; (2) general trade information; (3) price of each product (e.g. fresh meat, dried meat, gill rakers, fin and skin); (4) processing and preservation prices of fresh and dried meat; and (5) supply chain structure (Table S3). Both questionnaires contained qualitative and quantitative questions that included open- and closed-ended questions, multiple choice and a few repeated questions to triangulate possible biased answers. Non-probability sampling such as convenient, opportunistic

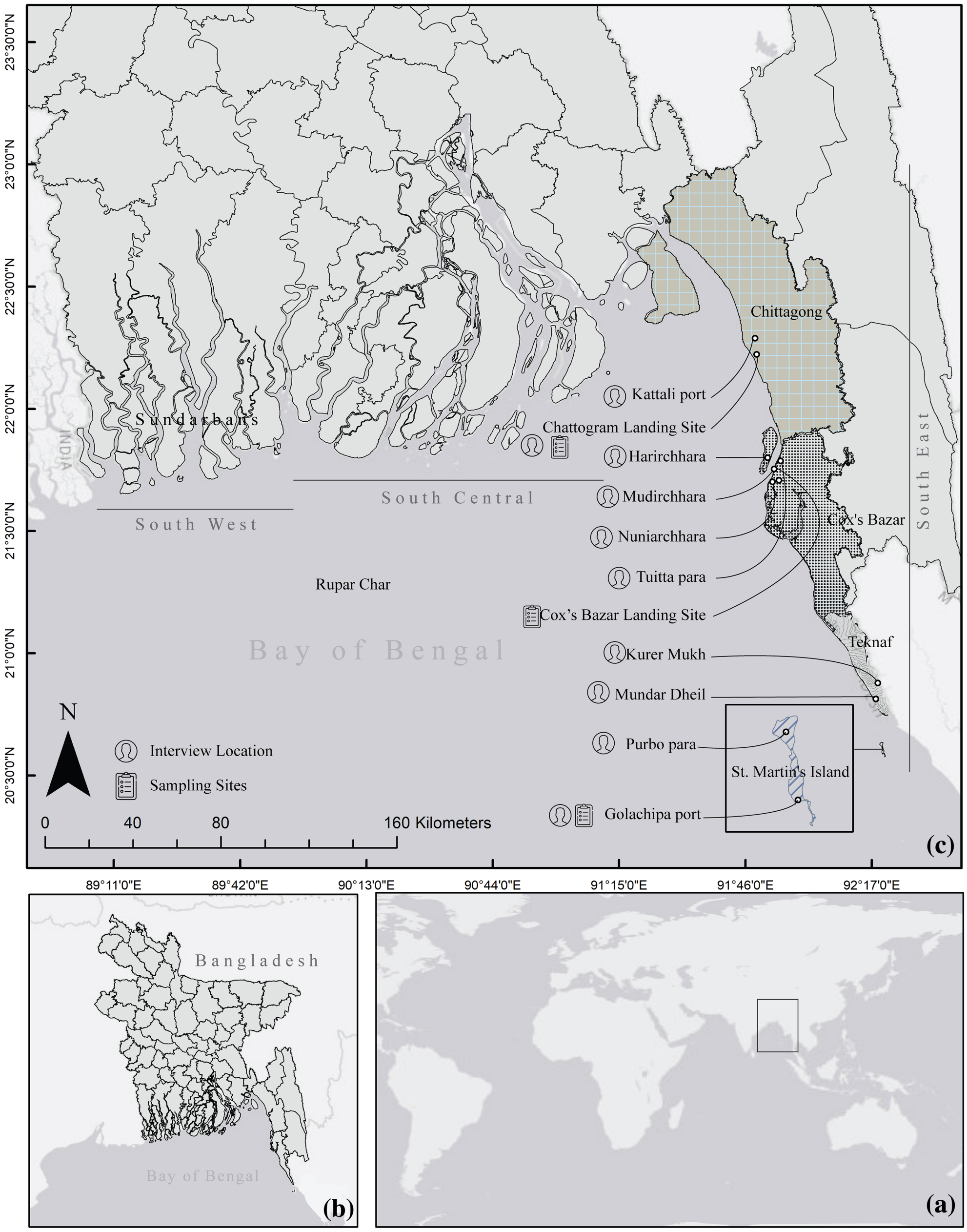

FIGURE 1 (a) Bay of Bengal within the Indian Ocean. (b) Bangladesh. (c) Map of the study area with the south-east coast of Bangladesh and the four study sites: Chattogram, Cox's Bazar, Teknaf and St. Martin's Island (shaded), interview survey and sampling sites

and snowball approaches were taken (Jabado et al., 2015; Liao, Huang & Lu, 2019; Patankar, 2019).

To conduct the interviews, the authors introduced themselves, explained the research and asked each interviewee for verbal consent to conduct the full interview. Each interview took between 45 and 90 min, and if the opportunity presented itself, conversations beyond the scope of the questionnaires were conducted. To encourage accurate answers to survey questions, and to attain reliable data, trust was built between interviewer and interviewees by spending time and discussing how the results would be used and shared (Moore et al., 2010; Jabado et al., 2015; Liao, Huang & Lu, 2019; Patankar, 2019). Where possible, survey results were corroborated with existing fisheries data, e.g. fisheries characterization from Ullah et al. (2014), Roy et al. (2007), Roy et al. (2014), Roy et al. (2015a), Islam et al. (2017) and Begum et al. (2020). Interviews were conducted in Bangla.

2.2.3 | Interview data analyses

Data on fishing practices were analysed according to boat type based on length (m), gear was classified according to types and stretched mesh size (cm) and perceived annual devil ray catch per boat calculated for each category. In response to low identification capacity for morphologically similar *Mobula* spp., 'sighting-at-sea and catch' data were categorized into two groups: (1) *Mobula birostris/alfredi* (easily identifiable by fishers by their larger size and presence of ventral spots/markings); and (2) all other species. Similarly, annual encounters for each species by the fishers were grouped into these same two categories and presented as a mean number of rays per fisher per boat. While this method could incorporate some bias, as juveniles of *Mobula birostris/alfredi* could have been counted within other species, results are presented on *Mobula* spp. as one group of rays.

Data obtained from open-ended questions on fisher's perception of devil rays, including perceived population trend, were grouped under broad themes, including (i) reasons perceived for decreasing trend (trawling, non-targeted catch, unselective gear use, etc.), (ii) reasons perceived for increasing trend (no profit hence not targeted and presence of enough nutrients in the habitats), and (iii) beneficial attributes (ecological benefits and socio-economic benefits). In order to incorporate all responses under these themes, where the same fisher gave multiple responses to the same question, these were treated as separate individual responses.

All results were translated from Bangla to English. Data analysis was conducted in 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.

2.2.4 | Reconstruction of trade route

A trade route for devil ray products within and outside Bangladesh was reconstructed from responses to the last section of the traders' questionnaire survey (Table S3) and insights from detailed conversations during key-informant interviews. Additional information gathered from both questionnaires and observational insights were included in this section to elaborate on the trade dynamics of devil rays in this region.

2.3 | Species sampling

Devil ray landing data were opportunistically collected to support and validate fishers' catch recorded in the interviews, and to create a preliminary species list of devil rays in Bangladesh. Only whole specimens and/or those with clear diagnostic characteristics were included, with identification based on Last et al. (2016) and regional experts. Sex was determined by the presence (male) or absence (female) of claspers, where possible.

3 | RESULTS

Six species of devil rays were documented from 97 specimens, including *Mobula eregoodoo*, *M. kuhlii*, *M. mobular*, *M. tarapacana*, *M. thurstoni* and *M. birostis*, with a few unidentified species (Table 1). The majority of landed specimens were caught using gill nets (58%) followed by trawl nets (*n* = 12, 23%) (this net was not represented in interview data), set-bag nets (*n* = 8, 14%) and longlines (*n* = 2, 5%).

3.1 | Demographics and income of interviewees

Of the 230 people interviewed, 87% were fishers (*n* = 200) and 13% were traders (*n* = 30). Interviewed fishers tended to be younger than traders, with 57% aged between 24 and 43 years, as compared with 67% of traders aged between 30 and 49 years. The proportion of fishers and traders without formal education was approximately 44% and 40%, respectively (Table S4). The average annual income of fishers varied between US$306 and US$5,594 (mean US$3,297 ± 3,116 SD) depending on their roles: boat owners had the highest primary annual earnings of US$1,275–23,760 (mean US$6,352 ± 6,571 SD), followed by captains (mean US$5,594 ± 6,464 SD), technicians (mean US $937 ± 371 SD) and crew (mean US$306 ± 80 SD) (Figure S1a). Approximately 25.5% of fishers (*n* = 51) (Figure S1b) had an opportunistic average annual secondary income of between US$154 and US $974 (mean US$394 ± 429 SD) from different sources (Figure S1b), including working as a (i) shrimp farmer, (ii) day labourer, (iii) retail business, (iv) crop cultivation, and (v) other businesses (e.g. salt cultivation, net business, chilli farmer and diesel business; Figure S1b). The average annual primary income for traders was US$1,146–4,680 (mean US$2,324 ± 1,303; Figure S1c) with opportunistic traders (43.3%) earning US$330–2,160 (mean US$1,146 ± 0.701 SD; Figure S1c). Over a third (*n* = 11, 37%; Figure S1d) of traders had average annual secondary incomes of US$1,440–3,240 (mean 2,151 ± 826 SD; Figure S1c) from various sources similar to those of fishers except for salt cultivation reported by one of the traders from Teknaf (Figure S1d).

TABLE 1 Morphological and biological data of landed *Mobula* spp.

Scientific name	Common name	Sampled specimen number	Sex ratio (M, F)	IUCN status	CITES
Mobula eregoodoo	Pygmy devil ray	4	3 ♂, 1U	Endangered (EN) (Rigby et al., 2020)	Appendix II
Mobula kuhlii	Shortfin devil ray	20	8♂, 12♀	Endangered (EN) (Rigby et al., 2020)	Appendix II
Mobula mobular	Giant devil ray	35	10 ♂, 24♀	Endangered (EN) (Marshall et al., 2019)	Appendix II
Mobula tarapacana	Chilean devil ray	10	4 ♂, 4♀, 2U	Endangered (EN) (Marshall et al., 2019)	Appendix II
Mobula thurstoni	Bentfin devil ray	16	6 ♂, 10♀	Endangered (EN) (Marshall et al., 2019)	Appendix II
Mobula birostis	Giant oceanic manta	4	-	Vulnerable (VU) (Marshall et al., 2019)	Appendix II

U, Unsexed.

3.2 | Vessels and gears

Three types of vessel were recorded: wooden motorized, wooden un-motorized (known locally as Darar boat) and asbestos boats. Of these, there were four large (>20 m, 75–120 hp engine), 45 medium (10–20 m, 20–78 hp engine) and 109 small (<10 m, 10–45 hp engine) wooden-motorized vessels, 17 wooden-unmotorized and 19 asbestos small boats (Table 2). Of the total 145 small boats, the majority were reported from Teknaf (*n* = 45) followed by St. Martin's Island (*n* = 38) (Figure 2a). These two areas reported only between one and four medium to large boats, whereas Cox's Bazar and Chattogram had 25 and 14 medium boats, respectively (Figure 2a). The majority of the large boats (*n* = 3, 75%) deployed set-bags and only one boat deployed gill nets (Figure 2b).

The majority of fishers used a range of gill nets (65%), followed by set-bag nets (28.5%), with individual hooks and longlines used the least, at 4% and 2.5%, respectively (Table 3). Gillnets ranged in length from 3.5 to 4,569 m and in height between 1.52 and 46 m, with mesh size between 5.08 and 22.8 cm. Gill nets were deployed for between 0.17 and 20 h. Set-bag nets were commonly used at all four sites, whereas individual hooks were only used in Cox's Bazar, with line length between 6.09 and 8 m and deployed at depths between 7.62 and 18.28 m for 0.16–0.5 h. Longlines were used in Cox's Bazar and St. Martin's Island only, comprising 2% (*n* = 4) and 0.5% (*n* = 1) of all fishing gear used across the study. Longlines ranged between 7.62 and 2,437 m in length and between 10.66 and 24.37 m in depth, with between 1,000 and 15,000 hooks. Longline deployment time ranged from 6 to 24 h (Table 3).

3.2.1 | General fishing practices

Fishers reported fishing almost every day during the fishing season (mean number of fishing days per month 21.8 ± 6.92 SD). Monthly

TABLE 2 Number of each fishing boat type, each gear used and at each home port, categorized by size

Boat classification by length			
	Large (>20 m)	Medium (10-20 m)	Small (<10 m)
Vessel characteristics			
Vessel length (m)	21.79–28.28 (23.39 ± 3.26)	10–19.58 (14.50 ± 2.33)	1.50–9.57 (5.44 ± 2.22)
Vessel storage capacity (kg)	16,000–20,000 (18,000 ± 2,309.40)	400–20,000(5,358.14 ± 4,221.39)	200–4,000 (1,786.10 ± 1,030.17)
Onboard engine power (hp)	75–120 (92.50 ± 21.76)	20–78 (54.43 ± 17.89)	10–45 (21.69 ± 5.68)
Distance (km)	20–600 (186 ± 250.87)	1.50–644 (99.99 ± 170.50)	0.05–550 (57.67 ± 80.33) (four fishers mentioned crossing more than 200 km)
Fishing depth (m)	12.18–60.92 (30.46 ± 21.68)	7.61–254.34 (91.04 + 67.96)	4.57–121.84 (42.98 ± 23.10)
Monthly fishing frequency (times/month)	2–4	2–4	2–60 (sometimes twice a day hence the maximum 60 times per month)
Monthly fishing frequency (days/month)	12–27	12–30	15–30
Vessel type			
Wooden – motorized	4	45	109
Wooden – unmotorized	—	—	17
Asbestos (motorized)	—	—	19
Gear used by each vessel			
Gill nets	1	25	100
Set-bags	3	12	41
Longlines	—	3	2
Individual hooks	—	5	2
Homeport			
Cox's Bazar	3	25	32
Chattogram	—	14	30
Teknaf	1	2	45
Saint Martin's	—	4	38
Catch			
Average annual catch of *Mobula* spp. (individual)	0–6 (3 ± 2.58)	0–200 (25.33 ± 45.20)	0–200 (33.11 ± 44.73)

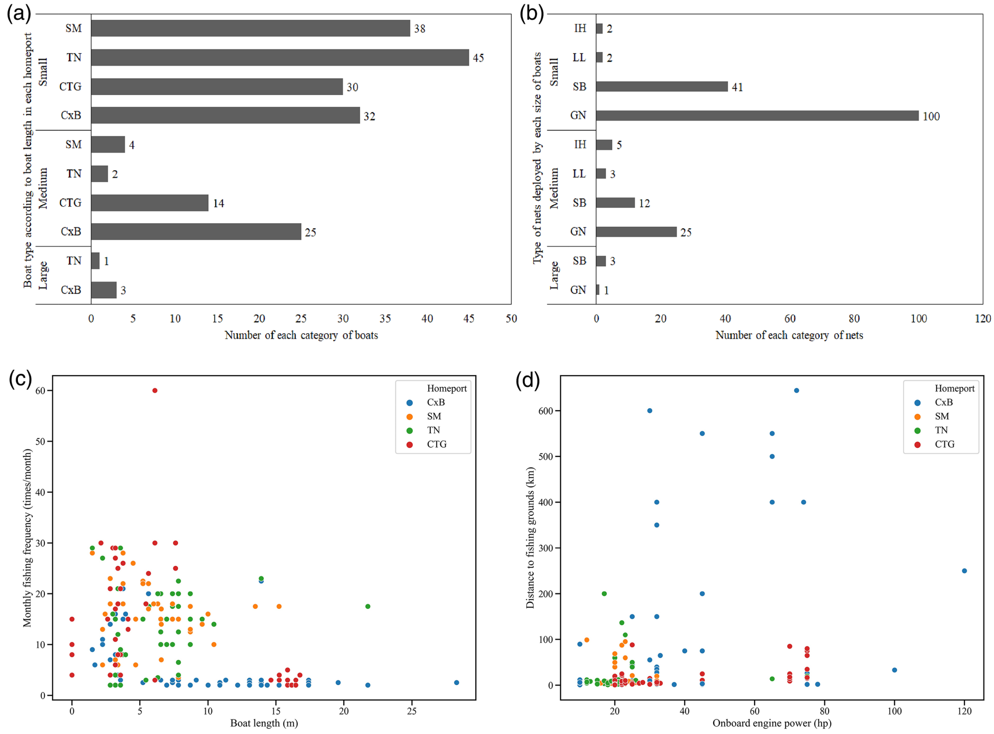

FIGURE 2 General fishing practice according to: (a) number of each category of boats according to home ports; (b) number and type of nets deployed by each size of boat; (c) monthly fishing frequency (times/month) according to boat length (m); (d) distance to fishing grounds (km) according to on-board engine power (hp) varying according to home port. AS, All seasons; M, monsoon; W, winter; WM, winter and monsoon; G, gill nets; LL, longlines; SB, set-bags; CTG, Chattogram; CxB, Cox's Bazar; SM, Saint Martin's; TN, Teknaf

TABLE 3 Type, number and size of fishing gear used at each home port

	Gill nets	Set-bags	Longlines	Individual hook
Number of sets of gear reported by each home port				
Cox's Bazar	32	18	4	8
Chattogram	35	13	—	—
Teknaf	36	12	—	—
Saint Martin's Island	27	14	1	-
Gear characteristics, range (mean ± SD)				
Mesh size (cm)	Small (*n* = 37)5.08–8.89 (6.42 ± 1.37)	Small (*n* = 16)5.08–8.89 (7.38 ± 1.16)	—	—
	Medium (*n* = 80)10.16–15.24 (11.41 ± 1.9)	Medium (*n* = 33)10.16–15.24 (11.08 ± 1.39)	—	—
	Large (*n* = 7)17.78–22.86 (20.68 ± 2.72)	Large (*n* = 3)17.78 (17.78 ± 0)	—	—
Gear length (m)	3.05–4,569 (424.03 ± 978.57)	3.05–6,092 (875.87 ± 1,578.86)	7.62–2,436.80 (1,119.40 ± 1,227.57)	6.09–8 (7.02 ± 0.88)
Gear height (m)	1.52–45.69 (11.38 ± 7.11)	1.52–116.05 (12.95 ± 16.03)	10.66–24.37 (15.74 ± 7.51)	7.62–18.28 (12.28 ± 3.42)
Soak time (hours)	0.17–20 (6.01 ± 4.03)	1–13 (4.98 ± 2.96)	6–24 (11.60 ± 7.40)	0.16–0.50 (0.29 ± 0.13)
Fishing depth (m)	4.57–254.34 (53.55 ± 43.65)	7.61–146.21 (49.44 ± 34.18)	19.8–121.84 (69.45 ± 43.06)	18–28-121.84 (68.34 ± 49.42)
No. of hooks	—	—	1,000–15,000 (9,200 ± 5,263.08)	1–4

fishing trip frequency was highest for small vessels, at between 2 and 60 trips, and lowest for large vessels (2–4 times). Mean monthly fishing days for medium vessels was 14.87 days (±9.15 SD). Number of fishing days at sea was approximately consistent among vessel size, at 15–30 days for smaller boats and 12–30 days for medium and large boats (Table 2). Chattogram recorded the highest monthly fishing frequency with daily or twice daily trips made by the entire asbestos boat fishing fleet (*n* = 19; Table 2). Moreover, the fishing frequency in relation to boat length by home port showed that an increase in boat length decreased the fishing frequency (trips/month; Figure 2c; coefficient = –0.83, r^2 = 0.19, r (d.f.) = 0.44, p < 0.05, 0.0000000002).

Across all study areas, 47% (n = 94) of fishers fish throughout the year, although with decreased activity during the summer storm season (Kal Baishakhi, in April) and during the national fishing ban period (June and July). During the monsoon (June to September) 24% (n = 48) fished, while another 29% (n = 58) fished only in winter (October to January; Figure S2). Smaller boats were mostly from Teknaf, Moheskhali and St. Martin's Island, and went to nearby fishing grounds, including carrying out illegal fishing during the ban period.

Fishing locations were most concentrated within 200 km from the shore of each home port (Figure 2d), although they were dependent on vessel size and home port. Large vessels (wooden-motorized) sailed a maximum distance of 600 km west of Cox's Bazar, 644 km south west of Chattogram, 250 km north, south and west of St. Martin's Island and 200 km west of Teknaf. Some fishers (43%) reported occasionally fishing around the Myanmar and Indian borders. Boat horsepower positively correlated with distance to fishing ground (coefficient = 1.16, r^2 = 0.04, r (d.f.) = 0.19, p < 0.05, 0.009). Almost two-thirds (60%) of boats went to south-central regions and the remaining 40% fished in nearby fishing grounds in the south-eastern regions of Bangladesh.

3.3 | Fishers' devil ray knowledge

Fishers' knowledge of devil rays (locally called 'শিং চোয়াইন' – shing chowaine – or 'বাদুড়া' – badura) was variable, with 66% (n = 132) reporting knowledge on four species on average (±2.36 SD), while 34% (n = 68) reported no knowledge of devil ray diversity. All fishers were able to differentiate devil rays (Mobulidae) from other ray families, especially from cownose rays (Rhinopteridae – locally called 'চোয়াইন', chowaine) but were less able to identify them to species level. Devil rays were differentiated from other rays by the presence of cephalic lobes (by n = 35, 20.6% fishers), colour (n = 35, 20.6%), other morphological differences such as body shape (n = 44, 25.9%) and acrobatic jumping out of the water (breaching; n = 5, 2.9%; Table S5). Additionally, 51 fishers (30%) noted that their experience of handling rays throughout their fishing careers enabled them to identify devil rays. A total of 170 responses came from 132 fishers as one reported several identifying characteristics (method of recognizing) for the studied species (Table S5).

Eighty-six fishers (43% of the total of 200 respondents) could specifically mention the breeding seasons (Figure 3a), which was based on first-hand observations (Figure 3b). Out of these 86 fishers, the majority claimed winter to be the most probable breeding season (n = 48, 60%), closely followed by the monsoon season (n = 32, 40%), while just six fishers reported summer (8%) as the probable breeding season (Figure 3a). In addition, six other fishers did not know the exact answer, but demonstrated knowledge of devil ray biology by using behavioural observations to identify pregnant rays (Figure 3b). For example, one of the most elderly fishers from St. Martin's Island said, 'Often devil rays (শিং চোয়াইন) are seen hiding near coral or rocky surfaces. It seems to me they are using them to rest and for shelter during pregnancy. In fact, we mostly sight them during winter near shallow or rocky shores'. The majority of the fishers stated that devil rays give birth once or twice a year (n = 82, 61.2%), and 43.5% reported devil rays as having one to two pups annually; however, some fishers overestimated birth rates (Figure 3c) and most-

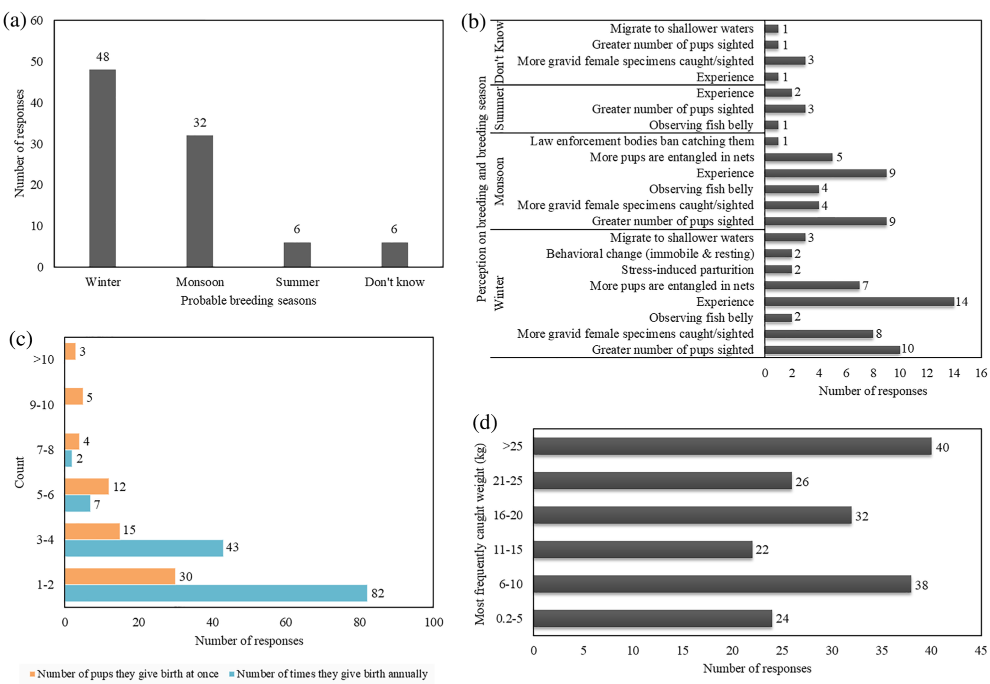

FIGURE 3 Fishers' perceptions of devil ray breeding season, biology and conservation solutions. (a) Total number of responses on probable breeding season. (b) Number of responses for each reason for perceived breeding season (n = 92). (c) Number of responses on devil ray pup number annual (n = 134) and at a time (n = 69). (d) Number of responses on most frequently caught weight of devil rays (n = 182)

frequently caught weight, which ranged between 1 and 50 kg (mean 14.77 ± 14.83; Figure 3d).

Perception of devil ray population trends and conservation requirements varied among fishers (Figure 4). Approximately 20% of fishers perceived populations to be stable or reported no knowledge, while 18.5% (*n* = 37) perceived increasing populations, although the majority, 62.5% (*n* = 125), perceived decreasing populations, particularly over the last 5–20 years (Figure 4a). The main causes for perceived population declines were attributed approximately equally to industrial trawling (27.3%), non-targeted catch (23.5%) and unselective gear use (24.2%) (Figure 4b). Within each of these categories, industrial bottom trawling (*n* = 28 responses), bycatch (*n* = 22) and gill net use (*n* = 15) were considered the most damaging to devil ray populations. Fishers also reported emerging income source to play a role in the declines (*n* = 17, 12.9%) and protein source as amongst the least important factor (*n* = 4, 3%; Figure 4b). Two fishers reporting having to sail further from their previous fishing grounds in order to see a devil ray owing to the substantial influx of foreign vessels exploiting all kinds of marine resources. Fishers also reported a decrease in sightings of devil rays jumping out of the water close to home ports, which is now only observed in deeper waters. Fishers that perceived increasing devil ray population trends proposed reasons including increased nutrient availability (Figure 4c).

Over three-quarters of fishers believed devil rays to confer benefits (79%, *n* = 157), of which 49.3% (*n* = 105) suggested these were ecological, such as by enhancing artisanal fish productivity (*n* = 67) and cleaning water through filter feeding (*n* = 38) (Figure 4d). Perceived socio-economic benefits of devil rays by 50.7% of 213 responses (*n* = 108) included for weather forecasting (*n* = 56; i.e. devil rays jumping often signalled fishers about an approaching storm), as an income source (*n* = 43) and for health and nutrition (*n* = 9; Figure 4d).

3.4 | Catch

Fishers reported not targeting devil rays, although almost all reported bycatch. Annual devil ray catches were 0–6 for large boats, and 0–200 for both medium and small boats, with the 17 unmotorized boats reporting between 2 and 110 (Table 2). Overall, estimated mean annual individual catch ranged between 0 and 200 (mean 30.35 ± 44.37 SD per fisher/boat) over their career (Table 3). The estimated annual catches for 2017 and 2018 mentioned by the fishers were between 0 and 500, with a mean of 32 ± 61 SD per fisher/boat. Sightings per trip (0.5–15 days) per boat were between 0 and 28 (mean 10 ± 5.9 SD). It is estimated that on average 6,400 individuals were caught between 2017 and 2018. While devil ray catch was reported spanning all size categories between 1 and over 25 kg, the most frequently caught size was over 25 kg (*n* = 40 fisher responses; Figure 3d). Mean wingspan of caught devil rays was reported to be 133 cm (± 67.5 SD, *n* = 184), ranging between 46 and 213 cm.

Perceived annual individual devil ray catch was greatest in the winter and monsoon seasons (Figure 5a). Across all study sites, perceived individual catches were higher for gill nets and longlines in Cox's Bazar, and gill nets in Chattogram, whereas Teknaf and St. Martin's reported higher catch for set-bag nets (Figure 5b).

Fishers caught up to 200 individual devil rays (mean 40.69) per net annually by gill nets (Table 3), although reported catch was highly

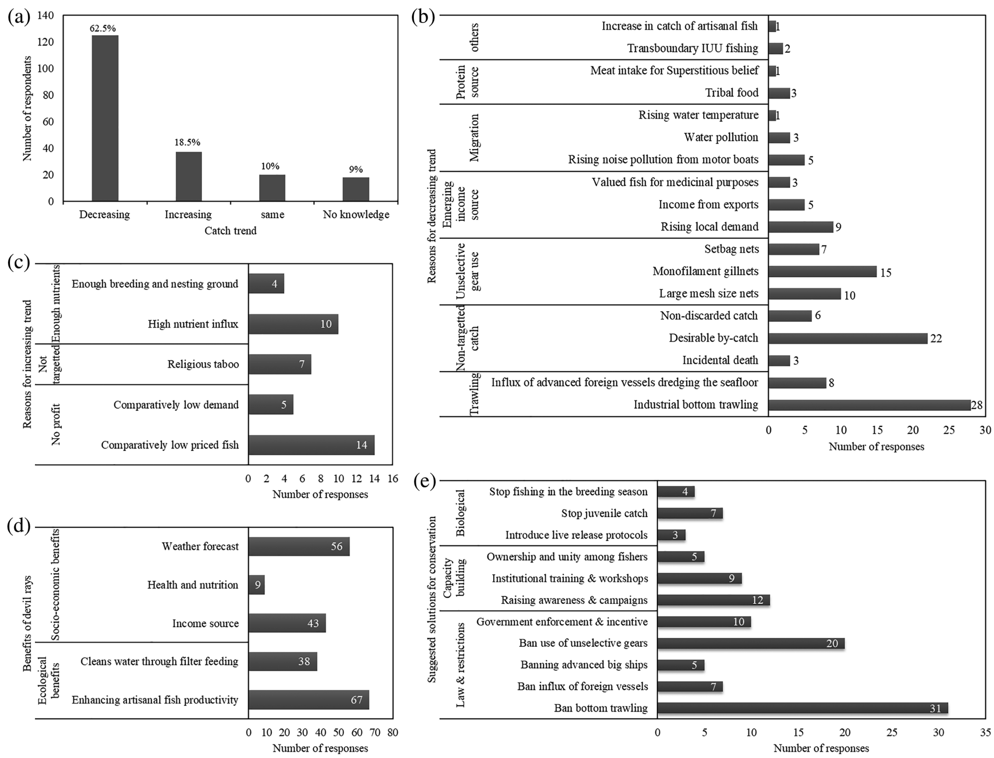

FIGURE 4 Fishers' perceptions of devil ray populations, with number of responses regarding (a) perceived population trend, (b) reasons for decreasing population trend perception (*n* = 132), (c) reasons for increasing population trend perception (*n* = 40), (d) benefits of*Mobula*rays,and (e) number of responses on perceived conservation solutions (*n* = 113)

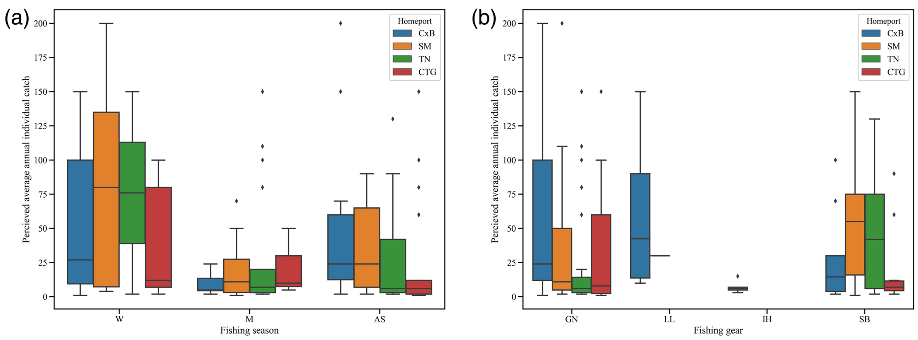

FIGURE 5 The perceived annual devil rays catch in relation to (a) fishing season by home ports and (b) type of fishing gears by home port. AS, All seasons; M, monsoon; W, Winter; WM, winter and monsoon; G, gill nets; LL, longlines; SB, set-bags; CTG, Chattogram; CxB, Cox's Bazar; SM, Saint Martin's; TN, Teknaf

variable. One interviewee explained, 'One day, I caught almost 200 individuals of devil rays mostly smaller sized. It was a lucky day for me and that was the maximum number of individuals I caught in a single attempt, however, there are days when not a single individual is caught. I would say on an average per trip I would catch 5–10 individuals.' Comparatively, medium mesh-sized gill nets tend to catch more devil rays on average annually (between 1 and 200, mean = 45.75 (Table S6), and last season up to 500 were recorded, mean = 50.57), than medium mesh-sized set-bags, which caught an estimated 1–150 individuals (Table 3). Annual devil ray catch by longlines was between 10 and 150 individuals per year per boat. There was a significant positive correlation between gill net and set-bag mesh size and annual devil ray catch (coefficient = 5.34, $r^2 = 0.03$, r (d.f.) = 0.16, $p < 0.05$, 0.0295). However, there was no relationship between either boat length or distance travelled and mean annual catch. Devil ray catch was the lowest for individual hooks at less than one per year, and only opportunistic and owing to entanglement (Table 3).

3.5 | Trade

One-hundred and fifty-six fishers (78%) sold devil rays after they were by-caught and landed. Thirty-six (18%) claimed to have released devil rays whenever they were caught, especially fishers from Muslim communities in Cox's Bazar and St. Martin's Island. However, around 2% of the fishers ($n = 4$) reported using them as bait or poultry feed. Four respondents (2%) reported releasing the younger rays and selling the larger ones, since the younger ones are not economically profitable.

3.5.1 | Product processing

An estimated 180,904 kg of devil rays were bought between 2015 and 2018, approximately 60,000 kg per year by traders (Figure 7a). Devil rays are gutted and processed for different products including gill rakers and meat, and are either dried immediately or sealed in airtight bags and stored in freezers until drying can occur. These are big freezers located at the landing sites and owned by the traders or middlemen, and are not publicly available. However, rays are often bought immediately and taken to the processing centres. The dried products are stored in the processing centres until local or international buyers collect them. There were between 175 and 650 local buyers and four to five international buyers, from Myanmar, identified during the study period.

3.5.2 | Uses

Larger devil rays are processed for meat and dried gill rakers, and are mainly exported to Myanmar for traditional Chinese medicine. Shark businessmen reported increasing demand for gill rakers (Figure 6); in particular, one trader with over 30 years' experience commented: 'Twenty years back devil rays were only locally consumed by some indigenous groups and had no international demand. But recently (specifically in the last five years) the demand for gill rakers of devil rays has increased greatly and they have become a very profitable sale as well'. Fresh devil ray meat has local demand, especially in the coastal and tribal areas. Smaller individuals are mainly processed for livers and meat, which is sometimes salted to reduce pest infestation and/or to increase the weight of the products. The livers are used for oil, for which there is a national demand, especially from the fish-feed industries and occasionally pharmaceuticals. Products in least demand (cephalic lobes, tails, intestines) are sold per kilogram, sometimes to fish feed industries in Dhaka (Figure 6). However, one fisher mentioned their use in the production of soap and lotions, though this was not corroborated. One key informant, from St. Martin's Island said, 'Ethnic communities of North Bengal often visit St. Martin's Island and collect parts of devil rays (mostly dried) to make talismans for good fortune. In fact, these indigenous communities also make tonics or potions which they believe cure diseases and also help conceive children'.

3.5.3 | Value and trade routes

A total of 87% ($n = 26$) of traders bought whole devil rays at the landing sites across the whole coast, using middlemen, with the highest price paid by the traders between 2015 and 2018 (Figure 7a) over different home ports (Figure 7b). Whole individuals are transported to nearby processing centres (within 1 km) owned by shark businessmen, especially in Cox's Bazar, or are sold at auction (in Chattogram) facilitated through connections with fishers and boat owners. In several cases local tribal consumers were observed buying smaller whole individuals at landing sites. From the processing centres, the dried meats

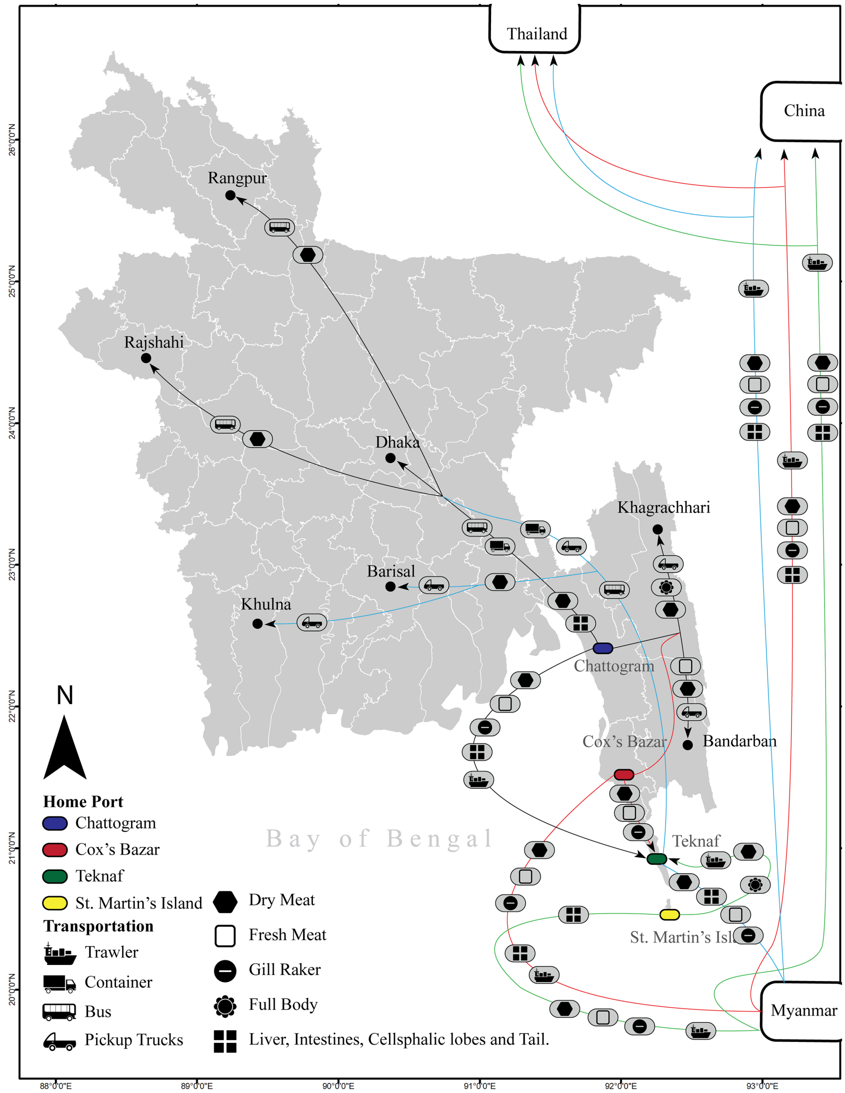

FIGURE 6 Possible trade route map of *Mobula* spp. and processed parts, according to national and international demand reconstructed from the traders' interviews. Home ports for Chattogram, Cox's Bazar, Teknaf and St. Martin's Island are represented in deep blue, red, green and yellow, respectively. The trade routes from each home port towards its final destination are also show in different colours: red for Cox's Bazar, black for Chattogram, light blue for Teknaf and green for St. Martin's Island. The goods are shipped by trawlers, containers, buses and pickup trucks from the processing centres situated at each home port. Products such as full body, dry meat, fresh meat, gill rakers and others (livers, cephalic lobes, intestines and tails) are illustrated with separate icons for better visualization. Although it has been shown in the figure that fresh meat and other products are exported to different countries, the predominant exported products remain gill rakers and dried meat

are distributed via middlemen to the indigenous communities (e.g. Burmese, Rakhain). For longer routes, products are transported via pickups, buses and trucks, to south and north-western Bangladesh (mentioned by traders, 17%, *n* = 5) and to the regions of Khagrachari, Bandarban and Rangamati (30%, *n* = 9) (Figure 6). The majority of the dried meat is exported to Myanmar (23%, *n* = 7), along with that of other elasmobranchs. A key informant from Chattogram (oldest shark trader in the area) said, 'the captains and owners of fishing vessels especially in Chattogram and Cox's Bazar have networks with the traders in both Bangladesh and Myanmar to help them remain up to date on the global trade news on these products'. Chinese buyers often contact middlemen or traders directly to order products that are then sent via Myanmar (Figure 6).

Although this is an indication of the increasing price of the devil rays in Bangladesh, this can also work as a proxy to help understand the amount (kg) of the rays that were bought (Figure 7c,d). In total, 26 respondents (87%) provided estimated values for at least one time interval and only four traders could not answer.

The most valuable devil ray products are gill rakers and meat (mentioned by 77% of the traders, *n* = 23; Table 4; Figure 8). The buying price from local fishing boats is US$0.60–2.40 per kg (mean US $1.42 ± 0.61 SD; Table 4), and the local traders' selling price for local consumption or traditional medicine is US$1.44–6.00 per kg (mean 2.50 ± 1.26 SD; Table 4). Dried meat is rarely bought by traders, and is sold for US$4.80–19.20 per kg for both local consumption and export. Gill raker value ranges from US$8.40 to 24.0 per kg, depending on size (Table 4), although price is not differentiated among species. Livers, cephalic lobes, intestines and tails are the least valuable products, at US$0.36–0.60 per kg, and are mostly traded locally.

3.6 | Knowledge on regulatory measures and sustainable management

The majority of the fishers (87%, *n* = 174) and 14 traders (47%) did not know about international (CITES) or national regulations protecting devil rays. Only 13% of the fishers (*n* = 26) vaguely knew

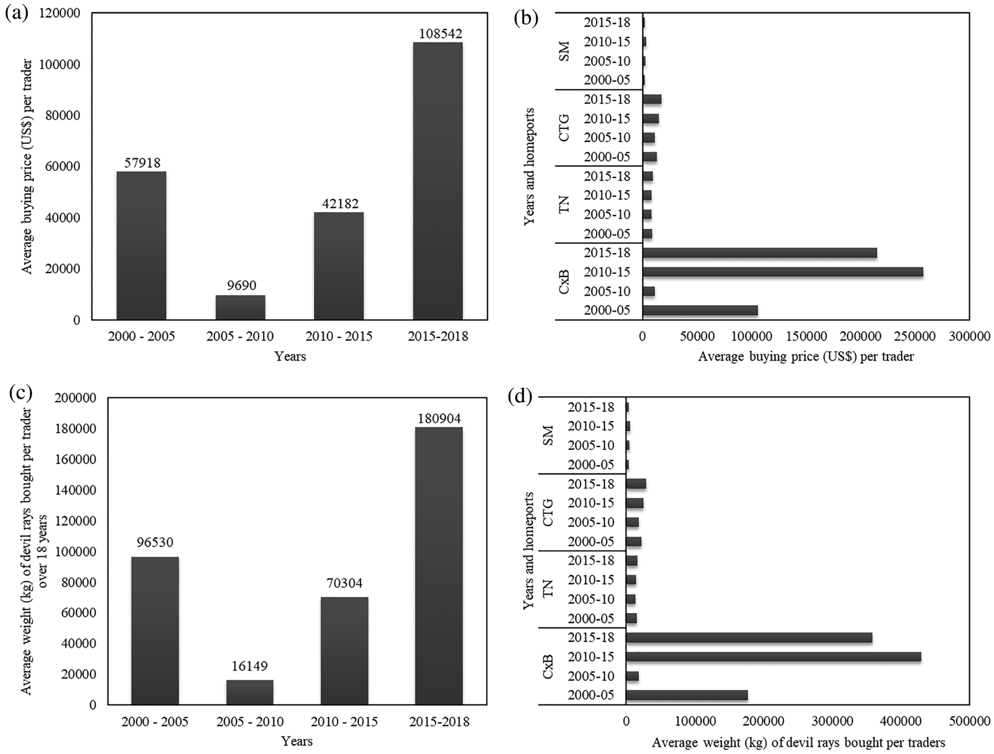

FIGURE 7 The average buying price (US$) and estimated weight of devil rays per trader between 2000 and 2018: (a) average buying price per trader between 5 or 3 year intervals; (b) average buying price per trader by home port (CTG, Chattogram; CxB, Cox's Bazar; SM, Saint Martin's; and TN, Teknaf); (c) average weight (kg) of devil rays bought per trader; and (d) average weight (kg) of devil rays per trader by home port

TABLE 4 Devil ray product value and uses

Product	Buying price/kg (US$) (mean ± SD)	Selling price/kg (US$) (mean ± SD)	Local (L)/export (E)	Uses (mentioned by respondents)
Fresh meat	0.6–2.4 (1.42 ± 0.61)	1.44–6 (2.50 ± 1.26)	Mostly L and rarely E	Food (*n* = 22), local belief or traditional use (*n* = 8)
Dried meat	—	1.8–9.6 (3.80 ± 2.12)	L and E	Food (*n* = 30)
Gill plates 1–6 inch	—	4.8–19.2 (16.46 ± 3.24)	E	Traditional Chinese medicine (*n* = 21), Don't know (*n* = 8)
Gill plates 8–10 inch	—	8.4–24 (16.46 ± 3.58)	E	
Livers, cephalic lobes, intestines and tails	-	0.36–0.6 (0.43 ± 0.09)	L	Liver Oil (*n* = 7), tanneries (*n* = 5), lotion and soap (*n* = 2), don't know (*n* = 16)

about some kind of restrictions for elasmobranchs, but could not specify the prescribed law. However, conservation solutions for sustaining the devil ray population in Bangladesh were suggested by 101 fishers, including (i) laws and restrictions (*n* = 73, 65%), (ii) capacity building (*n* = 26, 23%), and (iii) biological solutions (*n* = 14,12.4%). There were in total 113 responses and each broad category had several other solutions under it (Figure 4e).

4 | DISCUSSION

Devil rays are under threat globally, and there is growing concern about population declines (White et al., 2015; Stewart et al., 2018) and high extinction risk (Dulvy et al., 2014) from fisheries (Croll et al., 2016) and international trade (O'Malley et al., 2016; Haque et al., 2018). This has prompted research to fill the knowledge gaps on fisheries (Fernando & Stevens, 2011; Adnet et al., 2012; Croll et al., 2016; Pardo et al., 2016; Stewart et al., 2018), taxonomy (White et al., 2017), ecology (Couturier et al., 2012; Stewart et al., 2018) and trade (O'Malley et al., 2016) and an understanding of local ecological knowledge and perceptions (Acebes & Tull, 2016; Leeney, Mana & Dulvy, 2018; Braulik, Kasuga & Majubwa, 2020). This study addressed such a knowledge gap in Bangladesh, adding important information on devil ray fisheries and trade. It is evident that Bangladesh devil ray fisheries and trade require intervention for effective conservation and management in order to prevent further population declines in the Bay of Bengal.

4.1 | Status of devil ray fisheries

Six devil ray species were verified in Bangladesh, although there is no knowledge about their long-term population trends, critical habitats or ecology for this region, which is crucial for the development of

FIGURE 8 Photographic examples of catch, landing and trade on devil rays in Bangladesh. (a) Medium boats carrying devil rays with other elasmobranchs to land in Cox's Bazar; (b) *Mobula kuhlii* landed in Cox's Bazar; (c) a pup of *Mobula thurstoni* from a pregnant female after landing; (d) landing of devil rays in bulk; (e) dried gill rakers of *Mobula* sp. and (f) gill rakers of *Mobula birostris/alfredi*

effective conservation strategies (Stewart et al., 2018). Historical devil ray population trends for the Bay of Bengal and the Bangladeshi artisanal capture fishery is difficult to understand, in part owing to a lack of a species-specific landing accounting system. Despite this, from 2006 to 2010, a total of 10.55 t of *Mobula diabolus* (now *M. mobular*) and some *M. kuhlii* were landed at two landing sites in the south-eastern region of Bangladesh (Roy et al., 2014; Roy et al., 2015b). More recently, between 2011 and 2012, 442 individuals of *M. kuhlii* (1.72 t) were landed at these sites. There is a substantial annual catch of devil rays per boat from Bangladeshi waters, coincident with perceived population declines by fishers, potentially owing to growing fishing pressure and long-term catch. The declining population trend is also prevalent globally and is probably due to increasing fishing pressure (Stewart et al., 2018). For instance, between 1998 and 2009 the estimated annual global landing of devil rays increased from 200 to over 5,000 t (Ward-Paige, David & Worm, 2013), and in Africa and Asia alone, the catch was as high as >4,000 t in 2014 (FAO, 2016). Evaluating fisheries bycatch is a key research area for devil rays globally, as increasing bycatch presents a constant threat, with at least 30 fisheries operating in 23 countries (Stewart et al., 2018). The impact of fisheries-related mortality is a major threat to devil ray populations, and the focus of management strategies globally (Croll et al., 2016; Alfaro-Cordova et al., 2017; Lawson et al., 2017).

In Bangladesh, perceived catch was highest in the winter, potentially owing to the increased fishing effort. Many fishers believed winter to be the breeding season, with large numbers of devil rays found near-shore. While almost all gear types and vessels caught devil rays, catch was highest with gill nets, consistent with devil ray catch globally (White et al., 2006; White, Giles & Potter, 2006; White & Dharmadi, 2007; Bizzarro et al., 2009; Pierce et al., 2010). In one instance 78 devil rays were landed in one day from a large-mesh gill net at Cox's Bazar (Haque, A.B., 2016, unpublished data). The low number of devil ray catch by large boats is probably because only five large boat fishers were interviewed, and of those four used set-bag nets, which catch significantly fewer devil rays than gill nets. Medium-sized boats cruising long distances caught more devil rays than large boats; however, several small boats with higher engine capacity also caught high numbers. It is evident, therefore, that non-selective fishing practices, especially gill nets, pose a significant threat to devil rays in Bangladesh.

The majority of the respondents reported a perceived decline in devil rays in Bangladesh, indicating cause for concern for the future of devil rays. Trawling and bycatch were proposed as the primary causes for declines, highlighting an understanding of direct human impact on wild populations, similar to declines in Taiwan and Andaman Island (Liao, Huang & Lu, 2019; Patankar, 2019). In other locations, a reduction in landings and sightings of devil rays has been associated with possible population declines owing to high fishing pressure (e.g. *M. rochebrunei* in West Africa, Stewart et al., 2018). Such fisher perception, coupled with catch data, may be vital for helping to evaluate the long-term status of devil rays in Bangladeshi waters. Fishers reported that they now have to sail further distances from their previous fishing grounds in order to observe devil rays. While this perception could result from a shift in vessel type or increased vessel numbers, such a habitat shift may be an indication of population decline (Chin et al., 2012; Poortvliet et al., 2015), as a result of increasing fishing pressure owing to an increase in scale and modernization of fishing methods (Ward-Paige, Davis & Worm, 2013; Croll et al., 2016; Pardo et al., 2016; Abudaya et al., 2018).

Additionally, the life history of devil rays and the *k*-selectivity, probably contribute to their decline as populations are slow to recover (Couturier et al., 2012; Dulvy et al., 2014; Croll et al., 2016; Alfaro-Cordova et al., 2017). Devil rays have relatively low population growth rates (Dulvy et al., 2014; Pardo et al., 2016) and are subsequently less resilient to fisheries pressures, even with small population declines. As a result, devil rays are unlikely to provide sustainable fisheries, and with increasing fishing pressure, are cause for concern. In order to conserve devil ray populations, bycatch mitigation strategies should be strengthened and live release encouraged, ideally with mechanisms enabling reduced post-release mortality.

4.2 | Trade

Owing to the threats emerging from global catch and trade, all species of devil rays were listed in Appendix II of CITES in 2016, to ensure sustainable regulation of traded products and specimens. Although Bangladesh is a signatory, devil ray trade remains unmonitored and protective national law is not enforced. The national law provides limited protection as only one species is protected, *M. mobular*. The inclusion of just one devil ray species in national protection undermines the CITES treaty as, once cut and ready to export, visual species identification is impossible. Furthermore, fishers and traders are largely unaware of the existing law and CITES regulations on devil ray catch and trade, which has probably greatly contributed to non-compliance. It is therefore recommended that the national law is amended to incorporate all six species of devil ray species found in Bangladeshi waters.

To implement these regulations effectively, appropriate trade monitoring regimes are fundamental, along with awareness building. It is important to monitor the active trade routes and hubs used for devil ray trade so that the law can be enforced. In Bangladesh, the trade routes are complex and products are often traded aggregated with other elasmobranch products. Whereas most products were being exported to Myanmar during the study period, there were opportunistic buyers from different countries, including China, who have access to Bangladeshi traders and place orders for gill rakers. Institutional capacity building in monitoring these trade mechanisms is needed in consultation with traders.

Devil ray trade in Bangladesh, leading to high bycatch retention rates, is similar to that in China, India, Indonesia Philippines, Sri Lanka and Thailand (Couturier et al., 2012). The most lucrative devil ray products are meat and gill rakers, for both local consumption (Notarbartolo di Sciara et al., 2017) and international trade, including for Chinese medicinal uses (Couturier et al., 2012; O'Malley et al., 2016). Bangladesh has a long-standing elasmobranch trade relationship with a suite of countries including China and Myanmar (Haque et al., 2018). The devil ray gill rakers are one of the most valued elasmobranch products internationally (Heinrichs et al., 2011; Couturier et al., 2012; O'Malley et al., 2016), with a value of up to US $500–680 per kg in Chinese markets (Heinrichs et al., 2011; Dulvy et al., 2014). Although the prices are not as high in Bangladesh, it is still a valuable income for marginalized fishers and many traders. Furthermore, national consumption is also prevalent in coastal and tribal areas, making devil rays a very valuable catch. The current demand for devil rays both in Bangladesh and internationally, and their contribution to local livelihoods, suggest that effective conservation strategies may be difficult to achieve if evidence-based and inclusive management regimes are not introduced.

4.3 | Fishers' perception and conservation

The connection between evidence-based knowledge and fishers' perceptions in public decision-making can help to implement effective conservation actions (Mackinson et al., 2011; Dietz, 2013; Msomphora, 2015; Sánchez-Jiménez et al., 2019). The perception of fishers on devil ray fishing grounds, breeding season and historical accounts can provide a road map for further focused studies. To help mitigate the catch and trade of devil rays, careful involvement of fishing communities in the conservation and management of their local biodiversity is essential (Sánchez-Jiménez et al., 2019; Booth et al., 2020; Mason et al., 2020). For instance, in a study in South Georgia, on bycatch of procellariform seabirds, inclusion of fishers in the management and policy regimes combined with other mitigation strategies has shown reductions in bycatch of 80–100% (Cox et al., 2007).

A substantial proportion of fishers suggested that devil rays are beneficial, proposing, for example, that they are an indication of good ocean health, improve fishing conditions and are ocean cleaners. Cultural benefits of devil rays were also proposed, including for health and fertility. Sometimes these elements of cultural and traditional practices may provide an ideal opportunity for a community-led conservation project (Jabado et al., 2014; Liao, Huang & Lu, 2019; Patankar, 2019). This is particularly relevant for Bangladeshi coastal communities for whom fishing is culturally important and creates a shared identity amongst the fishers and traders (Trimble & Johnson, 2013; Haque, in prep.). Despite the perceived benefits and cultural practices, both fishers and traders lacked the biological and ecological knowledge necessary for effective conservation, such as on species identification, carrying capacity, seasonal variation, breeding and seasons (Leisher et al., 2012). Therefore, educational campaigns and knowledge-sharing sessions with experts may improve stakeholder engagement and management efficacy. Cultural sensitivity and efforts to compensate fishers for the effects of conservation efforts on income and livelihoods are also important (Davis & Harasti, 2020). Future management strategies need to consider that fishers' annual earnings are prohibitively low for them to take part in positive conservation action, such as bycatch release, without incentives (Cinner & Pollnac, 2004; Cinner, Daw & McClanahan, 2009). In many studies, non-consumptive alternatives such as devil ray-based tourism have been advised (Anderson et al., 2011; O'Malley, Lee-Brooks & Medd, 2013; Venables et al., 2016). However, these may not work in Bangladesh as the coastal water is very turbid and the number of fishers may be too high.

Many fishers were inquisitive about how to manage marine resources, including devil rays, and possible sustainable practices. Effective conservation requires direct involvement and support of all stakeholders; however, socio-economic stressors are often preventative. The primary annual income of the surveyed stakeholders was highest for the boat owners, followed by captains, technicians and crews. The majority of fishers depend entirely on marine resources for their livelihood, with the crew, captain and technician customarily paid proportional to the total amount of fish caught per trip, and most not having a secondary income. Developing alternative livelihoods could form part of a management strategy to ensure stable incomes for fishers' families (Roe & Booker, 2019) and disincentivize overfishing and illegal trade of threatened species, including devil rays. Having culturally appropriate and socially contextualized secondary income through alternative methods and innovative incentive regimes other than monetary incentives (healthcare benefits, scholarships for education, help in facilitating cooperatives) may prevent the worst effects of exhausting marine resources and bring positive behavioural change towards endangered species.

5 | CONCLUSION

Direct engagement with south-eastern Bangladeshi stakeholders of the Bay of Bengal devil ray fishery has helped fill data gaps on devil ray population size and catch, and provided insights into how to improve conservation efforts. For effective Bangladeshi devil ray conservation and implementation of sustainable fisheries and trade, key concerns that need to be addressed include: (1) increased monitoring of trade routes on waterways of shark and ray products, halting illegal, unregulated and underestimated elasmobranch trade from the territorial waters of Bangladesh; (2) amendment of national Wildlife (Conservation and Security) Act, 2012 to include all six Bangladeshi devil rays and effective enforcement; (3) inclusion of stakeholders in government decision-making and management initiatives; and (4) bycatch mitigation and devil ray biology and conservation education among stakeholders. Additionally, more research is needed on specialized and opportunistic shark and ray fisheries to assess the overall threats and catch rates in Bangladeshi waters so as to facilitate tangible conservation outcomes rooted in sustainable fisheries model.

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ORCID

Alifa Bintha Haque https://orcid.org/0000-0001-8250-0030
Nidhi Gloria D'Costa https://orcid.org/0000-0002-2444-8841
Amit Robert Baroi https://orcid.org/0000-0002-9971-4817
Nazia Hossain https://orcid.org/0000-0002-6530-3585

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