Fishing for the facts: river dolphin bycatch in a small-scale freshwater fishery in Bangladesh

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Abstract

Fisheries bycatch is a primary driver of cetacean declines, especially for threatened freshwater cetaceans. However, information on the factors influencing cetacean susceptibility to bycatch in small-scale fisheries is limited, impeding development of evidence-based conservation strategies. We conducted 663 interviews with fishers from southern Bangladesh to investigate the influence of net and set characteristics on seasonal bycatch rates of Ganges River dolphins *Platanista gangetica gangetica* and assess the sustainability of annual mortality levels. Between October 2010-October 2011, 170 bycatch events (and a minimum of 14 mortalities) were reported, 89% of which occurred in gillnets. The probability of bycatch increased as water depth declined, and as net mesh size increased. While the number of recorded bycatch incidents was higher in gillnets, risk of mortality was greater in set bagnets. Our mortality estimate indicates that fisheries-related bycatch currently exceeds the sustainable limit recommended by the International Whaling Commission by 3.5 times. Numerous regulations have been developed to improve the productivity of commercially important fisheries, if regulations were effectively enforced these may also reduce river dolphin bycatch.

Keywords: bycatch; gillnet; Ganges River dolphin; local informant data; *Platanista gangetica gangetica*, small-scale fisheries

1. Introduction

Incidental capture of non-target species in fisheries, known as bycatch, is a primary driver of declines in many animal groups including cetaceans (Lewison et al., 2004). The majority of global aquatic mammal bycatch is thought to occur in gillnets, curtain-like nets set vertically in the water column to trap fish by their gills (Read et al., 2006). Among cetaceans, bycatch-related mortality is considered the principal cause of the decline in vaquita *Phocoena sinus*, the world's most threatened cetacean, and to have contributed significantly to the extinction of the Yangtze River dolphin *Lipotes vexillifer* (D'Agrosa et al., 2000; Turvey et al., 2007). Concerns about the impact of bycatch on the status of aquatic species has prompted research into factors affecting bycatch rates. A range of factors have been identified and can be divided into: gear (e.g. mesh size, hook type; Kraus et al., 1997; Forney et al., 2011), operational (e.g. location, season; Vinther, 1999; Yeh et al., 2013), and species-specific (e.g. species behaviour, body size; Wallace et al., 2008; Yeh et al., 2013).

Independent-observer programmes are the ideal source of data on factors affecting bycatch, however, this is logistically unfeasible in many small-scale fisheries. Given the ubiquity of gillnets within small-scale fisheries (Moore et al., 2010), low-cost solutions for studying bycatch are urgently needed.

Interviews with local informants using the same environment as target species are an increasingly popular method for obtaining data on key conservation parameters rapidly, at low-cost, over wide geographic areas, and can also provide a perspective on past and present status and trends where data are otherwise absent (Moore et al., 2010; Turvey et al., 2013).

Interviews constitute an important alternative source of data for conservation and have been used to study harvesting intensity (Jones et al., 2008), population trends (Lozano-Montes et al., 2008) and bycatch (Moore et al., 2010; Liu et al., 2017) across many taxa. However, studies have demonstrated a range of biases affecting the accuracy of informant data, including: 1) under-reporting of illegal behaviours to avoid negative personal consequences (Tourangeau and Yan, 2007), 2) declining recall accuracy over longer time periods (Bradburn et al., 1987), 3) misremembering facts where the event is deemed 'unimportant' or occurs regularly (Daw et al., 2011), and 4) misidentification of species (Moore et al, 2010). For these reasons, standardised interview-based surveys have rarely been used to generate baselines on patterns and levels of bycatch for freshwater cetaceans.

Freshwater cetaceans are amongst the most threatened mammals (Reeves, Smith, Kasuya, 2000), partly due to small-scale fishery interactions and small population size which makes them vulnerable to even low levels of mortality (e.g. Krützen et al., 2018). Minimum estimates of bycatch indicate that fishing gear entanglement represents a significant source of mortality: e.g. 87% of Irrawaddy dolphin *Orcaella brevirostris* mortalities in the Mekong River are attributed to gillnet entanglement, making it the most significant threat to this population (Beasley et al., 2007; Beasley et al., 2013). However, the nature of these interactions and levels of mortality are poorly understood and impede the development of robust conservation solutions (Reeves et al., 2013).

The Ganges River dolphin *Platanista gangetica gangetica* occurs in Nepal, India, Bangladesh and possibly Bhutan, and is considered Endangered by IUCN (Smith, Braulik and Sinha, 2012). Given its conservation status, killing and trade of dolphins is prohibited under the Indian Wildlife Protection Act (1972), the Bangladesh Wildlife Preservation Act (2012), the

Nepal National Parks and Wildlife Conservation Act 2029 (1973), the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) and the Convention on Migratory Species (CMS). While efforts are ongoing to address knowledge gaps on abundance (Richman et al., 2014), habitat preferences (Smith et al., 2009) and population trends (Smith et al., 2001; Richman, 2015), there is a lack of resources for addressing knowledge gaps regarding patterns and sustainability of bycatch (Mansur et al., 2008).

Focusing on an isolated population of Ganges River dolphins in southern Bangladesh, we conducted an interview survey with fishers to identify the drivers of gillnet bycatch and to quantify annual mortality. We demonstrate that despite the biases associated with this approach, interviews are a powerful tool for addressing some of the knowledge gaps on freshwater cetacean bycatch in small-scale fisheries. We use these data to make informed recommendations for conservation management.

2. Methods

2.1. Data collection

Fisher interviews were carried out from October 2011-February 2012 in settlements bordering the Halda, Karnaphuli and Sangu rivers and the Shikalbaha-Chandkhali Canal, collectively known as the Karnaphuli-Sangu river complex (Figure 1). Interview teams visited every settlement within the study area. Because of the lack of a robust sampling frame of the target population (active fishers), random sampling was not possible. Informants were interviewed based on suitability and availability, and asked to suggest other potential

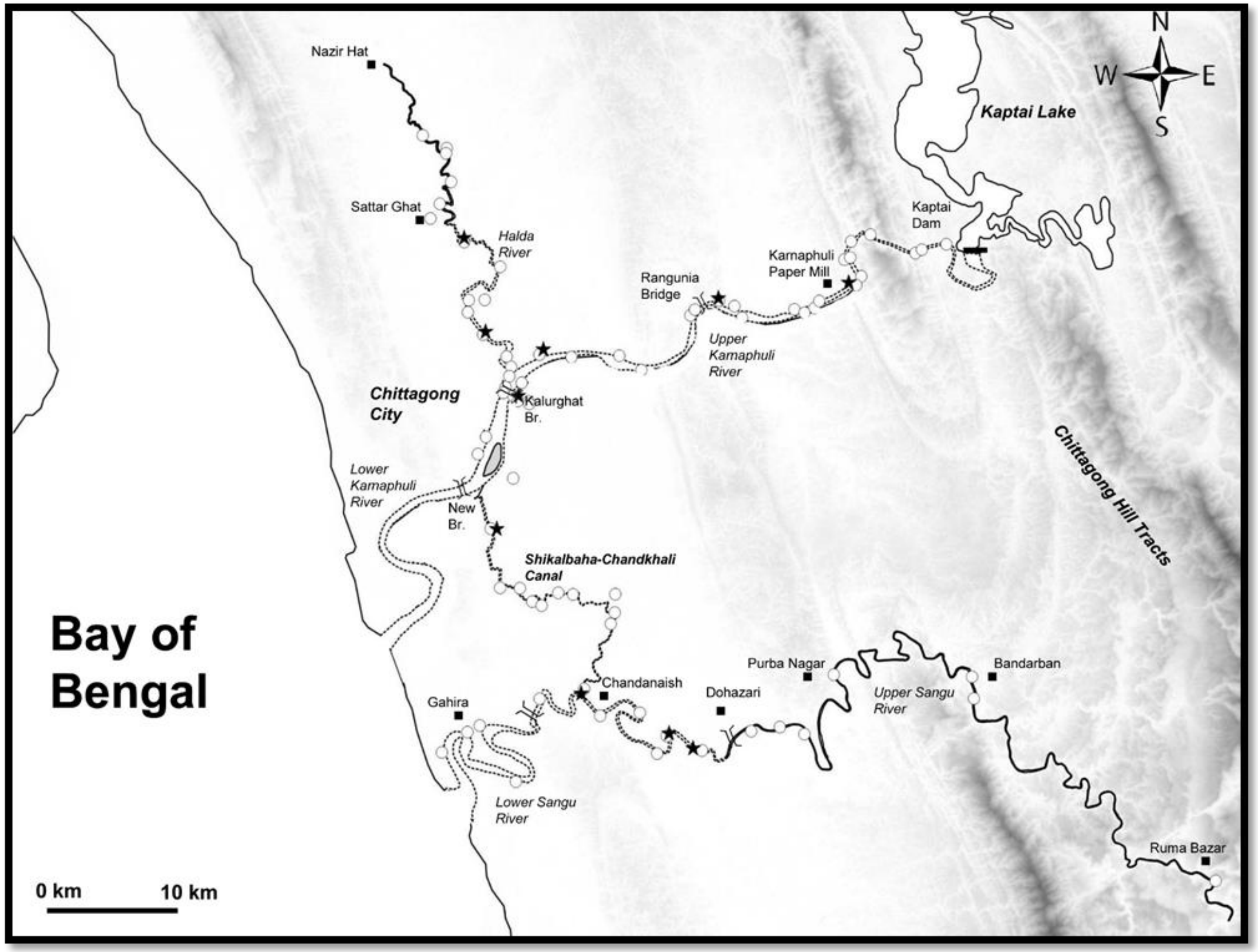

Figure 1: Location of pilot study sites (black stars) and interview sites (white circles) across the Karnaphuli-Sangu rivers complex in southern Bangladesh.

informants (Newing, 2011). Fishers fish in groups of two to ten individuals: to ensure no duplicate recording of bycatch events, members of each group were identified and only one individual from each group was interviewed. The aim of the interviews was to document: 1) information on the characteristics of bycatch events between October 2010-October 2011; 2) anecdotal information about older bycatch events, 3) knowledge and attitudes on fishery regulations. Interviews were carried out by three teams consisting of a translator (a zoology student from the University of Chittagong and living in the local fishing community) who was responsible for conducting the interview, and a note-taker (native English speakers) who recorded responses in English. Translators were told to ask questions in exactly the way they were detailed in the questionnaire, and to translate responses as provided. Translators were asked to inform the note-taker if they did not understand the informant's response. Interview teams were encouraged to maintain neutral expressions and neutral responses throughout the interviews so as not to bias informant responses (Bernard, 2006). A standardised questionnaire (Supplementary Table 1, 2) was used and designed to a maximum of 30 minutes to reduce potential non-responses or inaccurate responses from informant fatigue. Questionnaire design was based on recommendations in Bernard (2006) and comprised closed and open-ended questions. Closed questions incorporated a 'don't know' option to minimise pressure to provide responses, and an 'other' option to accommodate unforeseen responses. The questionnaire was developed in English and translated into Bangla by the three translators. The questionnaire was then translated back into English to ensure no loss of meaning. Discrepancies were discussed, and the translation process was iterated until satisfactory translation was achieved. Questionnaire and sampling design were trialled in a pilot study comprising 46 interviews in 10 settlements across all waterways (Figure 1). Informant consent was obtained prior to interviews; informants were assured of confidentiality and that they could end interviews at any time and were briefed on the objectives of the research. The project design was approved by the Zoological Society of London Ethics Committee.

Levels of relevant knowledge were assessed at the start of interviews by asking informants to identify the Ganges River dolphin and two local, common fish species (phasa *Setipinna phasa*; ilish *Tenualosa ilisha*) from photographs and describe where they occur (sea/river). If informants struggled to identify the dolphin, they were prompted with clues about behaviour and size. Informants were assigned to one of three reliability categories: high (identified all species); medium (identified dolphin and one other species); and low (recognised only one species, identified only the fish or unable to identify any species). Informants who received a low reliability score were not interviewed. Informants were asked where they fish, how long they have lived in the study area and whether they were retired to ensure information was specific to the area of interest and for the time-frame of interest (i.e. October 2010–October 2011). Informants were questioned about the types and characteristics of gear they use (e.g. mesh size, length, net depth, number of hooks); fishing effort (average days/week, months); and fishing location(s); and were assigned a median river depth based on their reported fishing location (see Supplementary Material for details regarding the estimation and validation of net measurements, and estimation of median river depth). A subset of informants (n=114), who were willing to participate in a longer interview, were asked questions about regulations governing local fisheries and the dolphin. To quantify levels of bycatch/year, informants were asked to describe all bycatch events from the approximate previous 12-month period of October 2010-October 2011 (e.g. gear involved, location). Informants were only asked to recall bycatch events from the last 12-months as the detail for events prior to this period became increasingly vague. If the last recalled bycatch event dated >1 year earlier, they were asked to describe this event only.

To validate numbers of informant-reported mortalities, an independent mortality monitoring network was established in October 2011. Informants were issued with a phone number to call if they saw/heard of dead dolphins or bycatch events. Rewards were not offered for reporting mortalities or bycatch to discourage intentional killings.

2.2. Data analysis

2.2.1. Informant reports of gear use, and comparison with observed gear use

For the interview data, numbers of gear types and people using each gear was calculated. Reported gears were assigned to one of six locations ((1) Halda River; 2) Shikalbaha-Chandkhali Canal; Sangu River, divided into 3) Lower and 4) Upper Sangu at Dohazari Bridge; Karnaphuli River, divided into 5) Lower and 6) Upper Karnaphuli at Kalurghat Bridge) to investigate variation in bycatch across the study area. The Sangu and Karnaphuli were split into lower and upper reaches based on the availability of suitable dolphin habitat, and presence of dolphins respectively. Seasonality in gear use was investigated by calculating the number of nets in use between monsoon months (June-October) and non-monsoon months (November-May) for gillnets, long-shore nets (a rectangular net set on poles running adjacent to the river bank), set bagnets (a funnel-shaped net fixed to the river bed) and seine nets (rectangular net where one end is held on shore, and the other is driven by boat in a large arc across the river and bought back to shore; both ends are simultaneously pulled to shore). We excluded dragnets, hand nets, long-lines and rod and lines from the analysis as fishers use these gear casually and see them as relatively unimportant, so we consider it likely that their use was under-reported. Reported numbers of active gear were validated by comparing numbers of reported gears in February, against numbers observed during boat-based surveys (see Supplementary Material for further details): the comparison was restricted to February as observational data was only available for this period.

2.2.2. Factors influencing bycatch in gillnets

A logistic generalised linear model with binomial error structure was used to investigate the effect of net and set characteristics (Table 1) on the probability of dolphin bycatch per gillnet per season. The analysis was restricted to gillnet bycatch as there were too few bycatch incidents in other gear types. We used all bycatch data dating back to 1986, though most (96%) reported bycatch events occurred in the last two years. The response was modelled per season (monsoon or non-monsoon) and was modelled as binary rather than a count due to little variation in bycatch events per season, or days fished per week in each season (mean number of days fished=5; SD=1.16). We excluded data from the Halda River and Shikalbaha-Chandkhali Canal, and the Upper Sangu River due to insufficient fishing effort and lack of dolphin sightings respectively (Richman et al., 2014). Midpoint values were used where measurements were reported as ranges. Data from informants who fish multiple locations, were retired, or of questionable capacity to recall facts accurately (i.e. drunk or nervous) were excluded, leaving a dataset of 2,149 observations (i.e. individual net set per season) from 580 informants.

The relationship between response and predictor variables was inspected for non-linearity using generalised additive model plots fitted with cubic smoothing splines using the ‘mgcv’ package in R version 3.6.0 (R Development Core Team, 2013), with continuous variables plotted in linear, log and quadratic forms. Variance inflation factors (VIF) were used to

Table 1. Net and set variables considered for use in models investigating factors influencing probability of bycatch.

Variable	Definition	Unit
Net characteristics		
Mesh size (continuous)	Inside stretched distance between two knots on opposite sides of same mesh	Centimetres
Net length (continuous)	Length along longest edge of net	Metres
Net depth (continuous)	Length along shortest edge of net	Metres
Net type (categorical)		Drifting Fixed
Set characteristics		
Location (categorical)		Upper Karnaphuli River Lower Karnaphuli River Halda River Lower Sangu River Shikalbaha-Chandkhali Canal
Season (categorical)		Monsoon (mid-Jun to mid-Oct) Non-Monsoon (mid-Oct to mid-Jun)
Median river depth (continuous)		Metres

identify collinear variables using the 'corvif' function in the R package 'AED'; VIF scores >3 were considered evidence of collinearity (Zuur et al., 2009), and the variable that explained a greater proportion of model variance was retained.

A global model containing all possible remaining predictor variables (Table 1) and three two-way interactions that described potentially meaningful relationships between variables (net length and mesh size, season and location, season and mesh size) was fitted in R. Backward stepwise selection was used to identify the best model according to Akaike's information criterion (AIC). Models were ranked according to AIC, and model selection was based on Δi (the difference in AIC between model *i* and the minimum AIC for the model set). Models with Δi <2 were considered to have equivalent support. Coefficient estimates from the best model were used to predict bycatch probability per gillnet per season across a range of mesh size (1-11cm) and river depth (1-12m) values taken from the the interviews in the Lower and Upper Karnaphuli, and Lower Sangu.

2.2.3. Annual mortality and validation with observational data

A minimum count of annual fisheries-related dolphin mortality was calculated by summing numbers of dolphins that were discovered alive but subsequently killed, found alive but died and found dead in all net types during October 2010-October 2011. To validate informant data, we compared the number of mortalities reported during interviews for October 2011 against the number of mortalities reported through the mortality monitoring network. Reported and observed mortalities were considered the same incident if they occurred at the same location and in the same month. Where possible we tried to verify the cause of death with post-mortem analysis.

2.2.4. Outcome of gillnet and set bagnet entanglements

Chi-squared tests were used to test for differences in mortality frequencies between gillnets and set bagnets (gears with greatest numbers of bycatch events), with bycatch events assigned to one of two outcomes (alive/dead). Dolphins discovered alive in nets but killed during release were also classed as ‘dead’. Data on bycatch events across all time periods were used to maximise sample size.

2.2.5. Sustainability of fishing-related mortality

The International Whaling Commission sub-committee on small cetaceans agreed that “*it would be a matter of concern if bycatches/ and/or directed takes exceeded half the maximum growth rate of a population*” (International Whaling Commission, 1996). The population growth rate of Ganges River dolphins is unknown, so we adopted a conservative value of 4% as recommended by Wade (1998) for cetaceans where growth rate is unknown. A population estimate of 196 (95% CI: 187-273) was used based on a survey from 2012 (Richman, 2015). It is assumed the population is closed as it is isolated from the Ganges River system by a stretch of the Bay of Bengal (Smith et al., 2001).

2.2.6. Fishery regulations: knowledge, attitudes and compliance

We calculated the proportion of informants who: 1) could describe local fishing regulations, including the regulation prohibiting the killing and trade of the Ganges River dolphin; 2) comply/ don’t comply with fishery regulations 3) are satisfied with the compensation scheme during the Ilish fishing bans. Informant data on regulation details were validated by the fisheries department. We extracted key statements from the interviews describing the perceived causes for the differences in levels of knowledge about fishing regulations and reasons for non-compliance.

3. Results

3.1 Informant reports of gear use, and comparison with observed gear use

A total of 663 interviews were carried out in 74 settlements; we assume this sample represents a substantial proportion of the region's fisher population for these reasons: 1) interview teams visited every settlement within the study area and continued looking for new fishers until further enquiry resulted in no new informants to interview); 2) the comparison of reported and observed gear types were similar (Supplementary Material Figure 2). Gillnets were the dominant gear type recorded during our interviews (n=1027) followed by set bagnets (n=196), seine nets (n=137) and long-shore nets (n=64). We detected seasonality in net use with numbers of active gear during monsoon months almost double that of the non-monsoon months.

3.2 Factors influencing bycatch in gillnets

Informants recalled 304 unique bycatch incidents from 1986 onwards, with 248 having sufficient detail on associated net characteristics. Of the 304 reported bycatch incidents, a total of 170 were recorded from October 2010-October 2011; the majority occurred in gillnets (89%, n=151) and set bagnets (10%, n=17), with two further bycatch incidents in long-lines (Table 2).

Net depth was excluded from the analysis due to collinearity with mesh size. Model selection favoured a single model retaining mesh size, location, season and median river depth (Table 3). We note that stepwise model selection may exclude some aspects of the model that are useful in understanding the mechanisms of bycatch. For example, there are five candidate models within 10 ΔAICc of our selected model. These models included net-length, net-type and some interactive effects of mesh-size. These effects have negligible impacts on our predictions (see models summaries in S1) but may be useful to consider in future studies. Probability of bycatch during October 2010-October 2011 declined with decreasing mesh size and increasing median river depth and showed a similar pattern of decrease across all locations and both seasons (Figure 2). There were spatio-temporal differences in the overall bycatch probability: there was higher probability in the Lower Sangu relative to the Lower and Upper Karnaphuli for all mesh sizes and depths, and a higher probability during the monsoon relative to non-monsoon for all locations (Figure 2).

3.3 Annual mortality and validation with observational data

Of the 170 bycatch events from October 2010-October 2011, 14 dolphins were reported dead: eight in gillnets, five in set bagnets, one in a long-line with the remainder released alive (Table 2). Of the 14 mortalities, 11 were dead upon discovery, one died during release and two were killed to assist with their removal from fishing gear (Table 2). Of the nine reports of intentional killings from 1986-2011, six were to assist with removal from fishing gear, two as punishment for damaging gear, and one for its oil.

The mortality estimate represents a minimum only as interview data were obtained non-randomly and so data was not extrapolated to the entire population, and fishers may have under-reported bycatch events. Independent data from the mortality monitoring network confirmed two of the dolphin mortalities reported during our interviews (October 2011), and

Table 2: Total number of bycatch events (Total [released alive, killed, alive but died during release, released dead]) between October 2010 and October 2011, and between October 2011 to 1986.

Gear type	No. bycatch events between Oct 2010 – Oct 2011 (Total [alive, killed, alive but died, dead])	Total no. bycatch events between 1986 - Oct 2011 (Total [alive, killed, alive but died, dead])*
Gill nets	151 [143, 2, 1, 5]	213 [189, 4, 4, 16]
Hand nets	0 [0, 0, 0, 0]	2 [1, 0, 0, 1]
Long line	2 [1, 0, 0, 1]	10 [6, 0, 0, 4]
Seine net	0 [0, 0, 0, 0]	8 [4, 3, 0, 1]
Set bag nets	17 [12, 0, 0, 5]	71 [42, 2, 1, 26]
Total	170 [156, 2, 1, 11]	304 [242, 9, 5, 48]

* Note that for bycatch events further back than October 2010 informants were not asked to recall every bycatch event each year, simply the last one they could remember.

Table 3: Model results summary of factors affecting dolphin bycatch.

Model	**K**	**AICc**	**ΔAICc**	**Weight**
Mesh size, River depth, Season, Location	6	789.36	0	0.59
Mesh size, River depth, Season, Location, Net length	7	791.37	2.01	0.22
Mesh size, River depth, Season, Location, Net length, Net length*Mesh size	8	792.57	3.21	0.12
Mesh size, River depth, Season, Location, Net length, Net length*Mesh size, Season*Mesh size	9	794.29	4.93	0.05
Mesh size, River depth, Season, Location, Net length, Net type, Net length*Mesh size, Season*Mesh size	11	796.01	6.65	0.02
Mesh size, River depth, Season, Location, Net length, Net type, Net length*Mesh size, Season*Mesh size, Season*Location	12	799.87	10.52	0.00

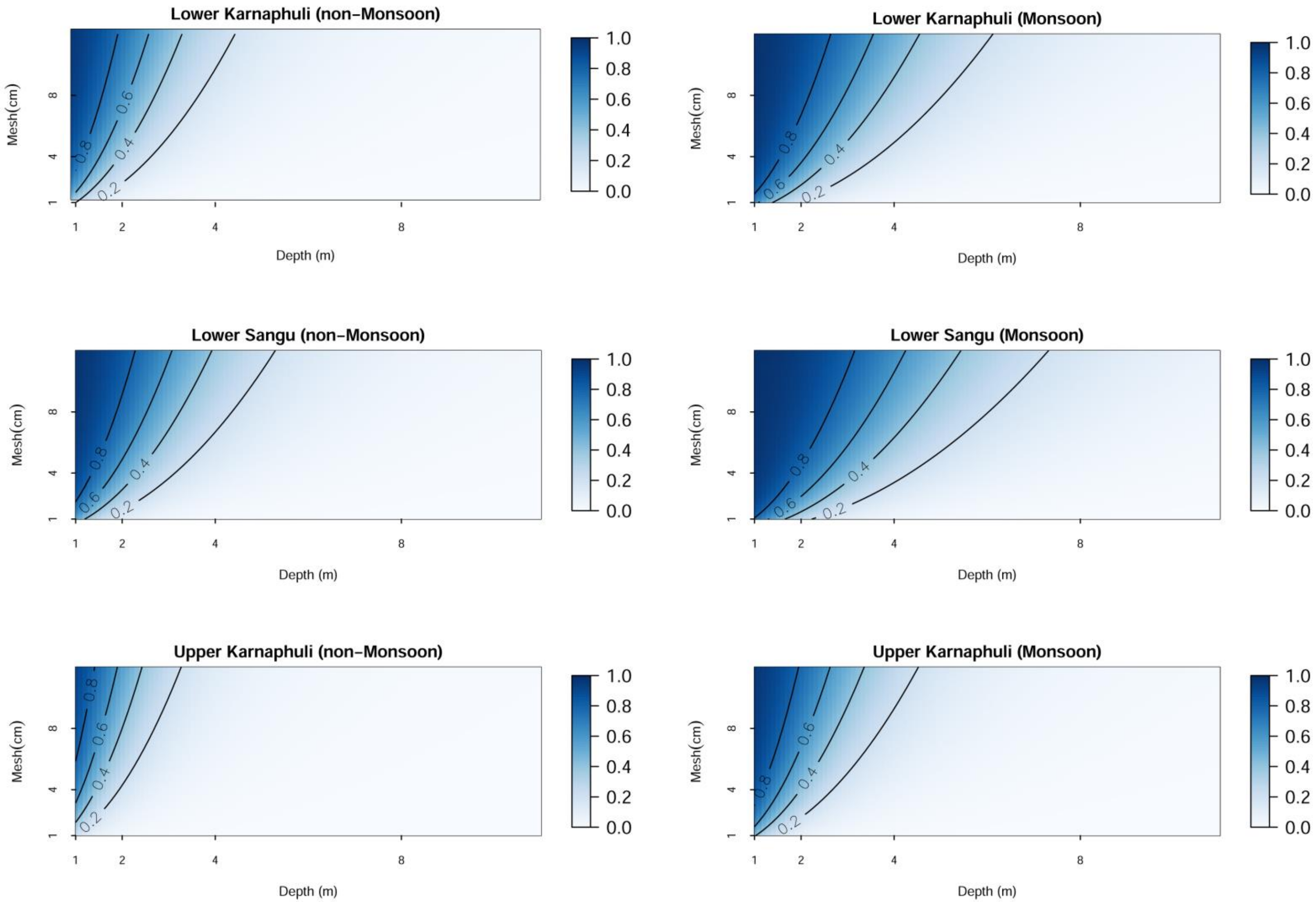

Figure 2: Probability of bycatch per gillnet per season (non-monsoon and monsoon) in the Lower Karnaphuli, Lower Sangu and Upper Karnaphuli rivers. Contour lines and shading represent probability of bycatch. See Supplementary Figures 3-5 for confidence limits.

confirmed a further two mortalities outside of our study period (November and December 2011). The October mortalities were not observed by the survey team but were verified by photographs that appeared in the local newspaper. The November and December mortalities were observed by the survey team.

3.4 Outcome of gillnet and set bagnet entanglements

The outcome of bycatch in gillnets and set bagnets differed significantly (χ^2=171.6, df=2, p<0.0001), with 41% (n=29/79) of set bagnet entanglements resulting in mortality relative to 11% (n=24/213) of gillnet entanglements (Table 2).

3.5 Sustainability of fishing-related mortality

The estimate of annual mortality (n=14) represents a mortality rate of 7% of the population (196 individuals) and therefore exceeds the sustainable limit (half the maximum growth rate = 2%) recommended by the International Whaling Commission.

3.6 Fishery regulations: knowledge, attitudes and compliance

Fishers described seven regulations in the form of gear bans, mesh-size restrictions, species-size restrictions and seasonal bans (Table 4). Only two of 580 informants knew it was illegal to kill the dolphin. Fewer than 50 percent of informants knew about the gear bans (Table 4). Knowledge was higher for the regulations affecting the Ilish fishery and the Halda fishing ban (>60 percent; Table 4).

Table 4: Details of fishery regulations in place in study area. Data were obtained from local informants and verified by the local fisheries department.

Type of regulation	Regulation details	Timing	Proportion who knew of the regulation	Proportion of informants who comply with the law
Gear ban	Monofilament, synthetic nylon gill nets (*current jaal*)	All year	37%	70%
	Explosives, weapons and poison for harvesting fish	All year	49%	99%
	Mosquito-mesh nets	All year	41%	12%
Mesh size restriction	Gill nets with stretched mesh size <10 cm in the Ilish fishery	All year	65%	51%
Species size restriction	Ban on harvesting young Ilish < 23 cm	November to May	68%	32%
Seasonal closure	Ban on all fishing activity in the Halda River, except fishers employed by government to harvest carp eggs	February to July	82%	45%
	Ten-day ban on all fishing activity every year to protect Ilish brood stock	15 days in September/ October	87%	35%

Levels of compliance with regulations were low (Table 4), other than for the laws banning explosives and *current jaal*. Informants provided the following reasons for the differing compliance levels: a) compliance with the *current jaal* regulation is high because fines are high (n=1); b) compliance with the mosquito-mesh net regulation is low because fines are low and nets are not confiscated by officials (n=2); c) compliance with the poison-fishing regulation is high as it's difficult to fish conspicuously and other fishers will punish offenders (n=1); d) compliance with the Ilish (n=4) and Halda (n=5) regulations is low because they're economically valuable fisheries so there's a lot to be gained from breaking the laws. Four fishers described that most fishers are in debt to informal money lenders (*Mohajan*) and the threat of failing to repay loans (i.e. physical threats to self and familymembers) is greater than the threat of sanction from fishery enforcement officers (i.e. fines, seizure of fishing gear).

Interviews revealed that the government compensates fishers for loss of earnings during the ilish ban with a 10kg sack of rice/household; however, 65 percent (n=74/114) receive it infrequently and 28 percent (n=32/114) had never received compensation. Ninety two percent of informants (n=103/114) said they were unsatisfied with rice as a form of compensation, and 86 percent (n=89/103) reported it doesn't allow them to repay debts.

4. Discussion

Fisheries-related mortality represents one of the most significant threats to freshwater cetaceans (Smith et al., 2001; Choudhary et al., 2006) but limited resources prevent quantification of levels and drivers of mortality in these conservation-priority taxa. We demonstrate that interviews provide much-needed insight into the drivers and levels of mortality of Ganges River dolphin bycatch in gillnets. Given the ubiquitous presence of these gear across the geographic range of Ganges River dolphins, these results are likely mirrored elsewhere. The scale of fisheries-related mortality we describe here is of major conservation significance for this endangered mammal and should be a catalyst for developing pragmatic solutions to bycatch.

4.1 Drivers of dolphin bycatch

Growing human demands for fishery resources will likely exacerbate aquatic mammal bycatch by intensifying competition for the same resource (Read, 2005). Previous studies have described a spatial overlap between Ganges River dolphins and small-bodied fish in shallow-water areas (Bashir et al., 2010; Kelkar et al., 2010). These feeding preferences might explain the elevated bycatch rates we detected in shallow-water areas. Worryingly, competition between fishers and dolphins is likely to increase as declines in large-bodied fish have been reported across India and Bangladesh (Kelkar et al., 2010), forcing fishers to switch to fishing smaller size-classes. Bycatch rates in shallow-water are further exacerbated by the 'barrier' effect created by gillnets set in these areas. Where the water depth is particularly shallow, mean gillnet length does not differ greatly from the width of the river (approximately 300m; Richman, 2015). Informal discussions with fishers revealed intentional setting of nets across the river to create a barrier to migrating fish, a pattern that has been observed elsewhere (e.g. Kelkar et al., 2010).

We'd assume a preference for small-bodied prey would increase dolphin vulnerability to bycatch in smaller-mesh gillnets, however, this contrasts with our findings. While dolphins exhibit less preference for large-bodied fish, previous research (Kelkar et al., 2010) describes the aggregation of dolphins around spawning ilish, catla and ruhi which are targeted using large-mesh nets. The presence of these feeding aggregations might also explain elevated bycatch rates during the monsoon, which coincides with a peak in spawning activity (Rahman et al., 2017).

We detected spatio-temporal patterns in the probability of bycatch that may serve to support more targeted efforts at reducing bycatch. Bycatch probability is higher in the Lower Karnaphuli and Lower Sangu than the Upper Karnaphuli, and increases markedly during the monsoon. The spatial differences in bycatch probability likely reflect the abundance of dolphins in these rivers (abundance is highest in the Lower Sangu and lowest in the Upper Karnaphuli (Richman, 2015). The relationship between bycatch probability and season may reflect changes in fishing effort that we were unable to capture using our question design. While we were unable to detect a difference in the mean number of days fished per season, data from other studies (Rahman et al., 2017) suggests there is a significant increase in monsoon fishing effort. Other studies using fisher interview data have effectively captured changes in harvesting and fishing effort (Jones et al., 2008; Daw et al., 2011), and so modified question design could provide further insights into the relationship between bycatch and season.

To date, the majority of bycatch mitigation effort for this species has focused on addressing gillnet bycatch. While gillnet fisheries undoubtedly pose a significant threat to the dolphin our data indicate that set bagnets constitute a significant source of mortality. This gear is rarely considered in bycatch studies, possibly reflecting low levels of mortality in other regions or differences in the detectability of bycatch cases. Given the prevalence of this net throughout river dolphin habitat in Bangladesh, studies are needed to assess the significance of this gear to overall bycatch.

4.2 Reliability of informant data

Interviews with local informants can yield accurate information on species status and constitute a low-cost tool for monitoring where standard monitoring methods may be prohibitively expensive (Turvey et al., 2013). Our findings regarding the distribution of bycatch in gear type, and the characteristics of these bycatch events agree with interview data from the Sundarbans and Brahmaputra (Mahabub et al., 2012; M. Datta pers. comm. 2014) leading us to conclude that interviews have proven an important tool for characterising dolphin bycatch in southern Bangladesh. Where possible we took a number of steps to control for cognitive biases (e.g. we limited the analysis to bycatch events recalled within the last year, validated reported net measurements), however, the accuracy of recall may have been improved by the fact bycatch events are regarded as memorable because of the damage they cause to nets resulting in subsequent loss of earnings.

Concern regarding the accuracy of the informant data largely relates to the quantifying of mortality: we believe this figure was underestimated, and so also the degree by which mortality is unsustainable. We incorporated numerous procedures to improve the accuracy of informant responses, however, two major sources of bias could not be accounted for: 1) interviewed fishers were a sample from the wider population, though the data suggests the sample incorporated the majority of active winter fishers, and; 2) fishers may have intentionally under-reported bycatch and intentional killings. Under-reporting of harvesting/ poaching is common in situations where the species is protected (Turvey et al., 2013). While the interviews revealed almost no awareness of the laws protecting dolphins, unintentional killing of animals is forbidden by religious laws and may have created an unwillingness to discuss these events. The low proportion of bycatch events that resulted in death may be seen as further indication of informant under-reporting. However, in the absence of data to assess survival rates from gillnet entanglement it is not possible to determine whether the gap between bycatch and mortality arises from under-reporting or high bycatch survivability.

4.3 Sustainability of dolphin bycatch

The extinction of the Yangtze River dolphin has been a wake-up call to the dire status of freshwater cetaceans. The area occupied by many species has declined dramatically, for the Indus River dolphin by as much as 80% since the 1870s (Braulik et al., 2014), and most species are listed as threatened on the IUCN Red List of Threatened Species. While there is historical evidence to suggest that the Ganges River dolphin has undergone a range decline following the construction of the Karnaphuli River dam in 1962 (Smith et al., 2001), little is known about trends in population size of the Karnaphuli-Sangu rivers population. In 2012, the population was estimated at 196 (95% CI: 186-208) individuals (Richman, 2015). Assuming our estimate of annual mortality is representative of previous years, it is difficult to reconcile with population persistence. Historically, it was thought the population was isolated from the Ganges river system by 75kms of marine water, (i.e. the Bay of Bengal; Smith et al., 2001). However, recent sightings of dolphins in full salinity seawater (Richman, 2015) leave us questioning whether this is in fact an open population. Given the implication of ongoing mortality at the level reported here, urgent efforts are needed to determine whether the population is closed and whether the mortality estimate is consistent over time.

4.4 Opportunities for mitigating bycatch

Intentional killing of river dolphins due to persecution, and for their products that are used for food, oil and most importantly medicine, is widely documented (Choudhary et al., 2006; Beasley, 2007; Richman, 2015). We found evidence of intentional killing for both purposes, though the market for dolphin products appears to be small and dying out due to its low economic value driven by a greater desire for conventional medicine (Richman, 2015). Our data suggest that intentional killing of bycaught dolphins is to ease with their removal from fishing gear, and as punishment for damaging nets are greater threats. Worryingly, there is a near absence of knowledge regarding the regulations that prohibit the killing of river dolphins in Bangladesh despite Ahmed (2004) recommending an awareness-raising programme. In 2013, the Bangladesh Cetacean Diversity Project (BCDP) established the *Shushuk Mela* project, a boat-based exhibition that engages local communities in freshwater cetacean conservation efforts. Part of their educational programme involves: 1) teaching fishers how to effectively release dolphins alive from fishing gear with minimal damage to the gear, and 2) the government regulations protecting dolphins. The exhibition has had a positive impact on attitudes towards freshwater cetaceans and changed local fishing practices (Mansur, Akhtar and Smith, 2014). The expansion of this scheme into the Karnaphuli-Sangu rivers complex could be an effective tool for overcoming the intentional killing of dolphins in this area.

Our data highlight numerous existing fishery regulations that, if enforced effectively, may reduce dolphin bycatch levels. Less-well adhered-to fishery regulations include the ilish fishing ban in the late monsoon (September to October), and the ban on the use of gillnets with a mesh size of less than 10cm in the ilish fishery. Effective enforcement of these measures would reduce dolphin bycatch by: a) limiting monsoon fishing effort, and b) limiting the use of nets with a mesh size that are associated with dolphin bycatch. Furthermore, bans on small-mesh nets, particularly non-selective gear such as mosquito-mesh nets, would reduce the exploitation and depletion of dolphin prey. However, both this and another recent study exploring concerns around ilish fishery management in Bangladesh (Dewhurst Richman et al., 2016) highlight many social and economic challenges (i.e. unfair distribution of compensation/benefits; a poor understanding of beneficiary preferences in terms of types of compensation; unintended consequences such as forcing fishers to use illegal fishing methods) that need to be addressed before these measures can be properly enforced.

A willingness to comply with regulations that govern the management of natural resources is largely determined by the probability that a contravention will be detected, and to a lesser degree, the severity of the punishment (Keane et al., 2008). Most studies of enforcement have focused on ensuring the gain from rule compliance is greater than non-compliance, such as increasing the severity of penalties (Keane et al., 2008). Increasing the severity of penalties on the Karnaphuli-Sangu fishers, in the absence of other efforts, will only exacerbate levels of debt and reliance on informal money lenders. Formal microcredit institutions with grace periods during fishing bans, adequate forms of compensation and financing of alternative income generating activities have been proposed (Dewhurst Richman et al., 2016) as potential mechanisms by which to overcome the compliance issues described here.

5. Conclusion

This study highlights the tremendous value of interviews for quantifying and characterising the harvest of a poorly-known species, while simultaneously exploring issues associated with governance and compliance. Given the ubiquitous use of gillnets across the range of the Ganges River dolphin our results are likely to be mirrored elsewhere highlighting the dire conservation status of this species. However, the many existing fishery regulations that are already in place for economically-important fish species could, if compliance were increased, contribute to simultaneously conserving river dolphins. River dolphin conservation need not hinder fishery production but instead could be yet another catalyst for addressing the social and economic barriers that impede sustainable fisheries management.

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