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Population demographics, habitat selection, and a spatial and photographic analysis of bycatch risk of Indo-Pacific humpback dolphins *Sousa chinensis* and bottlenose dolphins *Tursiops aduncus* in the northern Bay of Bengal, Bangladesh

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Abstract

Relatively large populations of Indo-Pacific humpback and bottlenose dolphins occur in the nearshore estuarine and submarine canyon waters, respectively, of Bangladesh.

Abundance estimates generated from a robust mark-resight analysis of 468 photo-identified Indo-Pacific humpback dolphins were 132 (SE=10, 95% CI = 115-153), 131 (SE=3, 95% CI = 124-137), and 636 (SE=58, 95% CI = 531-761) for winter seasons 2010-2013, respectively, with the substantial jump in population size in the third year explained by the large number of animals observed for the first time in a single group with 205 photoidentifications. The estimated probability of remaining in an unobservable state in the next survey when in an unobservable state in the previous survey was about 55%.

Abundance estimates generated from a robust mark-resight analysis of 1,144 photo-identified Indo-Pacific bottlenose dolphins were 1,701 (95% confidence interval = 1,533–1,888), 1,927 (95% CI = 1,851–2,006), 2,150 (95% CI = 1,906–2,425), and 2,239 (95% CI = 1,985–2,524) for winter seasons 2005–2009, respectively, with an overall apparent survival of 0.958 (95% CI = 0.802–0.992). Inter-seasonal probabilities of temporary emigration were 0.045, 0.363, and 0.300 for years 1–2, 2–3, and 3–4, respectively, and the overall probability of remaining in an unobservable state was 0.688.

Sampled populations of both species are almost certainly part of two larger superpopulations – extending west across the border with India and east towards the mouth of the Meghna River for humpback dolphins, and into the western portion of the SoNG in India for bottlenose dolphins.

More than 28% of photo-identified bottlenose dolphins and 15% of humpback dolphins exhibited injuries related to entanglements with fishing gear. This implies a strong potential for fatal interactions that could jeopardize the conservation status of both dolphin populations which otherwise appear favorable. During 90 medium mesh (9-10 cm) and 15 large mesh (18-20 cm) gillnetting trips between June 2013 and December 2015, an initiative that aims to protect small coastal cetaceans while improving safety conditions at sea for coastal fishermen documented one fatal entanglement of a humpback dolphin in a large-mesh gillnet, and two fatal entanglements of Indo-Pacific bottlenose dolphins in medium-mesh gillnets.

Entanglement risk was assessed using three years of cetacean and fishing gear survey data. Habitat models were consistent with known habitat preferences. Humpback dolphins were associated with lower salinity and more turbid waters, while bottlenose dolphins with higher salinity and less turbid waters. The models identified fishing grounds in areas with high and low predictions of species relative densities. These analyses provide the tools needed to reduce entanglement risk by establishing protective measures where there is the greatest overlap between cetaceans and fisheries, while concurrently meeting fishery needs by concentrating fishing effort in areas that coincide with lower species densities.

The Swatch of No-Ground (SoNG) Marine Protected Area was signed into law by the Ministry of Environment and Forest (MoEF) on October 27, 2014 to safeguard dolphins, whales, sea turtles, sharks, and other oceanic species. The MPA covers 1,738 km^2. It includes deep waters at the head of the submarine canyon from which it gets its name and coastal waters offshore the Sundarbans mangrove forest that provide priority habitat for humpback and bottlenose dolphins as well as other cetaceans at conservation risk.

Introduction

A line-transect survey in February 2004 covering 1,018 km of coastal waters offshore of the Sundarbans mangrove forest, Bangladesh, used a distance analysis to generate population estimates of 5,383 (CV=39.5) Irrawaddy dolphins *Orcaella brevirostris* and 1,382 (CV=54.8%) finless porpoise *Neophocaena phocaenoides*. This same survey also documented the occurrence of Indo-Pacific bottlenose dolphins *Tursiops aduncus* and Indo-Pacific humpback dolphins *Sousa chinesis* but the number of sightings was insufficient to generate an estimate of abundance using distance sampling. The distribution of small cetaceans in these waters was closely tied to environmental gradients with Irrawaddy dolphins and finless porpoises occurring in relatively shallow (<20 m), turbid, low-salinity waters; Indo-Pacific humpback dolphins occurring farther offshore in still shallow flats but where the water is more saline, warmer and turns from brown to green; and Indo-Pacific bottlenose dolphins along the margins of the SoNG straddling fairly shallow (19m) and deep-water (>200m) habitat (Smith et al. 2008).

Following this survey, in the winter seasons of 2005–2009 a photoidentification study was conducted of the bottlenose population which resulted in the identification of 1,144 individuals. Using a mark-resight analysis under Pollock's robust design abundance estimates were generated of 1,701 (95% confidence interval [CI] =1,533–1,888), 1,927 (95% CI =1,851–2,006), 2,150 (95% CI =1,906–2,425), and 2,239 (95% CI =1,985–2,524) individuals for seasons 1–4, respectively. Overall apparent survival was estimated as 0.958 (95% CI = 0.802–0.992). Inter-seasonal probabilities of transitioning to an unobservable state were estimated as 0.045, 0.363, and 0.300 for years 1–2, 2–3, and 3–4, respectively, and the overall probability of remaining in an unobservable state was 0.69. These probabilities, together with an apparent increase in abundance during the study period, indicate that the identified dolphins are part of a larger superpopulation moving throughout a more extensive geographic area. Of the photo-identified dolphins, 28.2% exhibited injuries related to entanglements with fishing gear. This implies a strong potential for fatal interactions that could jeopardize the conservation status of the population, which otherwise appears favorable (Mansur et al, 2012)

This paper provides new information on the population demographics, habitat selection and a spatial and photographic analysis of bycatch risk of Indo-Pacific humpback and bottlenose dolphins in the northern Bay of Bengal Bangladesh. This information is particularly important for conservation considering recent studies indicating that populations of both species in Bangladesh are phylogentically unique from neighboring ones of the same species (?) to the east and west (Amaral *et al.* in review a,b).

Methods

Field procedures

Vessel-based surveys were conducted to photo-identify Indo-Pacific humpback and bottlenose dolphins during the winter northeast monsoon seasons (December to February) in 2010-2013. Surveys were conducted from a local wooden fishing vessel (length=17m, beam=3.5m, 65hp diesel engine). Random transect lines were approximated by randomly choosing, without replacement, three sampling points for recording fishing vessels and gears according to type (see below), and then visiting each of the chosen points while surveying for dolphins along the shortest possible straight line route. After these transect lines were completed, the vessel surveyed haphazardly, albeit guided by where dolphins were thought most likely to occur (e.g., for humpback dolphins near set bag fishing vessels, because they often feed on fish falling from the nets when pulled, and for bottlenose dolphins near the edge of the SoNG).

When dolphins were sighted, the geographic position, and angle and range of the group from the transect line was recorded. Then turning towards the dolphins, their group size was estimated according to number of calves, juvenile/subadults, and adults, and data recorded on temperature, salinity, and depth. The entire group was then photographed to identify individuals from distinguishing marks on their dorsal fins. Photographs were taken with a Nikon D300s digital camera (12.3 megapixels) fitted with an 80-200mm f 2.8 Nikkor VR lens and sometimes a 2X Nikkor teleconverter, and a Nikon D200 digital camera (10.2 megapixels) fitted with a 300 mm f 4 Nikkor lens.

A grid of sampling points spread out at 5km intervals was created for the humpback (39 points in 937km^2) and bottlenose (28 points in 700km^2) dolphin study areas based on previous sightings and information on the habitat preferences of both species (Figure 1). In the humpback dolphin study area, each point was visited twice during the first two winter seasons and once during the third winter season. In the bottlenose dolphin study area, each point was visited once during the second and third winter season. At each point the occurrence of fishing vessels and gears were recorded according to type, as well as their activity state (fishing, traveling, resting, and unknown), estimated sighting distances to the vessels and gears, environmental parameters (depth, salinity, and temperature), and sighting conditions (according to Beaufort sea state). The humpback dolphin study area was prioritized for two surveys during the first two winter seasons because of the previous existence of similar point-transect data on fishing vessels in the bottlenose dolphin study area for two winter seasons in 2007-2009.

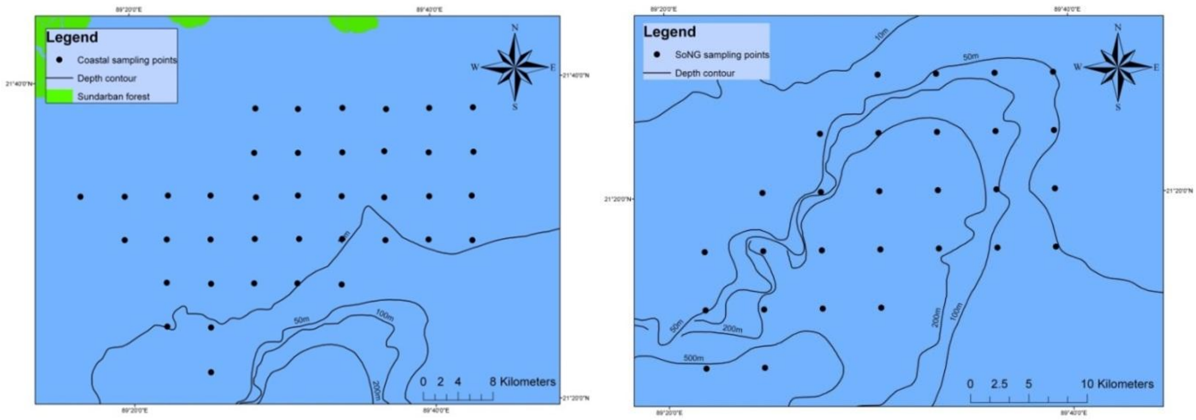

Figure 1. Map of the humpback dolphin study area showing the 39 sampling points (left) and the bottlenose dolphin study area showing the 28 sampling points (right) used for conducting point-transect surveys of fishing vessels and gears.

In addition to dedicated field work, information on Indo-Pacific humpback and bottlenose dolphin sightings and bycatch were documented by 16 gill net fishing vessel captains participating in a dolphin/safety network that aims to protect small coastal cetaceans by rescuing entangled animals while improving safety conditions at sea for coastal fishermen in Bangladesh.

Analyses

Fin-matching and compiling photo-identification catalogs

To ensure independence among sightings, multiple photo-identifications of an individual dolphin during a single day were counted only once. Each photograph that contained one or more dorsal fin images was evaluated according to the image quality. Quality was considered poor if the image(s) of the dorsal fin(s) were insufficiently clear for identifiable marks to be discerned. These photographs were deleted from the photo-database. Good quality photographs were defined as including one or more images of dorsal fins clear enough so that identifying marks could be discerned. Good quality photographs were edited using PICASA 2.0 software to improve the contrast and fill light if needed and to extract cropped images of each dolphin in the photograph.

Cropped fin photographs from each day were placed in their own folder of an ACDSEE 6.0 photo-database and sorted to identify the best image of each individual identified during the session. The 'best' photographs of individuals from each session were then compared to the 'best' photographs of previously identified individuals in the photo-catalogue. Each unambiguous match of a photograph with an existing individual from the catalog was considered a resighting. All matched photographs were then copied to the master folder for that individual animal. After all possible resightings were identified new individuals were assigned a unique identification number and attributes for dorsal fin and body marks. Good quality photographs of dorsal fins with no marks (i.e., clean fins) were placed in a separate file. The proportion of the total number of clean fin photographs compared to photographs with identifiable marks was used to estimate the number of unmarked individuals for the mark-resight analysis (see below).

The search for photographic matches (resightings) was made more efficient by assigning mark attributes to each newly identified dolphin. Individuals in the photo-catalogue were then filtered by mark types using the ACDSEE software. This allowed matching effort to focus on a smaller subset of individuals exhibiting similar diagnostic features. Only dorsal fin marks were used to confirm sightings or resightings; however, body wounds were sometimes used to narrow the identification search. Age classes of humpback dolphins were identified according to size and color patterns described in Jefferson *et al.* (2008) except that, due to the apparent greater retention of spotting in humpback dolphins occurring in Bangladesh compared to some other members of the *chinensis*-type of the species, we were unable to reliably distinguish between juvenile and subadults.

<u>Evidence of fishing gear entanglement from scars and mutilations</u>

Scars and mutilations connected with fishing gear entanglements were documented for all photo-identified bottlenose and humpback individuals (Figure 2). Complete or partial disfigurements, deep notches or gouges on the leading or trailing edge of the dorsal fin, or deep furrows anterior or posterior to the dorsal fin were considered as almost certainly related to fisheries interactions. Nicks on the tip or trailing edge of the dorsal fin were considered as possibly resulting from fishery interactions. Shark bite wounds were typically jagged, and dorsal fin wounds from shark bites were relatively uncommon compared to shark bite injuries on other parts of the body.

<u>Abundance estimates using mark-resight models</u>

A mark-resight analysis under Pollock's robust design was applied to photo-identification data collected on Indo-Pacific humpback dolphins in estuarine waters offshore the Sundarbans mangrove forest. The results for on a similar analysis applied to the Indo-Pacific bottlenose dolphin population in the SoNG were reported in Mansur et al. 2012 and are summarized above.

Images from photo-identification data permit the unique identification of a portion of bottlenose and humpback dolphins referred to as marked individuals. The encounters of marked individuals together, with additional data on the number of unmarked individuals, were analyzed with a (zero-truncated) Poisson-log normal mark-resight model (McClintock *et al.* 2009, McClintock and White 2009) using the software program MARK (White 2011). This model incorporates variation in sighting probability due to individual heterogeneity, caused by physical or behavioral differences between dolphins, and over time. This is particularly useful in cases where the lack of demographic or geographic closure may introduce individual heterogeneity in sighting probabilities. If geographic closure is violated, due to animals moving in and out of the study area during the time of a survey, the abundance estimates are for a ‘superpopulation’ of which a portion is associated with the study area during a particular survey.

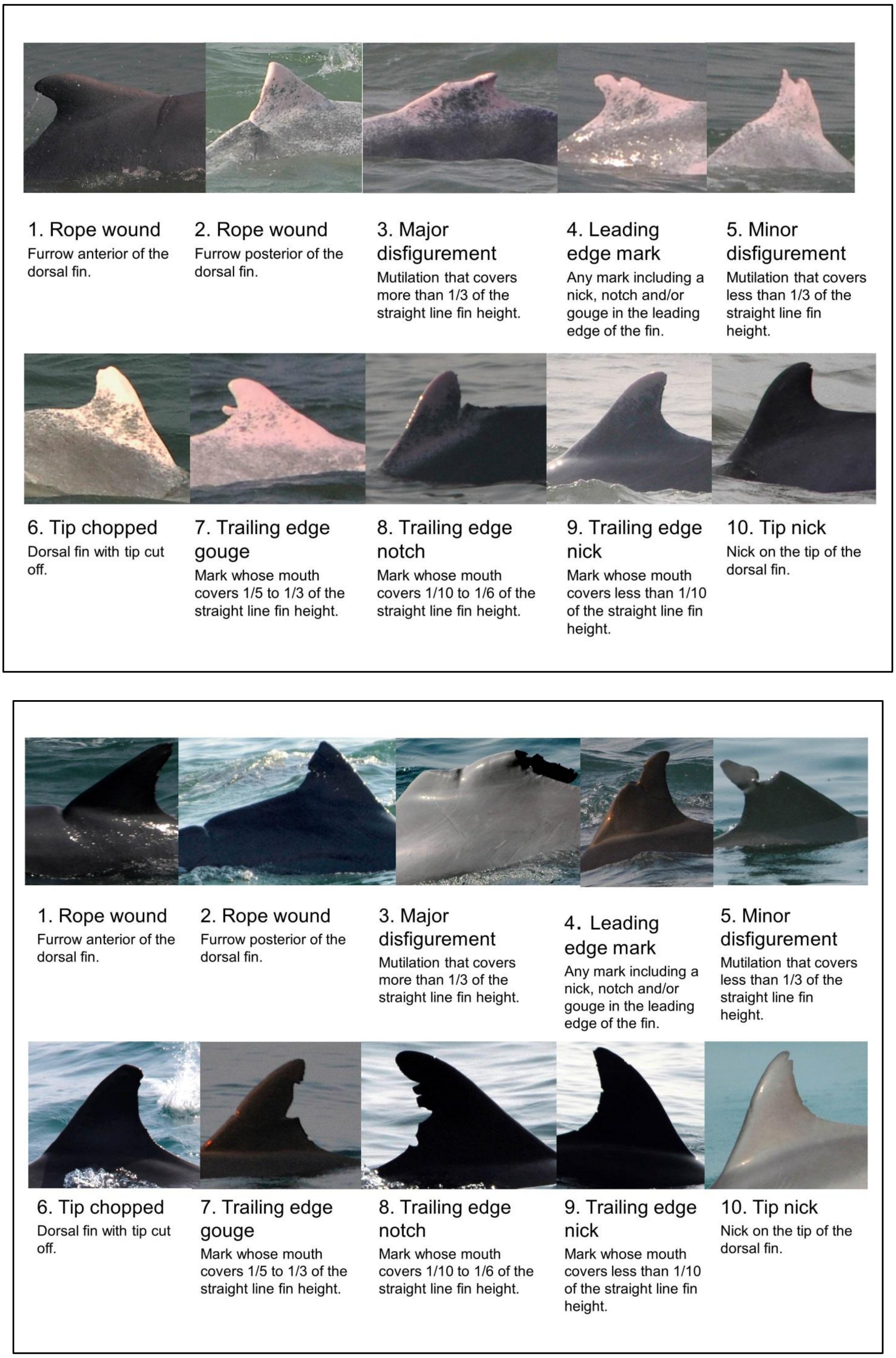

Figure 2. Criteria assigned to different wound types for humpback dolphins (top) and bottlenose dolphins (bottom) with categories 1-7 considered to be almost certainly associated with fisheries interactions and 8-10 considered to be possibly associated with fisheries interactions.

Estimates were obtained for abundance N, apparent survival (ϕ), and transition rates between observable and unobservable states (γ'' - probability of transitioning from an observable state in one survey to an unobservable state in the next survey, γ' - probability of remaining in an unobservable state in the next survey when in an unobservable state in the previous survey). During the estimation process the Poisson-log normal model generates estimates of the intercept for the mean resighting rate α, individual heterogeneity level σ^2, and the number of unmarked individuals U. The abundance estimate for each survey is derived from the estimated number of sightings of unmarked individuals U and the overall mean resighting rate λ, together with the total number of times photo-identified individuals were resighted one or more times.

We selected among potential models using the Akaike's Information Criterion (AIC) values produced by MARK and adjusted to take into account differences in effective sample size and lack of fit (AICc) (Burnham and Anderson 2002). We considered different parameter combinations where the intercept for the mean resighting rate α, individual heterogeneity level σ^2, the number of unmarked individuals U, apparent survival ϕ, and the transition rates between observable and unobservable states were allowed to change for each sampling session. We also considered models where individual heterogeneity σ^2 or the transition rates were set equal to zero.

Habitat selection and identification of core habitat and spatial risk of fishing gear entanglement

To understand habitat selection the number of bottlenose and humpback dolphin sightings and the kilometers of systematic and non-systematic survey effort were projected using UTM Zone 45N (WGS 84 datum) within each cell of a 1km x 1km grid of the study area. Monthly composites of remotely sensed turbidity (Aqua MODIS Diffuse attenuation coefficient at 490 nm (KD490), /m (or m-1), monthly, 4 km, http://oceancolor.gsfc.nasa.gov/) were averaged from December 2011 to February 2012 and December 2012 to February 2013. Monthly composites of chromophoric dissolved organic matter (CDOM), which are inversely proportional to sea-surface salinity, were downloaded from the Aqua and Terra MODIS satellites for the same months. Both climatologies were averaged to produce a single composite map of averaged turbidity and CDOM with values extracted at the center of each grid cell using bilinear interpolation. Bathymetry was derived from ETOPO1 (Amante and Eakins 2009) using a one arc-minute global-relief model. Slope was calculated using ArcGIS Spatial Analyst (version 10.1, ESRI). The Swatch-of-No-Ground (SoNG) submarine canyon was defined as having curvature values less than or equal to -0.005.

Generalized additive models (GAMs) were generated to relate the number of sightings of both species to bathymetry and oceanographic variables. We fit Poisson GAMs, in which overdispersion was corrected with a quasi-likelihood model, using the software package S+ (Version 8.1 for Windows, Tibco Software, 2008). The distance traveled on effort in each cell was used as an offset because the amount of effort varied among cells. The bathymetry and oceanographic variables included in each model and the degrees of freedom for cubic smoothing splines were selected by an automated forward-backward stepwise approach and Akaike's information criterion (AIC) (Becker *et al.* 2010).

Each GAM model was fit three times starting with the null model of no overlap between fishing gears and predicted dolphin densities including only the intercept. The dispersion parameter from the null model was used to calculate AIC values in algorithm step.gam which tested all predictor variables for inclusion in the second model as cubic smoothing splines with 2-3 degrees of freedom. For the third model, we used the dispersion parameter from the second model to calculate the AIC values in the algorithm step.gam, which tested all predictor variables for inclusion as linear terms or cubic smoothing splines with 2-3 degrees of freedom. These models were then used to predict the number of sightings in each cell of the 1km x 1km grid of the study area versus the distribution of fishing gears recorded according to type from sampling points spread out at 5-km intervals in the humpback and bottlenose dolphin study areas.

Results and Discussion

Search effort and sightings

<u>Indo-Pacific humpback dolphin study area</u>

During all three winter seasons of the study, the research team searched along a total of 3,065km of semi-random tracklines and 2,169km of haphazardly determined tracklines in open estuarine waters of the Bay of Bengal between the Sundarbans mangrove forest and the SoNG (Figure 3). Transect lines extended from a depth of about 2 to 36m and salinity from 9 to 28 parts per thousand (ppt).

A total of 88 humpback dolphin sightings were made with a mean group size of 17.5 individuals (SD=23.6, median=11, range=1-160) (Table 1). The age-class composition was estimated as 27% for adults (range=0-100%), 61% (range=0-100%) for subadults/juveniles, and 12% for calves (range=0-33.3). The mean depth was 10.2 (range=5-22), mean salinity 22.7 ppt (range=12.5-28.0), and mean temperature 24.5°C (range 20.9 – 28.5). The relatively large standard deviation and difference between the mean and median group size estimates reflects occasional sightings (once each year) of extraordinary large groups, estimated in the field as 95, 110, 160 dolphins, respectively, during winter seasons of 2010-2013.

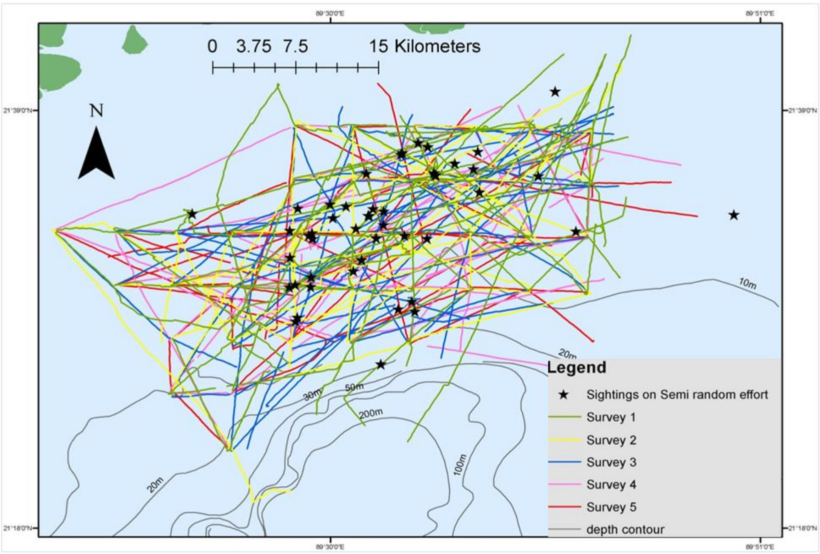

Figure 3. Semi-random tracklines followed and the locations of Indo-Pacific humpback dolphin sightings during surveys in December – February 2010/2013.

Table 1. Humpback dolphin survey effort, sightings and environmental parameters recorded in coastal waters adjacent to the Sundarbans mangrove forest Bangladesh during winter seasons of 2010-2013.

Winter season	Semi-random search effort (km)	Haphazard search effort (km)	Dolphin sightings	Groups size			Age class			Depth			Salinity			Temp		
				Mean	Range	SD	Adults (range) %	Subadults (range) %	Calves (range) %	Mean	Range	SD	Mean	Range	SD	Mean	Range	SD
2010-2011	1157	137	16	12.8	1-76	20.6	24 (0-75)	60 (0-100)	15 (0-33.3)	10	5-16	3	23.1	16.8-26.4	3.1	23.5	20.9-26.2	1.4
2011-2012	1362	1011	48	16.0	1-57	13.9	27 (0-100)	62 (0-100)	12 (0-33.3)	10	2-36	4	22.3	9.1-28.2	4.1	24.8	21.1-28.5	1.9
2012-2013	546	1012	24	23.5	1-160	37.1	29 (0-100)	60 (0-100)	11 (0-21)	9	6-20	3	23.1	18.9-27.6	2.9	24.6	21.6-27.0	1.4

Throughout their range, humpback dolphins are generally found in groups of less than 10 individuals. The maximum group sizes reported for the *chinensis*-type of Indo-Pacific humpback dolphins is 30 individuals and for the *plumbea*-type 100 individuals (Parra and Ross 2009). Photo-identification efforts on the largest group revealed that our estimate of 160 individuals was low. Through dorsal fin photographs we identified 205 individuals from the group. This count, combined with information on the proportion of unmarked non-calf individuals (26.0% - used in the mark-resight analysis below) plus the proportion of calves (12.0% - derived from field estimates reported above), suggests that the actual group size was around 330 individuals, making it more than three times larger than the maximum group sizes reported elsewhere for the species. During the three sightings of extraordinarily large size groups, the dolphins were generally traveling and engaging in occasional social behavior.

Differences in the social behavior of humpback dolphins offshore of the Sundarbans, compared to other members of the *Sousa* genus, might be expected given recent genetic evidence indicating a genetically unique population in Bangladesh with no shared haplotypes among extensive samples taken from the genus (Amaral *et al.* in review -a). The ecological and/or social reason(s) for these sporadic sightings of large groups are unknown but they appear to be related to the clumped nature of estuarine prey, both in space and time, driven by the complex dynamics of freshwater flow, and marine currents and tides.

Indo-Pacific bottlenose dolphin study area

During the three winter seasons of the study, the research team searched along a total of 764km of semi-random trackline and 964km of haphazard trackline in the SoNG submarine canyon (Figure 4, Table 2). Sixty nine bottlenose dolphin groups were detected in an area encompassing about 300km^2 at an average depth of 202m (SD=112, range=45-395), salinity of 25.6ppt (SD=1.5, range=19.7-28.1), and temperature of 24.3°C (SD=1.3, range=21.3-27.4). The mean group size for all bottlenose dolphin sightings was 38.1 individuals (SD=34.0, range=3-190). For all sightings, the age class composition was estimated as 83% for adults (range=50-100), 9% for subadults (range=0-21), and 9% for calves (range=0-33).

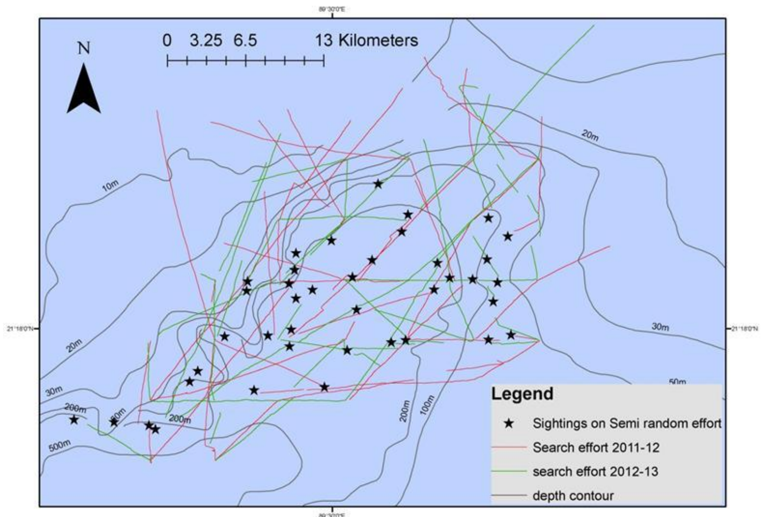

Figure 4. Semi-random tracklines followed and the locations of sightings during surveys for Indo-Pacific bottlenose dolphins in December – February 2010/2013.

Table 2. Bottlenose dolphin survey effort, sightings and environmental parameters recorded in the Swatch-of-No-Ground submarine canyon Bangladesh during winter seasons of 2010-2013.

Winter season	Semi-random search effort (km)	Haphazard search effort (km)	Dolphin sightings	Group size			Age class			Depth			Salinity			Temp		
				Mean	Range	SD	Adult (range) %	Sub adult (range) %	Calves (range) %	Mean	Range	SD	Mean	Range	SD	Mean	Range	SD
2010-2011	0	417	12	39.8	7-70	18.4	69 (50-88)	20 (8-31)	11 (0-21)	215.3	62-400	88.8	25.2	23.4-27.5	1.2	23.7	21.3-27.4	1.6
2011-2012	389	376	33	38.9	3-120	37.2	91 (67-100)	2 (0-21)	7 (0-33)	199.1	45-395	122.5	24.0	20.8-26.5	1.5	24.5	22.2-26.6	1.2
2012-2013	337	171	25	42.5	2-190	44.6	89 (76-100)	3 (0-19)	7 (0-20)	191.6	37-384	111.1	25.6	22.2-26.9	1.1	24.7	22.7-26.9	1.1

Photo-identification catalogs

Indo-Pacific humpback dolphins

Altogether 42,730 photographs were taken of the dorsal fins of humpback dolphins. After processing and examination (Table 3), a total of 468 dolphins were identified with an average resighting rate of 0.85/individual. A discovery curve of the cumulative number of identified dolphins versus the number of photo-identification days (Figure 5) reflects three sightings of exceptionally large groups (11 Dec 11 – estimated 95 dolphins with 27 photo-identified and only 14 resights, 8 Dec 12 – estimated 110 dolphins with 81 photo-identified and only one resight, and 9 Jan 13 – 160 dolphins with 205 photo-identified individuals and only seven resights).

Table 3. The frequency of occurrence of different mark types and their percent occurrence on the dorsal fins of newly photo-identified humpback dolphin individuals.

Mark type	Year 1 # (N=58)	Year 1 %	Year 2 # (N=46)	Year 2 %	Year 3 # (N=301)	Year 3 %
Nick	42	72.4	33	71.7	200	66.5
Notch (mouth covers from 1/10 to 1/6 of the straight line fin height.)	25	43.1	13	28.3	100	33.2
Gouge (mouth covers 1/5 to 1/3 of the straight line fin height.)	2	3.5	3	6.5	7	2.3
Large fin wound (mouth covers > 1/3 the straight line fin height.)	0	0	1	2.2	9	3.0
Leading edge mark (a nick, notch, and/or gouge on the leading edge of dorsal fin)	7	12.1	5	10.9	45	15.0
Tip chopped (piece of fin tip missing)	6	10.3	3	6.5	29	9.6

It is unclear if the discovery curve for humpback dolphins will continue to rise with additional photo-identification effort but the stair-step pattern of the "curve" in Figure 6 implies that the number of newly identified individuals may still be increasing but with the increases mainly due to the occasional occurrence of particularly large groups with a large proportion of newly identified individuals. A likely explanation for the large proportion of previously unidentified individuals is that we are sampling a portion of a larger superpopulation, with an unknown proportion moving in and out of the study area. This hypothesis is supported by the relatively low rate of re-identifications (Figure 7) especially in these large groups and the mark-resight analysis below.

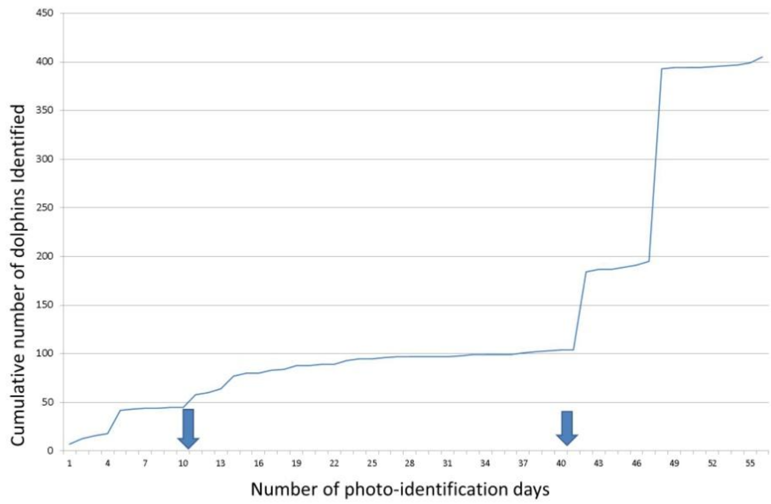

Figure 6. Discovery curve of the cumulative number of Indo-Pacific humpback dolphins identified from photographs versus the number of days of photo-identification effort during winter seasons 2010-2013.

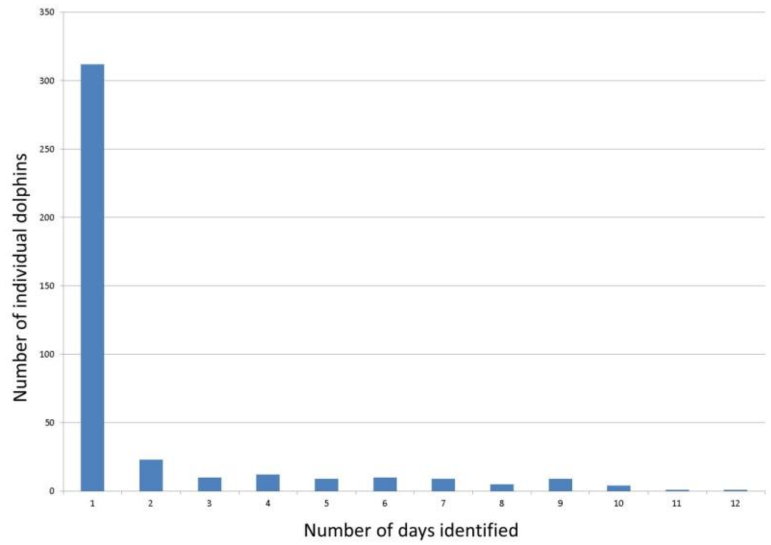

Figure 7. Frequency distribution of the number of identified Indo-Pacific humpback dolphins versus the number of days individuals were identified during winter seasons 2010-2013.

<u>Indo-Pacific bottlenose dolphins</u>

Photo-identification of bottlenose dolphins during the winter seasons 2011-1013 builds on a photo-catalog compiled for photo-identification effort from 2005 through 2009 which includes the identification of 1,144 individuals (Table 4). From a total of about 33,000 taken during 58 sightings 308 individuals were identified of which 73.7% were matched with dolphins in the photo-identification catalog for 2005-2009. The resighting rate within the two winter seasons was relatively low (0.76) (Figure 8) and a discovery curve of indicates that the number of new identifications is still increasing (Figure 9). This can be expected given a mark-resight estimate of abundance for the population of between 1,701 and 2,239 individuals from photo-identification data collected during 2005-2009.

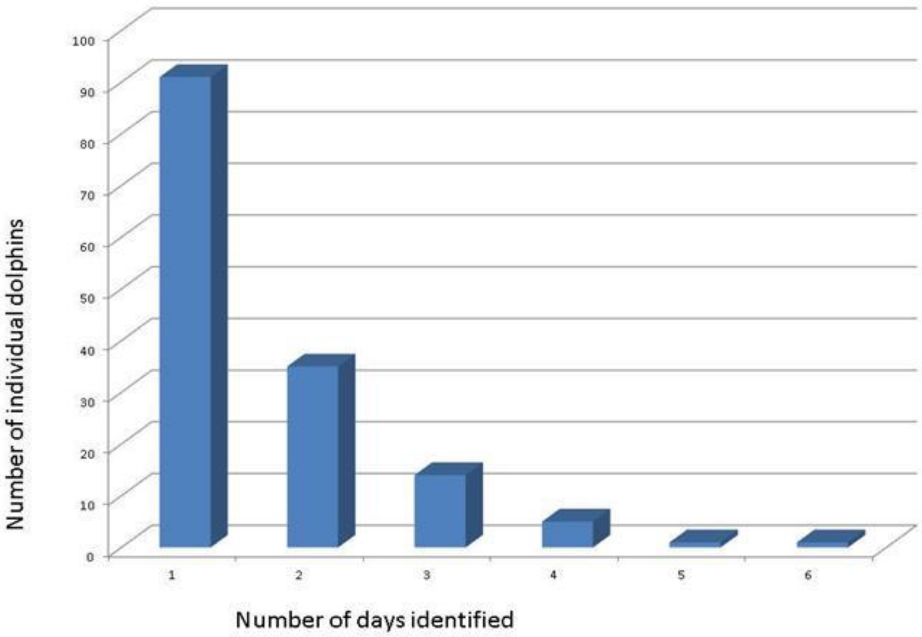

Figure 8. Frequency distribution of the number of identified Indo-Pacific bottlenose dolphins versus the number of days individuals were identified during winter seasons 2011-2013.

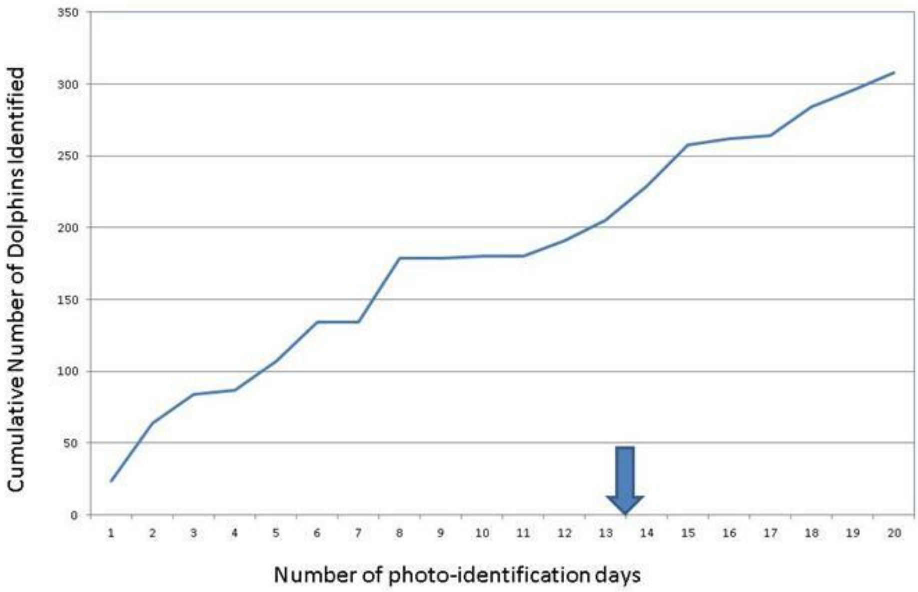

Figure 9. Discovery curve of the cumulative number of Indo-Pacific humpback dolphins identified from photographs versus the number of days of photo-identification effort during winter seasons 2011-2013.

Table 4. The frequency and percent of occurrence of different mark types on the dorsal fins of newly photo-identified bottlenose dolphin individuals.

Mark type	Year 1 # (N=392)	Year 1 %	Year 2 # (N=616)	Year 2 %	Year 3 # (N=92)	Year 3 %	Year 4 # (N=44)	Year 4 %
Nick upper	170	43.4	266	43.2	43	46.7	21	47.7
Nick middle	163	41.6	255	41.4	42	45.7	18	40.9
Nick bottom	153	39.0	233	37.8	32	34.8	19	43.2
Notch (mouth covers 1/10 to 1/6 of the total straight line dorsal fin height.) upper	178	45.4	204	33.1	39	42.4	21	47.7
Notch middle	161	41.1	190	30.8	30	32.6	20	45.5
Notch bottom	167	42.6	203	33.0	39	42.4	16	36.4
Gouge (mouth covers 1/5 to 1/3 of the straight line dorsal fin height) upper	67	17.1	55	8.9	11	12.0	4	9.1
Gouge middle	52	13.3	69	11.2	5	5.4	1	2.3
Gouge bottom	46	11.7	36	5.8	2	2.2	1	2.3
Large fin wound (mouth covers more than 1/3 the straight line dorsal fin height)	45	11.5	42	6.8	2	2.2	4	9.1
Leading edge mark (nick, notch, and/or gouge on leading edge of dorsal fin)	100	25.5	124	20.1	26	28.3	6	13.6
Tip notch	114	29.1	156	25.3	19	20.7	11	25.0
Tip chopped	66	16.8	90	14.6	10	10.9	3	6.8
Tip nick	57	14.5	107	17.4	15	16.3	7	15.9
Tip bent	16	4.1	11	1.8	1	1.1	0	0.0

Mark-resight abundance estimates

Indo-Pacific humpback dolphins

For the highest ranked mark-resight model α varied over time and U, ϕ and γ' were set to constant. For this model γ'' was set to zero and σ^2 was set to zero for the first season. The estimated abundance and mean resighting rates are shown in Table 5. There was a considerable jump in the population estimate in the third season compared to the first two seasons. This is due to the large number of animals observed for the first time in the third season (e.g., single group with 205 identifications) in combination with the relatively low mean resighting rate for this sampling occasion (see above), and also taking into account that the estimated probability of remaining in an unobservable state in the next survey when in an unobservable state in the previous survey γ' was about 55% overall. This indicates that the population is likely part of a superpopulation that occupies more extensive coastal waters of Bangladesh and probably across the border in India. The apparent survival rate was relatively high with an estimate of ϕ equaling 0.845 (95% confidence interval [CI] = 0.725-0.919).

Table 5. Estimates of abundance $\hat{N}$ and mean resighting rate $\hat{\lambda}$ for Indo-Pacific humpback dolphin. Estimates are shown for each of the three years along with the standard errors (SE) and 95% confidence intervals (95% CI).

Winter season	$\hat{N}$	SE	95% CI	$\hat{\lambda}$	SE	95% CI
2010/11	132	10	(115 - 153)	1.507	0.172	(1.207 – 1.883)
2011/12	131	3	(124 - 137)	5.849	0.248	(5.382 – 6.355)
2012/13	635	58	(531 - 761)	0.973	0.142	(0.732 – 1.293)

Indo-Pacific bottlenose dolphins

After the photo-catalog from winter seasons 2005-2009 has been combined with the photo-catalog from winter seasons 2010-2012, new estimates of abundance, survival, and movements will be generated using the robust mark-resight analysis described above. These estimates will be more precise and provide more detailed information on movements in and out of the bottlenose dolphin study area. The latter is particularly important given recent information from that the population at the head of the SoNG is probably phylogentically distinct from other members of *T. aduncus* occurring to the east and west (Amaral *et al.* in review –b).

Evidence of fishery interactions from wounds

Indo-Pacific humpback dolphins

From 407 Indo-Pacific humpback dolphin individuals in the photo identification catalog compiled from photographs taken during 2010-2013, 15.0% of the individuals exhibited marks (Table 6) that were almost certainly associated with entanglements in fishing gears (Figure 10) while 8.6% exhibited marks that were possibly caused by entanglements in fishing gear (Figure 11). Photographs from all three years of the study still need to be examined more thoroughly to analyze the accumulation of marks from one sighting to the next over the three years of the study period.

Table 6. Frequency and percent occurrence of wounds associated entanglements in fishing gear and other causes in newly identified humpback dolphins during winter seasons 2010-2013.

Cause	Year 1 # (N=58)	Year 1 %	Year 2 # (N=46)	Year 2 %	Year 3 # (N=301)	Year 3 %
Almost certainly entanglement	6	10.3	4	8.7	51	16.9
Possible entanglement	5	8.6	6	13.0	24	8.0
Deep rope cut on the body	2	3.5	1	2.2	18	6.0
Suspected shark interaction	4	6.9	2	4.4	14	4.7
Wound/physical abnormality from unknown origin	5	8.6	3	6.5	16	5.3

Figure 10. Examples of humpback dolphins with injuries definitely associated with fishery interactions (top – mutilated dorsal fin and bottom – rope wounds posterior of dorsal fin).

Figure 11. Examples of Indo-Pacific humpback dolphins that were categorized as having marks that can possibly be attributed to fisheries interactions.

Among the photo-identified humpback dolphins, 24 individuals exhibited stereotypical marks that we were unable to identify the cause (Figure 12). These marks consisted of a series of small sequential grooves situated along the spine posterior of the dorsal fin. At first we thought that a fishing line may have gotten wrapped along the tail stock but we would then expect the marks to appear slanted rather than oriented perpendicular to the body. Our impression is that these marks may be related to disease or a congenital deformity. There were no obvious signs of emaciation in photographs of these individuals. We plan to follow up with colleagues about the possible causes of these marks affecting roughly 6% of the total number of photo-identified humpback dolphins.

Figure 12. Two humpback dolphin individuals with sequential grooves posterior of their dorsal fin.

Indo-Pacific bottlenose dolphins

Of the 1,144 individual bottlenose dolphins photo-identified during 2005-2009, 28.2% exhibited marks or wounds that were almost certainly associated with entanglements in fishing gear and 11.0% exhibited marks or wounds that were possibly associated with entanglements with fishing gear (Table 7). Individual bottlenose dolphins identified during 2010-2013 are still being examined for injuries. Once our photo-catalogs are combined from 2005-2009 and 2010-2013, a more comprehensive analysis will be undertaken to estimate the accumulation of marks from one sighting to the next associated with fishing gear entanglement during the entire eight years (Figure 13).

Table 7. Frequency and percent of occurrence of wounds associated entanglements in fishing gear and other causes in newly identified bottlenose dolphins during winter seasons 2006-2010.

Wound type	Year 1 # (N=392)	Year 1 %	Year 2 # (N=616)	Year 2 %	Year 3 # (N=92)	Year 3 %	Year 4 # (N=44)	Year 4 %
Almost certainly entanglement	123	31.4	176	28.6	19	20.7	5	11.4
Possibly from entanglement	51	13.0	38	6.2	19	20.7	17	38.6
Deep rope cut on body	36	9.2	46	7.5	3	3.3	1	2.3
Deep rope cut on dorsal fin	110	28.1	168	27.3	35	38.0	22	50.0
Possible wound on dorsal fin from long line	96	24.5	133	21.6	19	20.7	10	22.7
Fresh raw wound	6	1.5	9	1.5	2	2.2	0	0.0
Suspected shark interaction	33	8.4	30	4.9	6	6.5	0	0.0

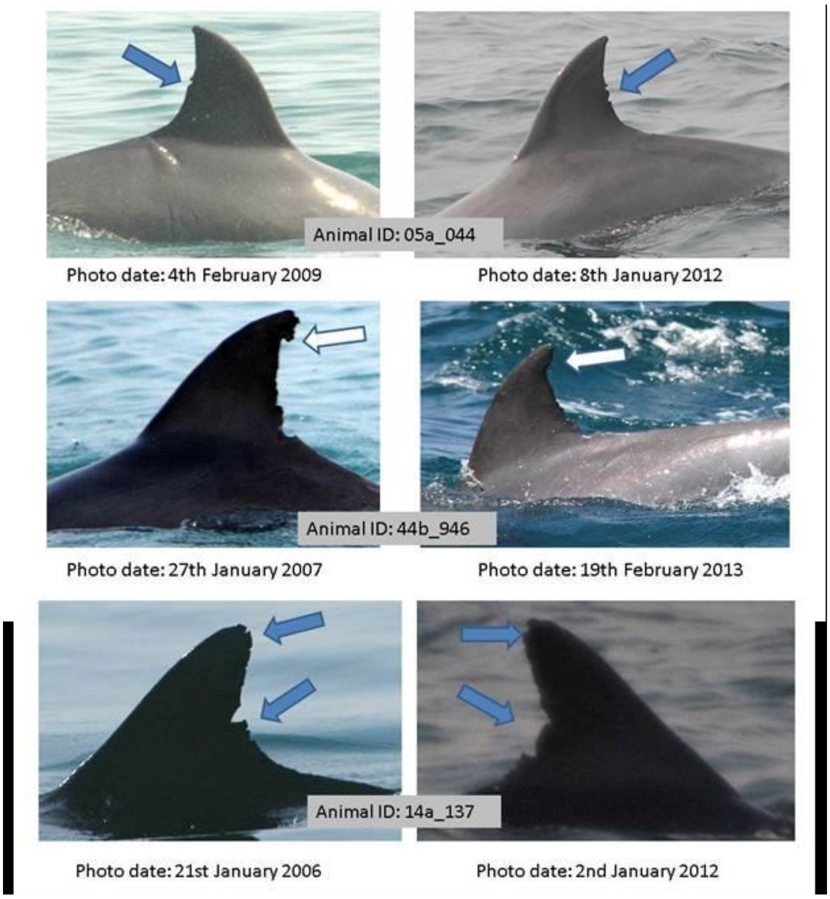

Figure 13. Example of mark/wound accumulation (and healing middle photo) in three bottlenose dolphin individuals over 3 to 7 years. Arrow points to the area of the fin where change has occurred.

Environmental parameters

Indo-Pacific humpback dolphins

Environmental parameters recorded at the 39 sampling points in the humpback dolphin study area indicated fairly shallow (4-23 meters), low salinity (10-28 ppt), moderate temperature (20-28 °C) waters (Table 8).

Table 8. Environmental parameters recorded at 39 sampling points spread out at 5-km intervals in the humpback dolphin study area during two sampling sessions in winter seasons of 2010/2011 and 2011/2012, and one sampling session in winter season of 2012/2013.

Winter seasons	Depth (m)			Salinity (ppt)			Temp (°C)		
	Mean	Range	SD	Mean	Range	SD	Mean	Range	SD
2010/2011(1)	9.9	4.9-24.5	3.7	23.9	13.3-27.7	2.5	23.2	21.3-26.2	1.08
2010/2011(2)	9.5	4.0-23.6	3.8	23.9	19.8-27.3	1.9	23.8	20.7-26.7	1.42
2011/2012(1)	9.8	3.5-24.7	3.9	20.3	10.2-28.0	3.6	23.8	20.9-27.5	1.63
2011/2012(2)	9.7	5.0-22.1	3.7	24.4	18.7-27.7	2.5	24.1	19.5-27.9	1.61
2012/2013(1)	9.5	4.6-23.0	3.5	21.9	10.4-27.3	3.5	25.3	21.3-28.3	1.40

Indo-Pacific bottlenose dolphins

Environmental parameters recorded at 28 sampling points in the bottlenose dolphin study area indicated relatively deep waters over a steep slope (range = 13 to > 500m deep), slightly higher salinity waters (20-27 ppt), and with similarly moderate temperatures (21-26 °C) compared to the humpback dolphin study area (Table 9).

Table 9. Environmental parameters recorded at 28 sampling points spread out at 5-km intervals in the Swatch-of-No-Ground submarine canyon Bangladesh during a single sampling session in winter seasons of 2011-2013.

Winter seasons	Depth			Salinity			Temp		
	Mean	Range	SD	Mean	Range	SD	Mean	Range	SD
2011/2012	151	14-531	145	24.4	20.8-26.7	1.4	24.1	21.1-26.2	1.4
2012/2013	154	13-442	142	25.4	22.4-26.8	1.1	24.9	22.8-26.3	1.2

Habitat selection models

For the habitat selection models we combined the humpback and bottlenose dolphins study areas and incorporated information from the number of sightings (86 and 158 for humpback and bottlenose dolphins, respectively) and individuals (1,534 and 6,910 individuals, respectively from group size estimates) and the number of survey transits through each of the 1,996km^2 cells comprising the combined humpback and bottlenose dolphin study areas.

Chlorophyll and temperature were excluded from the habitat selection models because the correlations between these and other variables were too high (Table 10). We built separate models using turbidity and CDOM because these two variables were too correlated to include in a single model. Finally, we did not use depth in the models. Instead we used slope and distance to the canyon head as a means of better exploring the relationship between species and the SoNG.

Table 10. Correlations between habitat variables considered in our analyses.

	SST	CHL	Turb	Depth	Slope	Dist to canyon	CDOM
SST	1	-0.532	-0.517	-0.247	0.260	-0.415	-0.54486
CHL	0	1	0.999	0.543	-0.470	0.061	0.759295
Turbidity	0	0	1	0.542	-0.465	0.047	0.749326
Depth	0	0	0	1	-0.761	-0.178	0.328579
Slope	0	0	0	0	1	0.201	-0.30969
Dist to canyon	0	0	0	0	0	1	0.405242
CDOM	0	0	0	0	0	0	1

The niches of both humpback and bottlenose dolphins were well captured in both the turbidity (Figure 14) and CDOM (Figure 15) models. Specifically, we found bottlenose dolphins occur in less turbid waters and humpback dolphins in more turbid waters. When the CDOM data are used, we found bottlenose dolphins in waters with lower CDOM values (higher salinity) and humpback dolphins in waters with higher CDOM values (lower salinity). We also see an interesting differentiation between the slopes associated with each species. The model captures the association between bottlenose dolphins and the steep slopes of the SoNG and the association between humpback dolphins and the much flatter slopes of nearshore coastal waters.

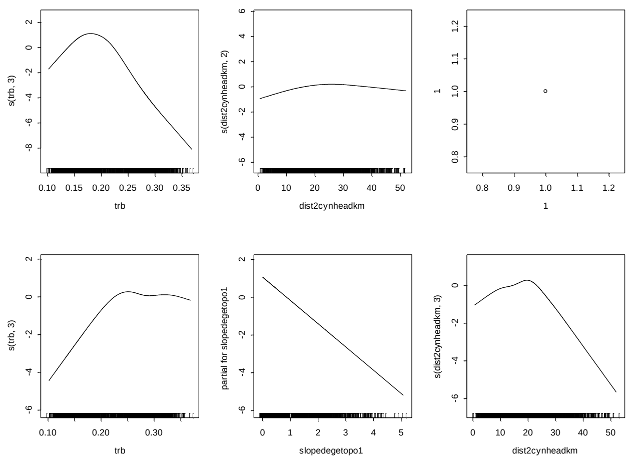

Figure 14. Functional forms for variables included in the generalized additive models relating the number of bottlenose (top row) and humpback (bottom row) dolphin sightings to turbidity (left) and the two bathymetry variables: slope (middle) and distance to the canyon head (right). Data points for each variable are shown as tick marks on the x-axes. The y-axes, representing the smoothing spline function, are labeled to indicate the degrees of freedom for the spline (linear terms are represented by a single degree of freedom).

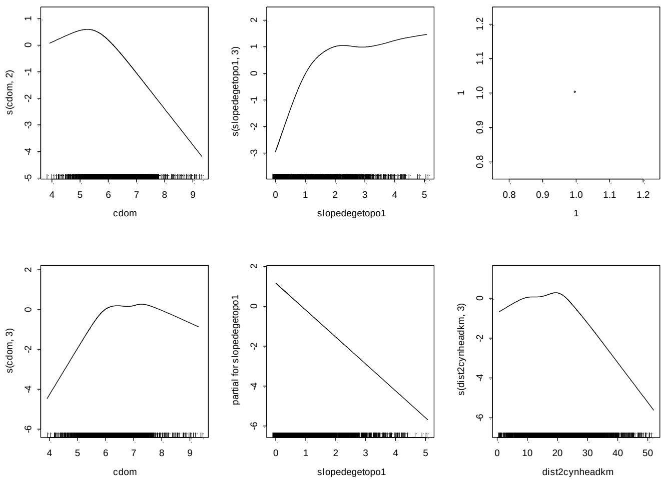

Figure 15. Functional forms for variables included in the generalized additive models relating the number of bottlenose (top row) and humpback (bottom row) dolphin sightings to CDOM (left) and the two bathymetry variables: slope (middle) and distance to the canyon head (right).

Predictions for the distribution of humpback dolphins were similar for the turbidity and CDOM models (Figure 16). Predictions for the distribution of bottlenose dolphins, although inclusive of a great deal of overlap, were different for the turbidity and CDOM models (Figure 17). We considered the CDOM model to be a better predictor of bottlenose dolphin distribution because the freshwater plume offshore of the Sundarbans results in a relatively smooth gradient from low to high salinity waters, whereas the gradient for turbidity is more variable with the formation of "circulation cells" resulting in a more blotchy climatology. The greater heterogeneity in the turbidity gradient is especially pronounced in bottlenose dolphin habitat at the head of the SoNG where reduced freshwater discharge from the Sundarbans during the winter season allows deep water upwelling to interact with the clockwise current gyre of the Bay of Bengal during the winter season.

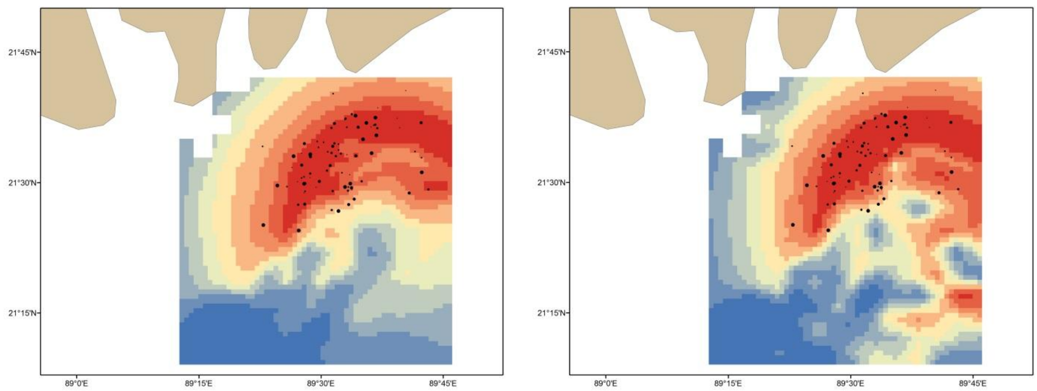

Figure 16. The number of humpback dolphin sightings predicted by the habitat models using turbidity (left) and CDOM (right) are shown in ten approximately equal categories (red indicates the highest densities and dark blue the lowest densities); the black dots have been scaled to represent the number of individuals in each sighting.

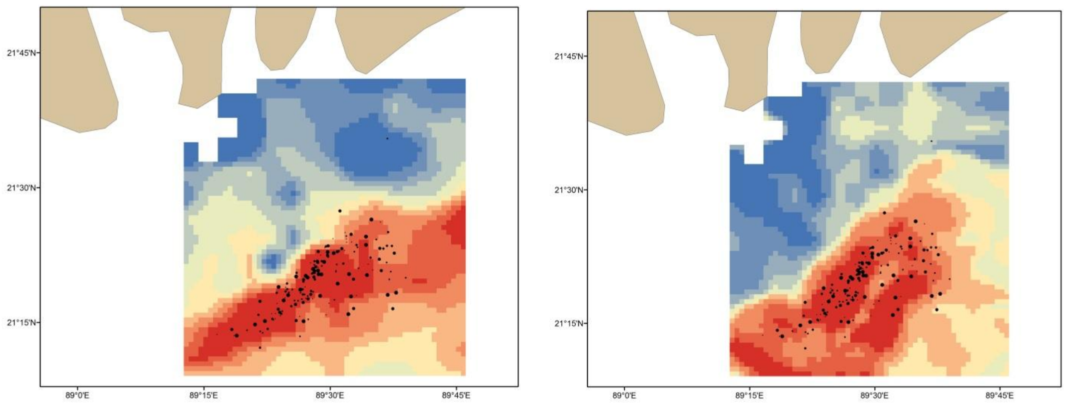

Figure 17. The number of bottlenose dolphin sightings predicted by the habitat models using turbidity (left) and CDOM (right) models.

The distribution of core habitat using CDOM models was then defined by the highest 10% of predicted values for humpback and bottlenose dolphin occurrence. There was no overlap between each species (Figure 18).

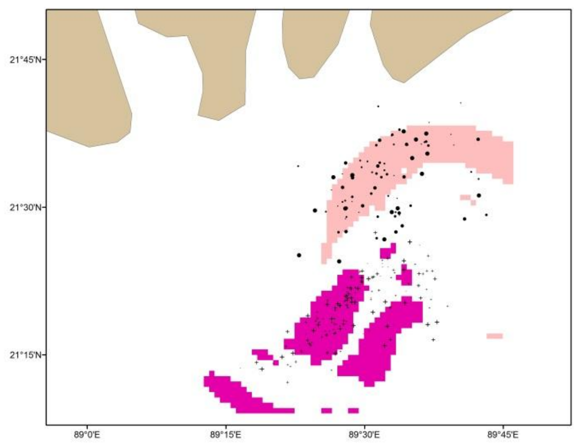

Figure 18. Core habitat for bottlenose (dark pink; sightings shown as '+") and humpback (light pink; sightings shown as dots) dolphins predicted by the CDOM model.

Fishing gears and practices

<u>Indo-Pacific humpback dolphin study area</u>

During five visits to each of the 39 sampling points over three winter seasons, a total of 4,516 fishing vessels/gears were recorded in the humpback dolphin study area (Figure 19, Table 11). There was a strong apparent overlap between the sighting locations of humpback dolphins and fishing gears. The most common gear was small set bag net, accounting for 78% of the total gears sampled, with 92% active. Drifting gillnets, long lines, and anchored gillnets accounted for most of the remainder, representing 9.8% (23% active), 4.2% (59% active) and 2.6% (37% active) of the total vessels and gears, respectively.

The overall low percentage of active gill netters during all three years probably indicates that they are fishing at night. Small mesh drifting gill nets are generally deployed from April to September (pre-monsoon and monsoon seasons), targeting Hilsa shad (*Tenualosa ilisha*), an economically valuable species that provides vital revenue from sale in local markets and international export.

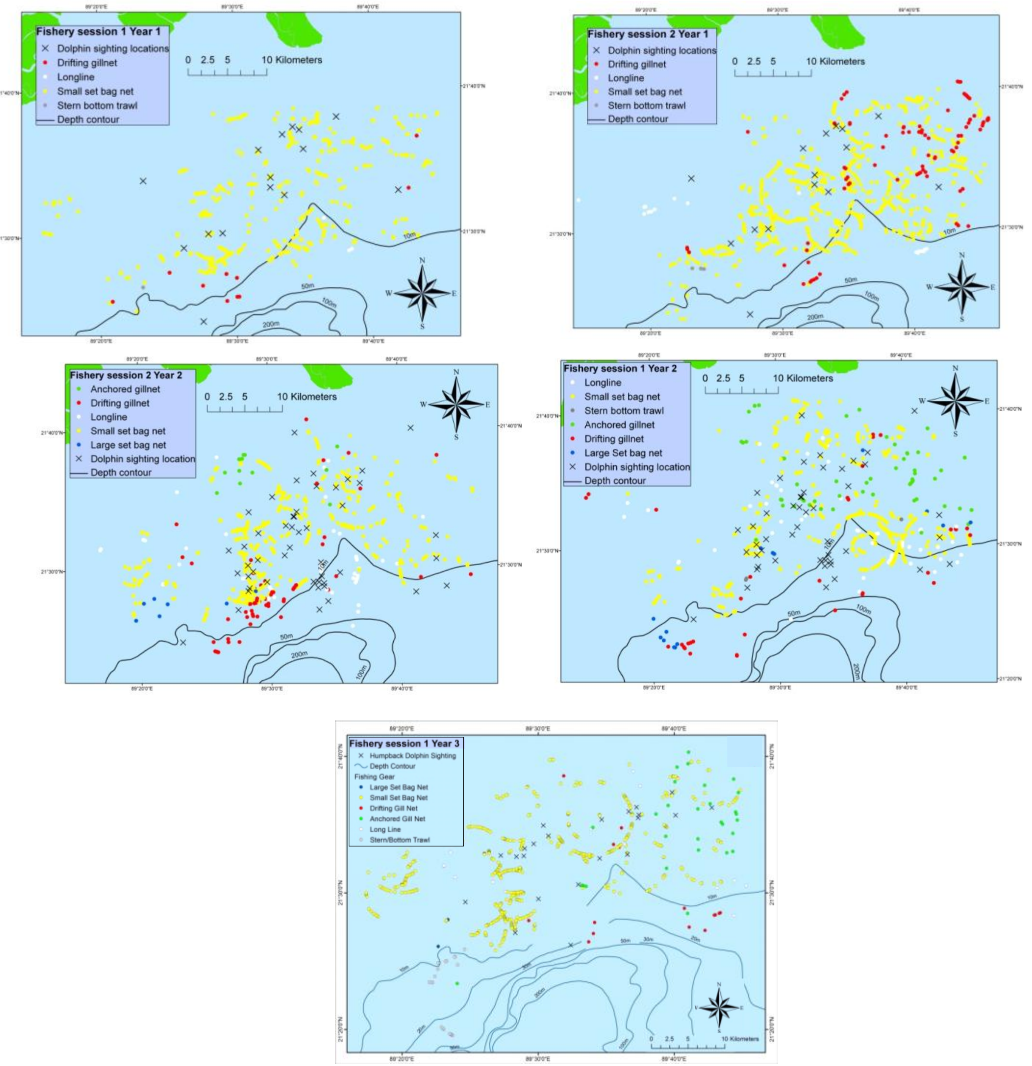

Figure 19. Locations of humpback dolphin sightings and estimated locations of fishing operations recorded from 39 sampling points during the winter season of 2010/2011 (two sampling session top row), 2011/2012 (two sessions middle row), and 2012/2013 (one session bottom). Circular patterns of fishing operations resulted from the practice of denoting sightings near the horizon as >5,000

Table 11. Fishing vessels and gears recorded from 39 sampling points spread out at 5-km intervals in the humpback dolphin study area during two sampling sessions in winter seasons of 2010 – 2012 and one sampling session in winter season of 2012/2013.

Winter seasons (sampling session)	Total vessel /gears	Anchored gillnet		Drifting gillnet		Large set bag net		Small set bag net		Long line		Stern trawler	
		% total gears	% active	% total gears	% active	% total gears	% active	% total gears	% active	% total gears	% active	% total gears	% active
2010/2011(1)	630	0	0	9	18	0	0	86	96	2	33	2	23
2010/2011(2)	1546	0	0	11	56	0	0	85	96	2	74	2	13
2011/2012(1)	738	7	69	6	5	2	67	73	96	8	80	1	0
2011/2012(2)	741	2	33	11	19	1	78	76	89	6	49	0	0
2012/2013(1)	861	4	81	12	17	1	25	73	85	3	60	4	66

By far the most common gear type used in the humpback dolphin study area is the set bag net. This is a funnel shaped net anchored to the ground and set against the tide. Between October and March, tens of thousands of set bag netters make temporary camp in Dubla Island situated on the southern tip of the Sundarbans within about 12 km from the northern edge of the humpback dolphin study area. Among the other two gears used in this area, long lines are more common than bottom trawlers, most of which are from India operating illegally inside Bangladesh waters. More detailed descriptions of fishing gears used in the humpback dolphin study area are in Appendix 2.

<u>Indo-Pacific bottlenose dolphin study area</u>

During two visits, one each winter season, to all of the 28 sampling points during 2010/2011 to 2012/2012, a total of 129 fishing vessels/gears were recorded in the bottlenose dolphin study area (Figure 20, Table 12). Except for 2012/2013, similar to the humpback dolphin study area, there was a strong apparent overlap between the sighting locations of bottlenose dolphins and fishing gears in the SoNG. The difference in 2012/2013 may be explained by the small sample size of gears recorded during this year.

During 2011/2012 the most common fishing vessel and gear were long lines accounting for 47% (76% active) of the total gears, followed by drifting gillnets (both small and large mesh), stern trawlers, and small set bag nets accounting for 19% (16% active), 15% (87% active), and 12% (100% active) of the total gears, respectively. There was an apparent change in the proportion of different gear types recorded in 2012/2013, when the most common gear was stern trawlers, accounting for 52% of the total number of gears (87% active), followed by long lines and drifting gillnets, accounting for 28% (25% active) and 21% (100% active), respectively. However, as noted above, there was also a much smaller number of total gears recorded in 2012/2013 (29) compared to 2011/2012 (100).

Large mesh gillnets are generally deployed in December – March (winter), targeting sharks and lakhua, or Indian salmon (*Polynemus indicus*). Lakua is a species that also has high export value. Sharks are caught mostly for their fins with little market for their meat. Most vessels operate year-round, changing their gear type according to season; and most vessel owners acknowledged incidental kills of small cetaceans, particularly in large mesh gill-nets. More detailed descriptions of gears and catches in the bottlenose dolphin study area are in Appendix 3.

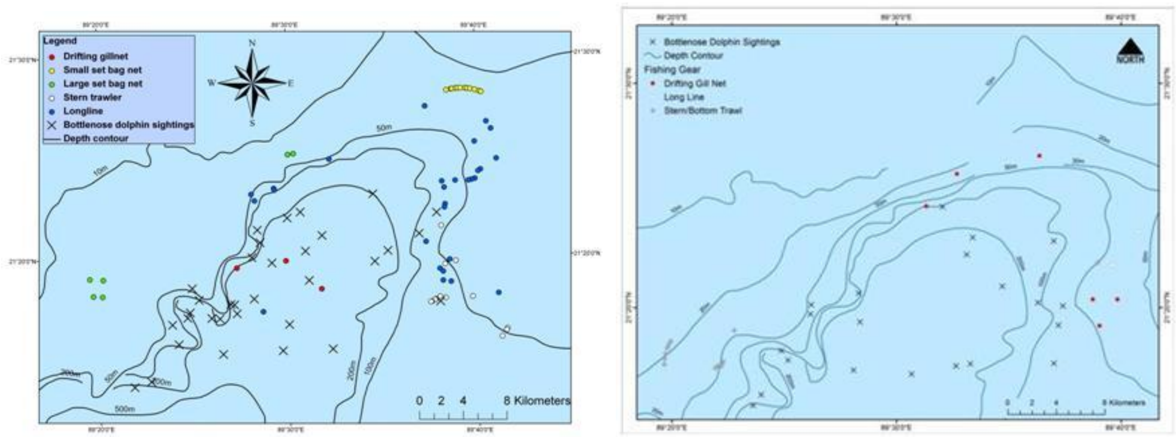

Figure 20. Map showing the locations of bottlenose dolphin sightings and estimated locations of fishing operations recorded from 28 sampling points at the head the Swatch-of-No-Ground submarine canyon during the winter season of 2011-12 (top) and 2011/2013 (bottom).

Table 12. Fishing vessels and gears recorded from 28 sampling points spread out at 5-km intervals in the Swatch-of-No-Ground submarine canyon Bangladesh during a single sampling session in winter seasons of 2010-2013.

Winter seasons (sampling session)	Total vessel/ gears	Drifting gillnet		Large set bag net		Small set bag net		Long line		Stern trawler	
		% total gears	% active	% total gears	% active	% total gears	% active	% total gears	% active	% total gears	% active
2011/2012(1)	100	19	16	6	100	12	100	47	76	15	87
2012/2013(1)	29	21	100	0	0	0	0	28	25	52	87

Identification of core habitat and spatial risk of fishing gear entanglement

Both bottlenose dolphins and humpback dolphins are at risk of entanglement in fishing gears with overlap between core habitat of both species and different types of fishing gears with different entanglement risks. The maps below suggest that during the winter season, overlap is greatest between humpback dolphins and fishing boats (Figure 21). The maps also suggest that there are fishing areas that do not overlap with the core habitat of both species. Concentrating fishing effort in these areas could reduce entanglement risk.

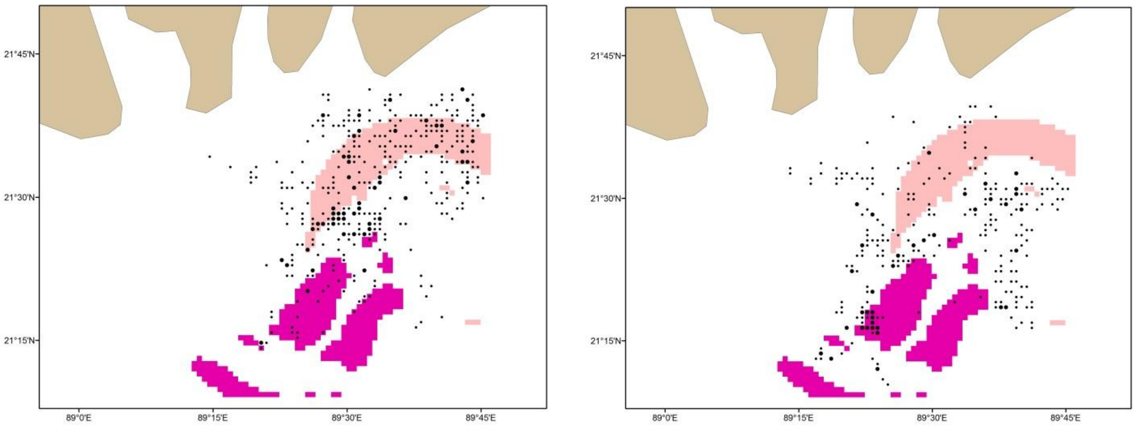

Figure 21. Core habitat for bottlenose (dark pink) and humpback (light pink) dolphins predicted using the CDOM model overlaid with sightings of fishing boats using anchored and drifting gillnets (left) and long lines or trawls (right). Larger black dots correspond to three or more fishing boats, while smaller dots correspond to 1-2 fishing boats.

Sightings and bycatch documented by dolphin/fishermen safety network

Between June 2013 and December 2015, during 90 medium mesh (9-10 cm) gillnetting trips targeting *hilsa* shad (*Tenualosa ilisha*) and 15 large mesh (18-20 cm) gillnetting trips targeting *lakhua* or Indian salmon (*Polynemus indicus*) as well as miscellaneous bass and groupers (Family Serranidae) and tuna (Family Scrombridae), gillnet fishermen reported 85 sightings of Indo-Pacific humpback dolphins, of which six were verified from photographs, and one fatal entanglement in a large-mesh gillnet; and 81 sightings of Indo-Pacific bottlenose, of which 11 were verified from photographs, and two fatal entanglements in medium-mesh gillnets (Figure 22).

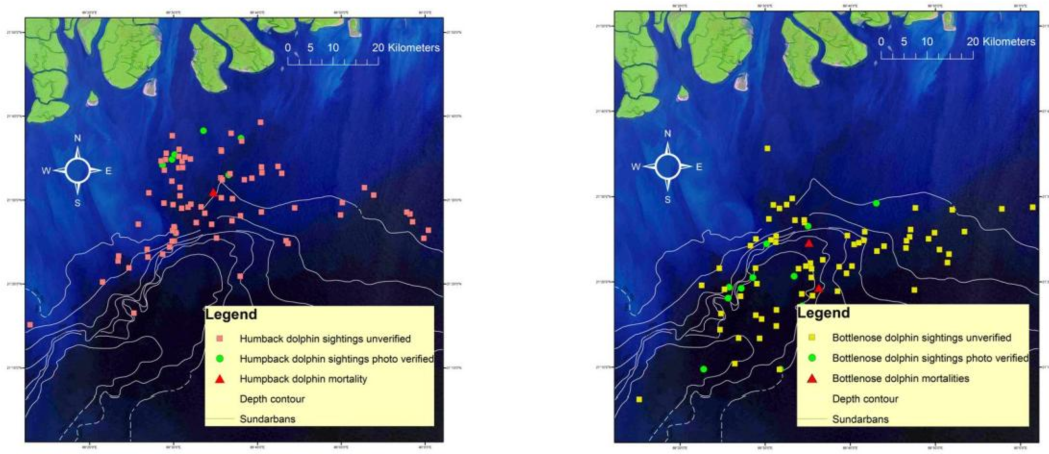

Figure 22. Maps showing the location of unverified (squares) and photo-verified (circles) sightings as well as fatal entanglements in gillnets (traingle) of Indo-Pacific humpback (left) and bottlenose (right) dolphins.

Conclusion

Large populations of both Indo-Pacific humpback and bottlenose dolphins, with relatively high survival rates, occur in the open estuarine and submarine canyon waters, respectively, of Bangladesh. Sampled populations of both species are almost certainly part of larger superpopulations extending west across the border with India and for humpback dolphins east to the mouth of the Meghna River mouth. Humpback dolphins occur in waters characterized by a lower salinity, higher turbidity, and much shallower depth with a gentle sloping bathymetry compared to bottlenose dolphins occurring at the head of the SoNG; and there is no overlap in their distribution. The relatively common occurrence of scars and mutilation in photographs, the extensive spatial overlap between fishing gears and preferred habitats, and fatal entanglements documented by gillnet fishermen of both humpback and bottlenose dolphins indicate that the currently favorable status of both species in Bangladesh could be threatened with increases in the intensity of fisheries. The genetic distinctiveness of the humpback and bottlenose dolphins in Bangladesh implies that both species should be treated a separate evolutionary unit and prioritized for conservation attention. Maps of the core habitat for humpback and bottlenose dolphins overlaid with the locations of different fishing gear types indicate that there are fishing grounds that do not overlap with both species thereby suggesting that fishing effort could be concentrated in these areas to reduce entanglement risk. Declaration in October 2014 of the Swatch of No-Ground (SoNG) Marine Protected Area to safeguard dolphins, whales, sea turtles, sharks, and other oceanic species in Bangladesh is a step in the right direction for conserving Indo-Pacific humpback and bottlenose dolphins. Now the challenge is to implement effective protection measures especially for reducing bycatch catch.

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