ASSESSING THE MAGNITUDE AND SOCIO-PSYCHOLOGICAL FACTORS OF CETACEAN BYCATCH IN COASTAL BANGLADESH

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Final Report on

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Background

Cetaceans (whales, dolphins, and porpoises) are a diverse group of mammals present throughout the world's oceans, with body length ranging from 150 cm for the vaquita (*Phocoena sinus*) to an average of 33 m for the blue whale (*Balaenoptera musculus*). These animals occupy a wide range of trophic levels, from filter-feeding (e.g., blue whales) to macropredators (e.g., killer whales, *Orcinus orca*) (Leatherwood and Reeves 1983).

One of the greatest anthropogenic threats to cetaceans is entanglement in fishing gear as bycatch (Perrin et al. 1994; Lewison et al. 2004; Read et al. 2006; Brownell et al. 2019). Bycatch is generally defined as incidental mortality or injury of non-target species in fishing gear (Reeves et al. 2013). It has been reported for centuries, but the magnitude has increased in recent decades due to stronger gear and other changes in fishing practices (Read et al. 2006; Reeves et al. 2013; Moore et al. 2021). Bycatch was a main cause in the extinction of the Yangtze River dolphin (*Lipotes vexillifer*), the first global extinction of a large vertebrate in 50 years and only the fourth extinction of an entire mammal family since 1500 AD (Turvey et al. 2007). Another 13 units of small cetaceans (population/subpopulation or an isolated group of species) are considered critically endangered, and studies have indicated the primary threat to these units is bycatch in small-scale fisheries (SSF hereafter) (Reeves et al. 2013; Brownell et al. 2019).

Although the impacts of bycatch on some cetacean populations are well studied (Lewison et al. 2004; Reeves et al. 2013; Brownell et al. 2019), the impact of bycatch on most cetacean populations remains largely unknown. Estimating the magnitude of bycatch is critical for understanding its population-level impacts and making robust legislative and management decisions (Punt et al. 2020). But this has been a challenge, especially in SSF in developing countries, primarily due to limited data and the nature of the fishery (small, numerous, often with no requirements for license or registration, and typically lacking predictable landing areas) (Reeves et al. 2013; Jog et al. 2022). An interview-based rapid bycatch assessment can be a relatively cost-effective tool to characterize and assess fishing effort and bycatch risk and their magnitude (e.g., Moore et al. 2010; 2021). Although interview survey data, especially self-reported data, have limitations, these can be effective proxies for intensive field studies over many seasons and fill critical knowledge gaps in local, regional, and global SSF fishing effort and bycatch (Moore et al. 2010).

While understanding the ecology of cetaceans is critical, understanding and changing behaviors of primary stakeholders of fisheries and wildlife management is recognized as

necessary for a long-term and effective outcome and is increasingly being recommended for cetacean bycatch management as well (Ambie et al. 2023; Elsler 2023; Eeden et al. 2020; Whitty 2018; Fulton et al. 2011). Although understanding fishers' behavior has received scientific attention since the 1970s (Pitcher & Chuenpagdee 1993; Branch et al. 2006; Hilborn 2007; Fulton et al. 2011), sociopsychological factors of behavior for individuals and groups of fishers, especially in the context of compliance with cetacean bycatch management strategies, are under-investigated (Manfredo 2004; Salas & Gaertner, 2004; Teh et al. 2012; Gkargkavouzi 2020; Andrews et al. 2022). Consequently, cetacean bycatch management efforts are less successful, and improper use of resources is hindering the overall success of management.

Arias (2015) described compliance as deference to the policies and social norms related to fisheries resource use and conservation and stated that compliance is a result of norms, beliefs, economic factors, and willingness to participate in risk-taking behaviors. Cognitive theories have suggested that other sociopsychological factors, e.g., intention to comply, beliefs, attitudes, and self-efficacy, also impact policy compliance (Azjen, 1991; Fishbein & Manfredo, 1992).

Although behavioral intention does not always indicate actual behavior, it can be useful for agencies to make decisions about policies based on the support level of specific stakeholders (Manfredo, Teel, and Bright 2004; Needham, Haider and Rollins 2016; Perry et al. 2017). Additionally, self-reported behavior intention can be a rigorous proxy predictor for future behavior when coupled with "objective indicators of behavior," i.e., a measure of behavior that is free of subjective bias, such as trends in confiscated fishing gear and penalties during a fishing season ban, observed amount of illegal fishing gear, and trends in trade of cetacean body parts identified through media searches (Gavin, Solomon, & Blank 2010).

SSFs are complex systems of diverse stakeholders who often influence each other's decision-making process. In this system, traders may influence social norms through sharing information, regulating the price of catch and bycatch, and using their broader financial and administrative capacity to contribute to formal decision-making processes (Bodin and Crona, 2009; González-Mon et al. 2019; Elsler 2023). Understanding the behavior of all stakeholders, especially the fisher-trader relationship, can play a critical part in the success of bycatch management.

The aim of this study was to utilize interview-based approaches to:

1. Characterize and quantify the nature and extent of cetacean bycatch in Bangladesh through a rapid bycatch assessment;
2. Estimate the effect of fishing efforts, and type of gear used on the probability of cetacean bycatch;

3. Estimate the effect of attitude, social norm, self-efficacy and subjective knowledge on the probability of the intention to comply with cetacean bycatch management strategies; and
4. Elicit the skills and conditions that stakeholders perceive as ideal to comply with the cetacean bycatch management policies.

This study is the first of its kind in Bangladesh and is a first step to integrating human dimensions data into cetacean bycatch management in Bangladesh.

Methods

Definitions

For this study, we define:

- SSF as any fishery that is managed at the household or community level, is not owned by a big company, uses vessels that are <18 m in length or have <10 gross tons capacity, and uses manually operated gear.
- Bycatch as the entanglement and mortality of any species that is not targeted, irrespective of whether it is discarded, used, or sold.
- Stakeholders as small-scale fishers and fish traders. The latter is someone who either owns vessels and/or gear or lends money to fishers for conducting fishing trips and directly or indirectly influences fishers' activities pertaining to bycatch.
- Behavioral intention as a person's perceived likelihood or subjective probability that they will engage in each behavior.
- Attitude as self-evaluation of the degree to which an object or issue is favorable or unfavorable.
- Injunctive norm as beliefs about what others think one should do and motivation to comply.
- Descriptive norm as perceptions about what others in one's social or personal networks are doing.
- Self-efficacy as perceived capability or skill (as opposed to actual skill) to perform a behavior.

Study Area

Coastal Bangladesh is characterized by shallow estuarine habitat created by the world's third-largest river system; the Ganges-Brahmaputra-Meghna (inputting some 10^9 tons of nutrient/yr into the coastal ecosystem). These nutrients are spread through the world's

largest mangrove forest, Sundarbans, ending in a deep submarine canyon (Milliman and Syvitski, 1992). A seasonal current creates upwelling of the canyon which redistributes and recycles the nutrients, making the Bangladeshi coast a hotspot for cetaceans (Babu et al. 2003; Smith et al. 2008).

Smith et al. (2008) reported the occurrence and distribution of six cetacean species: Irrawaddy dolphins, *Orcaella brevirostris*; Indo-Pacific finless porpoises, *Neophocaena phocaenoides*; Indo-Pacific humpback dolphins, *Sousa chinensis*; Indo-Pacific bottlenose dolphins, *Tursiops aduncus*; pantropical spotted dolphins, *Stenella attenuata*; and Bryde's whales, *Balaenoptera edeni*. Their distribution is linked to water depth, salinity, and turbidity gradients (Smith et al. 2008). Cetaceans are not targeted by fishers and have no economic value in Bangladesh, but fishers report that Irrawaddy dolphins are often bycaught in fishing gear (Smith et al. 2008).

Coastal waters of Bangladesh have among the highest fishing effort (5.4 boat-meters/km^2) in the world (Stewart et al. 2010). Fifteen percent of the total fish production of Bangladesh comes from marine fisheries, and 82% of this comes from SSF (FRSS 2017). This sector has grown significantly over the past decades, from 2,700 motorized vessels in 1980-81 to ~68,000 in 2016-17 (FRSS 2017). According to the Department of Fisheries (DoF) Bangladesh, primary gear types used in small-scale fishing are gillnets (the most predominant), set bag nets, and long lines; most fishing occurs in 5-40 m (Barua et al. 2019).

The primary target catch is hilsa, *Tenualosa lisha* (Islam et al. 2016). This fishery contributes 1% of the country's total GDP and employs 0.5 million fishers directly and another 450,000 people indirectly (Islam et al. 2016). About 65% of the country's hilsa is caught in coastal and marine waters (Shamsuzzaman et al. 2020). Additional economically valuable catch includes Bombay duck, *Harpadon nehereus*, ribbon fish, Trachipteridae, croakers, Sciaenidae, catfish, Ariidae, and sardines, *Sardinella spp.* (Barua et al. 2019).

Data collection

Data were collected from 19 fishing communities spread across nine coastal districts of Bangladesh (Figure 1). The highest number of fishers and traders involved in coastal and marine fisheries in Bangladesh inhabit these areas (BSYB, 2011). We conducted 352 (301 fishers and 51 traders) structured, in-person interviews between March and May 2024. Fishers and traders with less than five years of experience were not interviewed to account for sufficient knowledge of the fishing effort and cetacean bycatch and to ensure relevancy and accuracy of the data (Young et al. 2017).

Five local students were trained through group discussion and practice interview sessions in February 2024. During data collection, interviewers based themselves in places with high chances of meeting fishers on landing sites, such as jetties and tea shops (Figure 2), and selected participants using the intercept method, where potential participants were stopped by interviewers and asked if they would be willing to be interviewed. Oral consents were taken before starting each interview. Each interview took 35 minutes to complete on average. The interview effort started at 6 AM, when fishers typically finished landing their catch and the wholesale trade began and continued until sunset. Each day the first interviewee, after the data collection started, was recruited at random, and after that, every other person was approached for interviews to ensure systematic randomization. Additional interviews were conducted opportunistically.

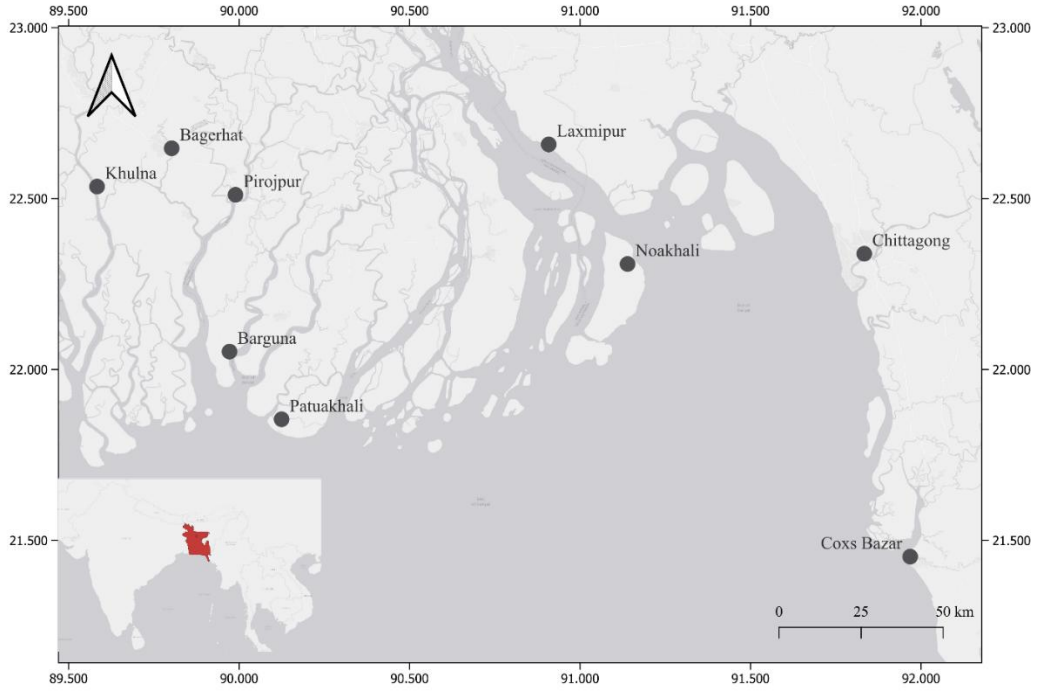

Figure 1. Districts where data were collected in coastal Bangladesh. The inset shows the location of Bangladesh in the larger Southeast Asia.

The questionnaire included 50 questions (supplementary material) and was divided into three broad sections.

- *Rapid bycatch assessment*: stakeholder's level of experience, types of fishing gear used, frequency and locations of fishing effort and practices, cetacean sightings, and cetacean-fishery interactions.
- *Sociopsychological assessment:* stakeholder's perceptions of cetacean bycatch, their attitude, norm (descriptive and injunctive), self-efficacy, and subjective knowledge and behavioral intention to comply with cetacean bycatch management strategies.

- Perceived ideal skill and conditions to comply with cetacean bycatch management policies.

Figure 2. (Left) Research team interviewing fishers in Pirojpur during gear maintenance and fishing trip preparation; (Right) traditional fishing vessels docked at Patuakhali fish landing site after returning from multi-day fishing trip.

The questions were designed as a foundational tool to assess stakeholders' perceptions of cetaceans as a taxonomic group. This approach was adopted due to the lack of prior information on fishers' and traders' ability to accurately identify cetaceans at the species level. Most questions were closed-ended (respondents were asked to choose from a set of predetermined responses). Questions eliciting sociopsychological factors were collected as summated scale data. Responses were recorded on paper during interviews and were later compiled, encoded, and anonymized in standardized spreadsheets. The questionnaire and methods were approved by the Oregon State University's ethics board (IRB #: HE-2024-825).

Data analysis

Rapid bycatch assessment:

We used descriptive statistics (i.e., means, standard deviations, and percentages) to quantitatively describe and summarize rapid bycatch assessment data and then fitted multilevel Bayesian regression models to estimate the probability of cetacean bycatch. The focal predictors used to estimate cetacean bycatch probability are listed in Table 1.

Bayesian analysis methods are gaining popularity as a reliable tool to estimate plausible inferences in skewed and data-limited scenarios. These methods calculate a range of probabilities of a parameter or unknown quantity of interest (also known as posterior distribution) in a statistical model using observed data and previous knowledge of the parameter (Wade 2000). Given the uncertainties and skewness around self-reported

interview-based data, we used Bayesian models to account for the uncertainties while predicting credible probabilities of cetacean bycatch.

Because of the multilevel structure of the data (i.e., respondents clustered within districts, districts clustered within fisheries, and wildlife management zones), we used multilevel models. We included varying (random) intercepts for the home port of the vessel reported by respondents in all models. We assume that the varying intercepts capture contextual (fishing effort) and behavioral (sociopsychological factors) fixed effects shared within the home port districts (equivalent to management zones) that could affect individual-level fishing effort and behavior.

For the overall bycatch probability, we fitted logistic regression models using Markov-chain Monte Carlo (MCMC) methods with Stan (Stan Development Team, 2022), using the brms (Bürkner 2018) package in R (R Core Team 2024), where the predictors were average days per fishing trip and minimum and maximum depth of operation (hereafter fishing effort). We assume that the parameters of the variables are normally distributed and set weakly informative priors for model fixed effects (e.g., the fishing effort variables) with a mean of zero and standard deviation (SD) of 0.1. The population intercept (overall intercept for all of Bangladesh) was also assumed to be normally distributed with a mean of 0 and an SD of 1.5. District-specific random intercepts were estimated to come from a normal distribution with a mean of zero and a distribution-specific standard deviation of 1.

In the model a linear equation:

$$y \sim \text{Bernoulli}(\mu) = \mu^{y} (1 - \mu)^{1-y}$$

where μ is the parameter value and for a generalized model, μ can be expressed as:

$$g(\mu_i) = \beta_0 + \beta_1 x_{1,i} + \beta_2 x_{2,i} + \cdots + \beta_n x_{n,i}$$

μ gave the log-odds of "success" and "failure" of cetacean bycatch, as a function of predictor variables (Table 1). We used "logit" link function to estimate the main effect of the parameters in log-odds and later inversed the estimates to quantify the probability.

Table 1: Variables used to predict the probability of cetacean bycatch in coastal Bangladesh.

Variable	Description
Outcome	
Respondents reporting any cetacean bycatch in their gear through the duration of their career	Binary (Yes/No)
Predictors	
Average days per fishing trip	Discrete
Minimum depth of operation	Discrete
Maximum depth of operation	Discrete

To describe the effects of each fishing effort variable, we computed marginal effects (effect of a unit change in predictors on the outcome variable). Uncertainty of a predictor's effect was estimated from its respective posterior density (readily available via MCMC samples).

The posterior distribution was drawn from four MCMC chains, each with 30,000 iterations from which 15,000 were discarded in the burn-in process. The posterior predictive check for every parameter (intercept, slope of each predictor, and population SD) of the model showed convergence both numerically and visually (Figure 3). The estimated scale reduction factor (also known as *Rhat*) is a quantitative measure of convergence and was 1.0 for all parameters with an effective sample size of more than 10,000. This proves reliable convergence diagnostics of the model (Gelman and Rubin 1992; Gelman et al. 2013).

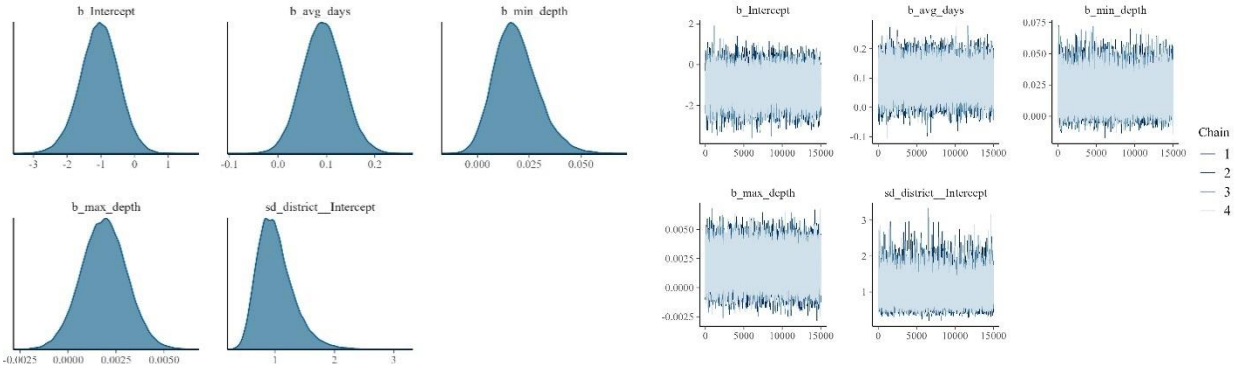

Figure 3: (Left) The density of the posterior distribution of the model showing the probability of bycatch (intercept) as a function of the fishing effort variables (average days per fishing trip, minimum and maximum depth of operation) based on the sample data, and (right) trace of posterior distribution showing the convergence of four MCMC chains respectively confirming reliability of the model estimates.

Sociopsychological assessment:

To estimate the probability of complying with cetacean bycatch management strategies, we used Bayesian regression models. We selected seven management strategies; five are currently in place as fisheries management policy; two are being considered. Details of these strategies and the rationale to use them are listed in Table 2.

Table 2: Existing and potential fisheries and cetacean bycatch management strategies used in assessing the probability of compliance by stakeholders.

Management strategy	Relevant Statute in Bangladesh	Current levels of enforcement in Bangladesh
Vessel registration	Marine Fisheries Act 2020	Limited
Marine Protected Areas (MPAs): Spatial closures	Marine Fisheries Act 2020	Very limited
Fisheries ban: Temporal closures	Marine Fisheries Act 2020	Extensive
Monofilament nets ban: Gear switching	Protection and Conservation of Fish Act, 1950	Moderate
Set 45 mm as the minimum mesh size for all gear: Gear specification	Protection and Conservation of Fish Act, 1950	Limited
Pingers as an acoustic measure: Gear modification	Conservation Action Plan for *Ganges River Dolphin* and *Irrawaddy Dolphin* of Bangladesh, 2021-2030	Not in practice yet
Sub-surface gillnet: Operation method modification	Assessed in Pakistan and Florida, USA	Not in practice yet

We used descriptive statistics to quantitatively describe and summarize the preliminary data and then fitted ordinal logistic regression models in a cumulative framework with Stan (Stan Development Team, 2022), using the brms (Bürkner 2018) package in R (R Core Team 2024).

The predictive model assumed that the observed behavioral intention Y (indicated by respondents), is a function of unobservable continuous predictor variables: knowledge, attitude, descriptive and injunctive norm, and self-efficacy towards the policy. We used ordered logistic model and "logit" link function to estimate the log-odds and later inversed the estimates to quantify the probability.

We set default non-informative priors for each predictor as no prior information on the behavioral intention of these communities is available. The posterior distribution was drawn from four MCMC chains, each with 30,000 iterations from which 15,000 was discarded in the burn-in process.

Results

Interviews included fishers from all zones and districts except Khulna, and traders from all zones and all but Lakshimpur district (Table 3). Forty-three percent of the fishers were captains, and 57% were crews.

Table 3: Number and percent of total fishers and traders interviewed for this project by zone and district in coastal Bangladesh.

Zone	District	Number of Fishers	Percent of Fishers	Number of Traders	Percent of Traders
West	Bagerhat	52	17%	3	6%
	Khulna	0	0%	2	4%
	Pirojpur	27	9%	4	8%
South	Barguna	39	13%	10	20%
	Lakshmipur	39	13%	0	0%
	Patuakhali	59	20%	15	27%
	Noakhali	31	10%	6	12%
East	Chittagong	29	10%	8	16%
	Cox's Bazar	25	8%	3	6%

Rapid Bycatch Assessment

On average, fishers had 25 and traders had 23.5 years of experience (SD = 11.27, range = 5-60 years; SD = 11.74, range = 6-59 years, respectively). Most of the fishers (39% n=120) had 16-30 years of experience and 14% had more than 40 years of experience of fishing in coastal and marine environments.

Twenty-three percent of fishers owned their vessel and/or gear; 2% had shared ownership. Forty-nine percent of captains owned their vessel/gear. Traders owned or shared ownership of between 1 and 300 vessels.

The number of fishers employed by traders varied among districts and ranged from 10 to 5,100 (Table 4).

Table 4. Number of fishers employed by traders according to district in coastal Bangladesh.

District	Minimum	Maximum	Average
Bagerhat	18	100	59.00
Pirojpur	45	500	185.75
Khulna	120	180	150.00
Barguna	11	625	181.20
Patuakhali	10	2500	473.36
Chittagong	25	5100	1076.38
Noakhali	13	4500	1128.50
Cox's Bazar	15	60	38.33

The majority (77%, n = 233) of fishers reported fishing as their only source of income. Twenty percent of the remaining respondents mentioned one other source of income. Only six respondents mentioned more than one income source.

Fishing Gear

Seven types of gear are known to be used in coastal Bangladesh: four types of gillnets, one additional net type, and two types of long lines (Table 5; Wildlife Conservation Society - Bangladesh, unpublished data). Of the fishers interviewed for this research, 37% percent used more than one type of gear.

Table 5: Fishing gear type and characteristics used in small-scale fisheries in coastal Bangladesh (source: Wildlife Conservation Society, unpublished).

Gear Type	Maximum Length (m)	Mesh/Hook size (cm)
Anchored gillnet (AGN)	Not known	1.3-12.0
Small mesh drifting gillnet (SDGN)	9000	2.5-8.0
Medium mesh drifting gillnet (MDGN)	7,000	8.1 - 13.0
Large mesh drifting gillnet (LDGN)	5,000	13.1-20.0
Set bag net (SBN)	50	0.5-10.0
Baited long line (BL)	27,000	4.0
Unbaited long line (UL)	5,000	5.0

Use of gear varied by seasons (Table 6). Medium mesh drifting gillnets were the most frequently used gear, accounting for 69% or greater of all fishing gear in all four seasons (Table 6).

Table 6. Reported use of fishing gear by season (spring – *March-May*, summer – *June-August*, fall – *September-November*, winter – *December-February*). The number of fishers, and percent of total for that season represented by that gear type. Abbreviations as in Table 5. "None" indicates no fishing during that season.

Season	Anchored gillnet	Large mesh drifting gillnet	Medium mesh drifting gillnet	Small mesh drifting gillnet	Set bag net	Baited long line	Unbaited long line	Other	None
Spring	9 (3%)	40 (13%)	208 (69%)	37(12%)	13(4%)	2(1%)	1(0%)	3(1%)	15(5%)
Summer	5 (2%)	38(13%)	266 (88%)	12 (4%)	10(3%)	2(1%)	0(0%)	3(1%)	2(1%)
Fall	6 (2%)	38(13%)	266 (88%)	30(10%)	17(6%)	2(1%)	0(0%)	3(1%)	2(1%)
Winter	8 (3%)	32(11%)	223 (74%)	46(15%)	12(4%)	2(1%)	0(0%)	3(1%)	14(5%)

Fishing Effort

Fishers reported 11 coastal districts across all zones as the home port of their vessel (Table 7). Forty-three percent of the fishers were captains, and 57% were crews. On average, fishers had 25 years of experience (SD = 11.27, range = 5- 60 years).

Table 7: Reported home port of vessels within management zones in coastal Bangladesh.

Zone	District	Number of fishers	Percent of fishers
West	Bagerhat	62	21%
	Khulna	1	0%
	Pirojpur	21	7%
South	Barguna	43	14%
	Bhola	5	2%
	Barisal	8	3%
	Lakshmipur	37	12%
	Patuakhali	46	15%
	Noakhali	31	10%
East	Chittagong	31	10%
	Cox's Bazar	16	5%

Gear was operated at depths ranging between 1 and 500 m; the median depth ranged between 11 and 144 m.

Duration of fishing trips (including travel time to and from the fishing grounds) ranged from one to 22 days, with 11 days being the most reported duration. Trip duration varied by districts (Figure 4).

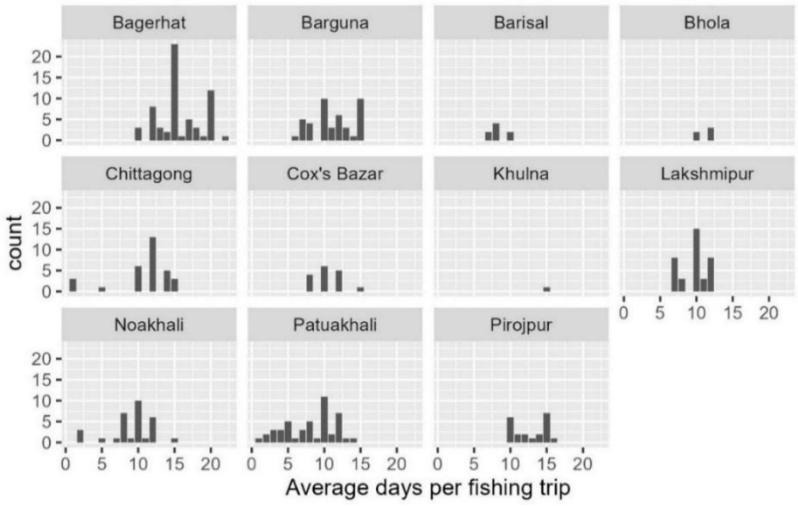

Figure 4. The average number of days per fishing trip by District. Each bar represents a single interviewee.

There are currently three declared Marine Protected Areas (MPAs) in Bangladesh: Swatch-of-no-Ground (SoNG), Nijhum Dwip, and St. Martin's. Swatch-of-no-ground was used by 80% of fishers and 76% of traders; Nijhum Dwip by 57% and 75%, and St. Martin's by 38% and 86% of fishers and traders, respectively. Sixty-seven percent of fishers and 35% of traders also reported fishing inside or at the edges of the Sundarbans mangrove forest, adjacent to the Swatch-of-no-Ground MPA (Figure 5).

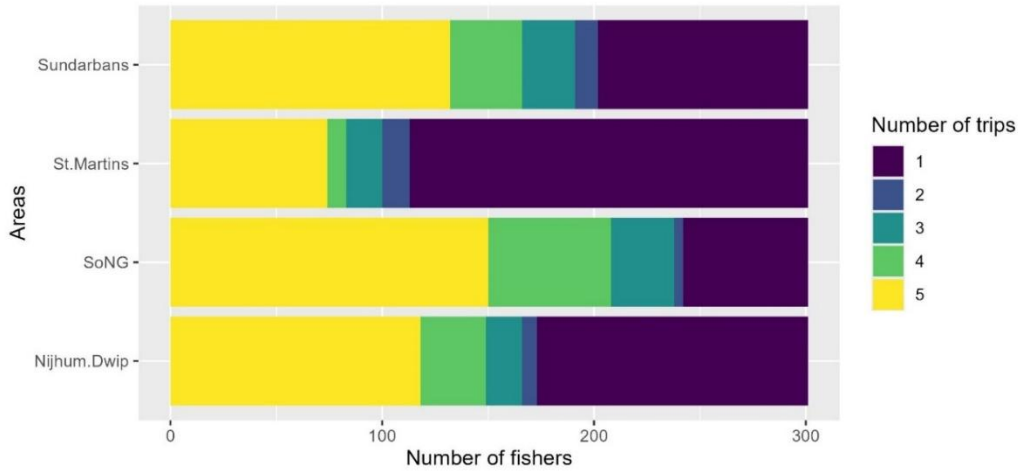

Figure 5. Fishing activity in three Bangladeshi Marine Protected Areas (MPAs) and the Sundarbans mangrove forest.

Cetacean Sightings and Bycatch

Most fishers reported seeing cetaceans while travelling to fishing areas (99%) and while fishing (96%; Figure 6). Few traders reported seeing cetaceans while travelling to fishing areas and while fishing (5% and 16%, respectively).

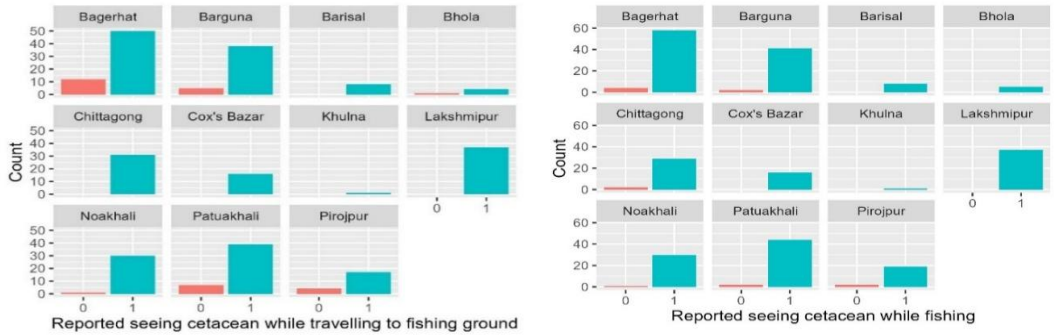

Figure 6. Number of fishers seeing cetaceans while travelling to fishing areas (left) and while fishing (right), presented by District. Blue bars reflect "Yes" and red reflect "No" responses.

More than half (53.1%, n = 160) of fishers reported bycatch of one or more cetaceans during their career and almost half (45.5%, n = 137) reported awareness of one or more cetaceans being taken as bycatch during their career (Figure 7). The majority (28%, n = 85) of entanglements occurred while fishing in water deeper than 40m.

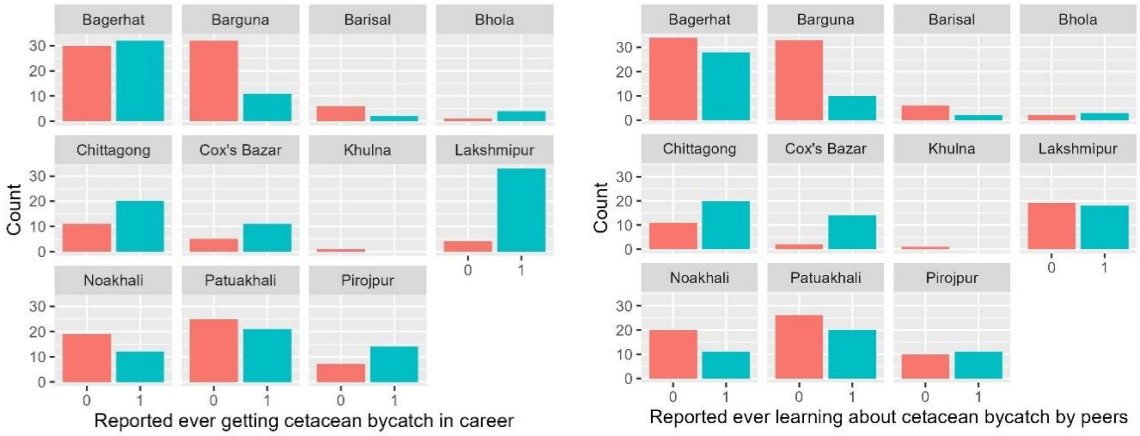

Figure 7. Number of fishers reporting one or more bycaught cetaceans in their gear (left) and awareness of one or more bycaught cetaceans (right) at any time during their career. Results are presented by District. Blue bars reflect "Yes" and red reflect "No" responses.

Eighteen percent of fishers reported at least one bycaught cetacean in their gear within the past year; four fishers reported at least one bycaught cetacean per month; one fisher reported one bycaught cetacean per week. Sixty-eight fishers reported awareness of one or more bycaught cetaceans in the past year, while three reported awareness of one or more bycaught cetaceans at least once a month in the past year.

All reported bycaught cetaceans were discarded (if dead) or released (if alive). None were reported to be used as bait or sold for oil or bait.

Fishing effort (measured by average number of days per fishing trip, and minimum and maximum depth of fishing) was positively related to the probability of cetacean bycatch (Table 8). This pattern held for trip durations ranging from 1-22 days, and minimum and maximum fishing depths ranging from 1-180m and 8-500m, respectively.

Table 8: Probability of cetacean bycatch (Estimate) and uncertainty associated with this probability (lower and upper confidence intervals of 2.5 and 97.5%) according to fishing effort, as measured by average number of days per trip, and minimum and maximum depth of fishing.

Average days per fishing trip				**Minimum depth of operation (m)**				**Maximum depth of operation (m)**			
Days	Estimate	2.5 %	97.5 %	Depth	Estimate	2.5 %	97.5 %	Depth	Estimate	2.5 %	97.5 %
1	0.43	0.27	0.62	1	0.57	0.48	0.66	8	0.56	0.46	0.66
10	0.61	0.53	0.68	8	0.60	0.52	0.68	54	0.58	0.49	0.67
11	0.62	0.55	0.69	11	0.61	0.53	0.68	144	0.62	0.54	0.68
14	0.68	0.59	0.75	15	0.62	0.55	0.69	360	0.69	0.57	0.79
22	0.80	0.34	0.91	180	0.96	0.63	0.99	500	0.74	0.57	0.86

The probability of cetacean bycatch varied by districts, with the highest probability in Lakshmipur (with an average of 10 days per fishing trip at 5.4-360 m depths), and the lowest in Barisal (with an average of 8 days per fishing trip at 3.5-45 m depths; Table 9).

Table 9: Probability of cetacean bycatch (Estimate) for the entire Bangladeshi coast and for each district using a Bayesian framework (see Methods). Also shown are the lower and upper credible intervals (CI) for each probability.

Probability of Cetacean Bycatch	Estimate	2.5%	97.5%
Entire Bangladeshi coast	0.62	0.56	0.66
District			
Bagerhat	0.61	0.49	0.72
Barguna	0.40	0.27	0.54
Barisal	0.33	0.11	0.61
Bhola	0.73	0.42	0.93
Chittagong	0.78	0.63	0.89
Cox's Bazar	0.81	0.61	0.94
Khulna	0.60	0.14	0.91
Lakshmipur	0.86	0.73	0.94
Noakhali	0.42	0.26	0.57
Patuakhali	0.58	0.45	0.71

The clear discrepancy between fishing effort and bycatch probability across districts, especially between Bagerhat and Lakshmipur may be attributed to differences in access to and utilization of fishing grounds and fishing practices. Fishers from Bagerhat usually travel farther from their home ports, resulting in longer travel times, therefore, in higher measured fishing effort.

In contrast, fishers from Lakshmipur operate in productive, shallow estuarine waters near the mouth of the Ganges-Brahmaputra-Meghna river system, an area recognized as critical habitat for several cetacean species (Smith et al., 2004). Additionally, their reported fishing at depths of up to 360 meters suggests that these fishers are also operating within the Swatch-of-No-Ground MPA, another important cetacean habitat. This operational range across two critical cetacean habitats likely increases spatial overlap with cetaceans, thereby elevating their likelihood of getting more bycatch without increasing overall effort, as measured by the metric of this study.

Sociopsychological assessment

Four agencies are responsible for fisheries and bycatch management in Bangladesh: DoF, Coast Guard (CG), Navy (BN), and Bangladesh Forest Department (BFD). Of these, DoF has primary responsibility for fisheries through conservation, management, and aquaculture. They conduct fisheries resource surveys to produce stock assessments, publish annual fisheries statistics, and assist ministries in proposing acts and policies. CG and BN are responsible for at-sea monitoring during temporal fisheries closures and general oversight of territorial waters. BFD is not responsible for managing marine fisheries but is a key player in the protection and conservation of marine wildlife through their mandate to declare MPAs.

Fishers' knowledge of these agencies provides valuable insights into compliance with existing regulations. Awareness of each agency ranged from 62% (DoF) to 43% (BFD; Table 10).

Table 10: Degree of awareness of fisheries and bycatch management agencies reported by fishers in response to the question: Do you believe that this agency is responsible for fisheries/cetacean bycatch management in Bangladesh?

Agency	Yes (N, %)	Unsure (N, %)	No (N, %)
Department of Fisheries (DoF)	187 (62%)	58 (19%)	56 (19%)
Coast Guard (CG)	183 (61%)	68 (23%)	50 (17%)
Navy (BN)	134 (45%)	87 (29%)	80 (27%)
Forest Department (BFD)	128 (43%)	73 (24%)	100 (33%)

Fishers' knowledge of the existing policies and other potential management strategies provides valuable insights into compliance. This is summarized in Table 11. Almost all fishers were aware of temporal closures and banning monofilament nets. More than 90% of fishers were also aware of vessel registration and minimum mesh size restrictions. Only 30% of fishers were aware of any MPAs in Bangladesh and fewer (23%) were aware of any MPAs in the areas where they fish. Similarly, few fishers (3% - 36%) were aware of gear and fishing method modification policies.

Table 11: Degree of awareness of existing and potential fisheries and cetacean bycatch management strategies reported by fishers in response to the question: Do you believe this fisheries policy/management strategy is in place? For spatial and temporal closures, monofilament nets ban and minimum mesh restriction, fishers were asked as it pertains to a) all of Bangladesh, b) the areas where they fish.

Fisheries policy/bycatch management strategy	True (N, %)	Unsure (N, %)	False (N, %)
Temporal closure (fishing ban) across Bangladesh	298(99%)	1(0%)	2(1%)
Temporal closure (fishing ban) in their fishing area	298(99%)	1(0%)	3(1%)
Ban of monofilament nets across Bangladesh	298(99%)	1(0%)	2(1%)
Ban of monofilament nets in their fishing area	298(99%)	0(0%)	2(1%)
Vessel registration	286 (95%)	5(2%)	10 (3%)
45mm minimum mesh for any gear across Bangladesh	281(93%)	11(4%)	9(3%)
45mm minimum mesh for any gear in their fishing area	278(92%)	11(4%)	12(4%)
Operation method modification (subsurface nets)	109(36%)	107(36%)	85(28%)
Spatial closure (MPA) across Bangladesh	89(30%)	112(37%)	100(33%)
Spatial closure (MPA) in their fishing area	69(23%)	111(37%)	121(40%)
Gear modification (pingers)	8(3%)	190(63%)	103(34%)

Table 12 summarizes the probability of fishers' intention to comply with cetacean bycatch management strategies as a function of attitude, social norms, self-efficacy, and subjective knowledge. Of all management strategies, the highest probability of compliance was associated with vessel registration (0.97, 95% credible interval lies within 0.96-0.98).

Table 12: Probability of fishers' compliance (estimate) and associated uncertainty (lower and upper confidence intervals of 2.5 and 97.5%) with cetacean bycatch management strategies as a function of sociopsychological factors. Here "Against" reflects the probability of noncompliance and "For" reflects compliance.

Fisheries and Bycatch Management Strategy	Compliance	Estimate	2.5%	97.5%
Vessel registration	Against	0.02	0.01	0.04
	For	0.97	0.96	0.98
MPAs: Spatial closure	Against	0.17	0.13	0.20
	For	0.63	0.58	0.67
Fishing Ban: Temporal closure	Against	0.49	0.45	0.53
	For	0.48	0.44	0.52
Monofilament nets ban: Gear switching	Against	0.03	0.01	0.04
	For	0.97	0.95	0.98
45 mm minimum mesh for all nets: Gear specification	Against	0.13	0.10	0.16
	For	0.79	0.76	0.82
Pingers: Gear modification	Against	0.02	0.01	0.04
	For	0.72	0.68	0.75
Subsurface gillnet: Operation method modification	Against	0.18	0.15	0.20
	For	0.65	0.62	0.68

The lowest probability of compliance was associated with temporal closures. Equity, reduced corruption, aligning temporal bans with neighboring countries to reduce the

number of foreign vessels entering Bangladeshi waters, and optimal incentive distribution during temporal bans were reported by respondents as drivers of improved compliance.

Additional analysis in the future will focus on estimating the effect of each of the factors independently on probability of compliance and quantifying similar probabilities and effects for traders.

Significance

The project findings have several significant contributions towards reducing cetacean bycatch in Bangladesh and the greater region. First, it established a baseline understanding of stakeholders' perceptions and behavioral intentions regarding approved bycatch mitigation strategies, such as their acceptance of acoustic deterrents (pingers). This evidence-based assessment forms the basis to identify the most effective management strategies, enhancing stakeholder acceptance and resource efficiency and ultimately maximizing benefits for both cetaceans and humans.

Second, this project developed and validated a cost-effective, time-efficient, interview-based tool for collecting sociopsychological data, ideal for collecting baseline cetacean bycatch information in data-poor contexts. The tool's replicable nature could potentially enhance global understanding of policy acceptance related to cetacean bycatch.

Finally, this project has clearly positioned cetacean bycatch in SSF as a significant but addressable threat in Bangladesh. With appropriate science-based conservation actions that consider stakeholder psychology, we believe we can create clear pathways to bycatch reduction.

Future Directions

To enhance the outcome of this project, we aim to develop and validate a human behavior change framework in the near future. The framework would include specific metrics to quantify both reduced cetacean bycatch rates and improved compliance with mitigation measures.

This effort will require collaboration among marine mammal scientists, behavior change experts, and science communicators to design effective behavior change interventions and communication materials tailored to the psychological profiles of stakeholders. Future projects would focus on partnering with government agencies to ensure that behavior change frameworks strengthen trust in governance and establish direct communication channels to enhance transparency to achieve maximum conservation success.

To achieve this goal, we have identified the following next steps that build directly on the current project:

1. **Conduct scenario-based conservation planning** that utilizes the current sociopsychological data to prioritize influential factors driving bycatch reduction policy compliance.
2. **Conduct a Social Network Analysis** to identify key information channels to target communication efforts through identified influential informants, maximizing information spread with minimal resources, and tailor engagement strategies based on how different stakeholder clusters prefer to receive and share information.
3. **Collaborate with relevant government agencies** to co-develop feasible implementation pathways.

These logical extensions of the current project would significantly enhance conservation outcomes and reduce cetacean bycatch in SSF. We are working on securing resources and partnership opportunities to pursue these directions.

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