

Coexistence of Fisheries with River Dolphin Conservation

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Abstract: *Freshwater biodiversity conservation is generally perceived to conflict with human use and extraction (e.g., fisheries). Overexploited fisheries upset the balance between local economic needs and endangered species' conservation. We investigated resource competition between fisheries and Ganges river dolphins (*Platanista gangetica gangetica*) in a human-dominated river system in India to assess the potential for their coexistence. We surveyed a 65-km stretch of the lower Ganga River to assess habitat use by dolphins (encounter rates) and fishing activity (habitat preferences of fishers, intensity of net and boat use). Dolphin abundance in the main channel increased from 179 (SE 7) (mid dry season) to 270 (SE 8) (peak dry season), probably as a result of immigration from upstream tributaries. Dolphins preferred river channels with muddy, rocky substrates, and deep midchannel waters. These areas overlapped considerably with fishing areas. Sites with 2–6 boats/km (moderately fished) were more preferred by dolphins than sites with 8–55 boats/km (heavily fished). Estimated spatial (85%) and prey–resource overlap (75%) between fisheries and dolphins (chiefly predators of small fish) suggests a high level of competition between the two groups. A decrease in abundance of larger fish, indicated by the fact that small fish comprised 74% of the total caught, may have intensified the present competition. Dolphins seem resilient to changes in fish community structure and may persist in overfished rivers. Regulated fishing in dolphin hotspots and maintenance of adequate dry season flows can sustain dolphins in tributaries and reduce competition in the main river. Fish-stock restoration and management, effective monitoring, curbing destructive fishing practices, secure tenure rights, and provision of alternative livelihoods for fishers may help reconcile conservation and local needs in overexploited river systems.*

Keywords: alternative livelihoods, fisheries, fish-stock restoration, Ganges River dolphins, human-dominated river systems, resource competition, resource overlap

Coexistencia de Pesquerías con la Conservación de Delfines

Resumen: *La conservación de la biodiversidad dulceacuícola generalmente es percibida como un conflicto entre el uso por humanos y la extracción (e.g., pesquerías). Las pesquerías sobreexplotadas alteran el equilibrio entre las necesidades económicas locales y la conservación de especies en peligro. Investigamos la competencia de recursos entre pesquerías y delfines del Río Ganges (*Platanista gangetica gangetica*) en un sistema fluvial dominado por humanos para evaluar el potencial para su coexistencia. Muestreamos un tramo de 65 km de la cuenca baja del Río Ganga para evaluar el uso de hábitat por delfines (tasas de encuentro) y la actividad pesquera (preferencias de hábitat de pescadores, intensidad de uso de redes y lanchas). La abundancia de delfines en el canal principal incrementó de 179 (ES 7) (mediados de la estación de sequía) a 280 (ES8) (pico*

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de la estación de sequía), probablemente como un resultado de la inmigración desde afluentes río arriba. Los delfines prefirieron canales del río con sustratos lodosos, rocosos y las aguas profundas en medio del canal. Estas áreas se traslaparon considerablemente con las áreas de pesca. Los sitios con 2–6 lanchas/km (pesca moderada) fueron más preferidas por delfines que los sitios con 8–55 lanchas/km (pesca intensa). El traslape espacial (85%) y presa-recurso (75%) estimado entre pesquerías y delfines (principalmente depredadores de peces pequeños) sugiere un alto nivel de competencia entre los dos grupos. Un descenso en la abundancia de peces grandes, indicado por el hecho de que peces pequeños comprendieron 74% del total capturado, pudo haber intensificado la competencia actual. Los delfines parecen resistentes a cambios en la estructura de la comunidad de peces y pueden persistir en ríos sobreexplotados. La pesca regulada en sitios de importancia para delfines y el mantenimiento de flujos adecuados en la estación de sequía pueden sustentar delfines en los afluentes y reducir la competencia en el río principal. La restauración y manejo de poblaciones de peces, el monitoreo efectivo, el control de prácticas pesqueras destructivas, la seguridad en los derechos de propiedad y la provisión de formas de vida alternativas para pescadores pueden ayudar a reconciliar la conservación con las necesidades locales en sistemas fluviales sobreexplotados.

Palabras Clave: competencia por recursos, delfines del Río Ganges, formas de vida alternativas, pesquerías, sistemas fluviales dominados por humanos, restauración de poblaciones de peces, traslape de recursos

Introduction

Rivers and associated freshwater habitats are among the most threatened ecosystems of the world (Revenge et al. 2005; WWF 2006). Projected extinction rates for freshwater fauna in North America alone are over five times higher than for terrestrial fauna (Ricciardi & Rasmussen 1999). Modification of river flows (especially from dams), alterations in sediment and nutrient fluxes, habitat destruction, river pollution from urbanization and agriculture, boat traffic, illegal intentional hunting, and overexploitative fisheries threaten the biodiversity and ecosystem services in floodplain river systems of densely populated regions in southern Asia (e.g., Manel et al. 2000; Dudgeon 2000b; Gergel et al. 2002). Landscape-level threats, through geomorphologic changes, often translate to local resource declines (Gergel et al. 2002; Wiens 2002). Riverine protected areas, under pressure from diverse local needs, cannot be managed with exclusivist approaches that alienate human resource users. At the same time, unmanaged open-access systems cannot sustain biodiversity. Therefore, sanctuaries for charismatic riverine species (e.g., dolphins, crocodiles, otters) can be successful if they provide viable economic benefits (e.g., from fisheries) to dependent local people. Nevertheless, declining productivity of river fisheries due to pollution, habitat degradation, dams (Payne & Temple 1996; Bannerjee 1999; Dudgeon 2000a, 2000b, 2005), and overharvesting has affected local livelihoods and increased pressure on sanctuary resources.

Piscivorous freshwater species such as river dolphins interact closely with fisheries, often with negative consequences. The recent ecological extinction of the Chinese river dolphin (*Lipotes vexillifer*) was attributed primarily to destructive fishing practices (Turvey et al. 2007). Because the Indus river dolphin (*Platanista gangetica minor*) and Ganges river dolphin (*Platanista gangetica gangetica*) are endangered (Smith & Braulik 2008), con-

servation of river dolphins in southern Asia has become a critical issue. For these species, habitat fragmentation by barrages, excessive water abstraction, and river pollution are major threats (Smith & Smith 1998; Smith et al. 1998; Sinha 2006). Illegal, intentional killing of river dolphins in India and Bangladesh to extract blubber oil for catfish fisheries and incidental mortality by entanglement in gill-nets are examples (Smith & Smith 1998; Sinha 2006) of negative interactions of dolphins with fishing practices. Conserving dolphins by disallowing fishing is often recommended, although this conflicts with human needs.

Management of human-affected rivers for fisheries or wildlife often lacks the quantitative data and rigorous inferential approaches needed to develop strategies for coexistence. To reconcile conservation and local livelihoods (fisheries) a description and quantification of spatial overlap between species of concern and human activities are needed. Yet, few researchers have assessed the role of prey availability in determining spatial distribution of dolphins (e.g., Benoit-Bird & Whitlow 2003); thus, they have also not assessed competition between fishers and dolphins for the same fish resources (Matthiopoulos et al. 2008). Total-count surveys and threat assessments have been conducted (e.g., Sinha et al. 2000; Choudhary et al. 2006), but there are few empirical data on the ecology of Ganges river dolphins (Reeves & Brownell 1989; Smith et al. 1998; Sinha 2006).

The Vikramshila Gangetic Dolphin Sanctuary in Bihar, India, is a legally protected area in a human-dominated floodplain river system. As in stretches within the distribution range of the Ganges river dolphin, however, management effectiveness and active legal enforcement is minimal. But local nongovernmental organizations have been involved in monitoring, and awareness programs for fishers (Choudhary et al. 2006) have reduced direct killing of dolphins. The sanctuary has relatively high dolphin abundance and is under heavy fishing pressure. Thus, it offers a unique situation with which to explore

the potential for multiobjective management of fisheries and river dolphins.

We investigated biophysical and ecological factors that may explain the spatial overlap of dolphins and fisheries. We estimated the relative effects of fishing intensity on prey availability to dolphins and identified situations conducive to their coexistence. Freshwater biodiversity conservation and scientific, economically viable fisheries management, if embraced by decision makers, can be complementary and not antagonistic, and thus foster coexistence.

Methods

Study Area

The Vikramshila Gangetic Dolphin Sanctuary (VGDS) is a 65-km stretch of the Ganga River between Sultanganj (25°15'15"N, 86°44'17"E) and Kahalgaon (25°16'54"N, 87°13'44"E) towns in Bhagalpur, Bihar, India. Established in 1991 specifically to protect the endangered Ganges river dolphin (Choudhary et al. 2006), VGDS lies in the lower Ganga floodplain belt, which is characterized by high fluvial volume, river meanders, granite hillocks, alluvial islands, and sandbars (Singh et al. 2007). In the dry season during our study (December 2007 to May 2008) river width was 0.15–2 km and river depth was 0.2–40 m. The depth declined over 2 m in this period. Indirect threats (e.g., untreated sewage, agricultural runoff, embankments, and boat traffic) persist here, but deliberate killing of dolphins has decreased significantly (Choudhary et al. 2006). Pressure on fish resources is high, with over 3000 dependent fisher households. Criminal gangs in the area are involved in destructive fishing and have severely curtailed the rights of access of regular fishers.

Dolphin Distribution

To record dolphin distribution, we conducted 18 temporal replicates of 28 straight line, boat-based surveys of 2.5-km-long river segments in upstream (east to west) and downstream (west to east) directions. Surveys were undertaken in good weather and visibility conditions. Each river segment was sampled in morning and afternoon hours. Three trained observers (two on the sides and one in the center of the boat) recorded number and age class (adult, subadult, calf) of dolphins sighted. Observers measured sighting distances in tens of meters (with a laser range finder) and sighting angles with a magnetic compass. Boat locations for all dolphin sightings were logged into a global positioning system and projected to universal transverse mercator (UTM-45N). We estimated approximate x- and y-coordinates of dolphin groups from sighting distances and angles and plotted them on geocoded IRS-P6 LISS-3 satellite images of

the area (pixel resolution 23.5 m) in the software Idrisi Andes (version 15.0; ClarkLabs 2006).

Dolphin Abundance

Because of the linearity of river habitats and the navigational difficulties midchannel islands present, neither random placement of line transects with respect to animal distribution nor a zigzag design (Dawson et al. 2008) were feasible. We estimated abundance with two-sample capture-recapture methods that accounted explicitly for imperfect detection. Two teams (three observers in each team) recorded dolphins simultaneously and independent of each other. Both teams were stationed on two separate platforms on the same boat. Sighting time was used to identify dolphin(s) sighted in common by both teams. These “double-observer” surveys (Laake & Borchers 2004) were conducted in early March and late April. We surveyed at boat speeds of 4.5–5 km/h to improve sighting right in front of the boat (often missed), to detect individual surfacing events without double counting, and to estimate cluster size and group composition without misidentification. Regular breaks were taken to avoid observer fatigue and to verify sightings. We used the Lincoln-Petersen and Chapman’s bias-corrected abundance estimators (Chao & Huggins 2005). These estimators assume the proportion of animals commonly sighted by both teams of those sighted by only one team is equal to the ratio of animals sighted only by the other team to the total unknown population; that is, if n_1 and n_2 animals are sighted by teams 1 and 2 and m is the number of common sightings, then $\frac{m}{n_1} \approx \frac{n_2}{\hat{N}}$, where \hat{N} is the unknown population. Estimated population is thus $\hat{N} = \frac{n_1 n_2}{m}$. Detection probability (Laake & Borchers 2004), variance, and 95% confidence intervals of abundance estimates were calculated (Chao & Huggins 2005).

Habitat Use and Spatial Overlap

We used dolphin encounter rates as a proxy for habitat use. Different ecological and anthropogenic activity covariates were also measured at the segment level (Table 1). We identified locations of embankments (flood control structures on banks), industrial outlets, towns and settlements, waste outlets, and boat traffic, and used unsupervised classification of satellite images with the CLUSTER tool in Idrisi Andes to distinguish land-use categories. We mapped fishing areas and intensity levels from observations and from information provided by fishers interviewed. Spatial overlap between dolphin distribution and fishing areas was calculated from raster-image overlays.

To identify ecological factors affecting the encounter rates of dolphins and the intensity of fishing at the segment level, we used classification and regression trees (CART). Because explanatory variables were riverine

Table 1. Ecological and anthropogenic activity covariates measured in the study of habitat use by river dolphins and fishers.

Variable ^a	Measurement details	Covariates
Water depth (S)	depth meter ^b ; continuous recording; depth measured at every 200 m	depth at midchannel, at eroded banks, at depositional banks (m)
Channel width (S), channel type (Ct)	laser rangefinder ^c at every 200 m, observation	mean channel width (m), wide straight, wide meandering, channel with islands
Substrate type (Ct)	physical collection of sediment samples	major substrate type (1, sand; 2, mud; 1.5, sand + rock; 2.5, rock + mud; 3, sand + mud)
Flow speed (Ct)	observation	0, slow; 1, moderate; 2, rapid
Vegetation (B)	observation	present/absent
River profile (Ct)	average profile from transverse, valley-type cross-sectional depth data by continuous recordings at start, middle, and end of transects	transverse section types (T, uniformly shallow; U, uniformly deep; D, deep channels with shallow banks; W, deep channels with islands)
Motorized boats, fishing boats (S)	observation	number per transect
Boat noise (O)	ranked as per ambient noise	high, medium, or low
Net usage (O)	frequency of occurrence of net types	rated by fishers (1–4)

^aAbbreviation for variable type: S, scalar; Ct, categorical; O, ordinal; B, binary.

^bHondex digital depth sounder 3394 (Forestry Suppliers, Jackson, Mississippi).

^cNikon laser rangefinder laser1200 S (Nikon, Melville, New York).

geophysical factors, they were mutually correlated (Wiens 2002) and spatially autocorrelated (Urban et al. 2002). The CART method is robust, nonparametric, and can accommodate a lack of statistical independence between covariates and nested nonlinearity (De'ath & Fabricius 2000). It allows for rule-based hierarchical splitting of heterogeneity in the response variable because variation is partitioned into homogeneous subclusters on the basis of chosen covariate combinations (De'ath & Fabricius 2000). Models with the lowest residual heterogeneity (deviance) and the optimal number of terminal nodes were chosen for parsimony, and checked for consistency in covariate selection. Two separate trees were generated to explore and compare covariates that explained dolphin habitat use (regression tree) and human fishing intensity (classification tree). These results were validated with the habitat preferences of fishers determined in interviews. We determined whether pairwise dissimilarity in covariate values was significantly correlated to pairwise dissimilarity in dolphin encounter rates across river segments with a Mantel correlation test (Urban et al. 2002).

Prey–Resource Overlap

To determine the size distribution of dolphin prey, we compiled information on stomach contents ($n = 8$) of dolphins. These dolphins were killed when they became accidentally entangled in gillnets, and carcasses were found by the local conservation team during monitoring surveys between 2001 and 2008 (Choudhary et al. 2006; S.C., unpublished data). We sampled relative abundance of fishes at selected sites in the river through 60 passes with 50×1.8 m monofilament gillnets for 30 min each with the predominantly used mesh size (20 mm). Fish catch weights, number of fish caught, standard lengths (snout to base of caudal fin), and species richness were recorded for each gillnet pass. Sampling sites represented different

habitats, and sampling was rotated to keep weather conditions constant. To assess overlap in prey, we compared the distributions of mean length of fish in dolphin stomachs with the mean length of fish caught in gillnets across these sites.

Fisheries Assessment

We conducted interviews with fishers ($n = 105$) and recorded types and mesh sizes of nets they used, fishing effort (time spent, distance traveled), preferred fishing areas, size of fishes caught, and socioeconomic information. Interviewees identified destructive fishing practices (mosquito nets and beach seines) used by criminal gangs (not interviewed) as the main threat to fisheries. We assigned fishing intensity ranks to each river segment on the basis of the observed number of fishing boats, nets, and information from interviews (e.g., effects of nets used) (Table 1). Fishing intensity was categorized as low (0–2 boats/km), medium (2–6 boats/km), and high (8–55 boats/km). Nets with mesh of 0–40 mm ($n = 237$) and >40 mm ($n = 81$) were classified as small- and large-mesh nets, respectively. Interviews with fishers and available data on the relationship of length with age class for many of the sampled fish species (Froese & Pauly 2009) supported this classification.

Decreases in the abundance of large fishes caught, loss of selective fishing, and mesh-size reduction indicate overfishing (Murawski 2000; Layman 2004; Shin et al. 2005). We used fish length to assess exploitation because it is a useful indicator of the variable (Haedrich & Barnes 1997; Ault et al. 2005). A higher abundance of small-sized fish indicates overexploitation. Bayesian analysis was used to link these assumptions with observed data. Bayesian analysis differs from frequentist methods in that model parameters are treated as random variables rather than unknown constants (Ellison 1996). Because

model parameters are random variables, external information (e.g., expert opinion, historical information, and scientific literature) can be incorporated into models by constructing probability distributions (defined as prior distributions) to describe uncertainty in parameters. Often, prior distributions that contain no information about the value of model parameters are used (called uninformative priors) (McCarthy 2007). The Bayes' theorem combines prior knowledge about parameters with observational data to estimate posterior distribution of parameters:

$$p(\theta|x) \propto p(x|\theta) \times p(\theta), \quad (1)$$

where the posterior probability (p) of the candidate model (θ) given the data (x) is directly proportional to the prior probability times the likelihood (probability of data given the model) (Ellison 1996).

The beta distribution with two parameters (a, b) is used to summarize prior knowledge on proportion variables because it is defined over the interval (0, 1). It has mean $\frac{a}{a+b}$ and associated variance $\frac{a,b}{(a+b)^2(a+b+1)}$. The parameter a is the number of successes (number of cases when small-sized fish were obtained) and b the number of failures. Appropriate beta distributions can be chosen to represent different prior beliefs or opinions about indicators of status of fisheries (proportion of small fish in total catch per net pass). The choice of a and b is made on the basis of expected mean proportion and associated uncertainty ($a + b$ is number of observations that contributed to the prior distribution). For example, a beta (1, 1) prior represents an opinion about the total catch in which the prior expected proportion of small fish is $\frac{1}{1+1}$ or 0.5 and associated uncertainty is high because it is based on only two observations. Similarly, beta (1,3) would indicate a mean proportion of one-fourth (0.25) on the basis of four observations. We used mesh-size data (small- or large-sized nets) to update prior beta distributions that represented different proportions of small-sized individual fish out of the total catch (0.1, 0.25, 0.5, 0.75, and 0.9) and estimated posterior credible intervals for proportion. Strength of priors was assessed (McCarthy 2007) with deviance information criterion (DIC) (Spiegelhalter et al. 2002). We interpreted estimated posterior mean values relative to fisher perceptions of the level of exploitation of the local fisheries. In a Bayesian regression framework, prior beliefs about the magnitude, direction, and precision of the slope parameter can be summarized as an appropriate probability distribution. For example, if one assumes a positive slope on the basis of confirmed previous knowledge, one can choose a lognormal prior distribution with low variance. Similarly, if one does not expect a regression effect or expects a slope of zero with high uncertainty, a "flat," normal distribution with zero mean and high variance can be chosen (McCarthy 2007). Different competing priors can then be combined with the same data to give correspond-

ing posterior distributions for the model parameters. We used generalized linear models (logistic regression) to model dolphin preference as a function of fish availability, and analysis of variance to compare fish availability under high, medium, and low levels of fishing intensity. Dolphin preference was assigned to fish-sampling sites on the basis of observed local abundance as 1, highly preferred, or 2, not preferred under one of the assigned levels of fishing intensity (1, high; 2, medium; or 3, low). The logistic regression with log link and binomial error term was represented as

$$Y \sim \text{binomial} \left(p = \frac{e^{b_0 + b_1 X}}{1 + e^{b_0 + b_1 X}}, N \right), \quad (2)$$

where X is the covariate (fish count, fish length, species richness, weight of fish catch), Y is the binomial response of dolphin preference, p is the probability of preference (from a Bernoulli distribution), N is the number of sampling events, b_0 is the intercept, and b_1 is the regression slope. Because we expected a positive relationship between prey availability and dolphin preference, we used a lognormal prior to constrain slope to positive values. We chose a normally distributed prior with negative mean and high precision for the slope for fish length because we expected a negative slope (to indicate presence of small fish in stomach contents). We based intercepts of regression models on uninformed flat priors. Posterior means for slope from informed regression models were compared with those for uninformed priors.

Using Bayesian analysis of variance (ANOVA) as $y = \alpha_i + \varepsilon$ (where the error is $\varepsilon \sim \text{normal}(0, \sigma^2)$, α is the mean of the fish resource variables, and σ^2 is the variance at intensity level i), we tested whether fish relative abundance, length, weights, or species richness differed across the three fishing intensities. We set only uninformative prior means for all intensities. Markov chain Monte Carlo (MCMC) simulations were run in the program WinBUGS 1.4.3 (Spiegelhalter et al. 2007) and checked for model convergence. We discarded the initial 10,000 iterations and generated 100,000 samples for predicting parameters. We used the DIC for model selection (Spiegelhalter et al. 2007). Posterior median values for ANOVA parameters were compared visually. All other analyses were conducted in R 2.7.0 (R Development Core Team 2008).

Results

Dolphins were highly clustered at specific, widely separated sites. These sites were often located near embankments, pollution sources, and settlements (Supporting Information). Abundance in the main channel for 65 km was estimated at 179 (SE 7, 95% CI 148–208) and 270 (SE 8, 95% CI 240–304) in the mid and peak dry seasons,

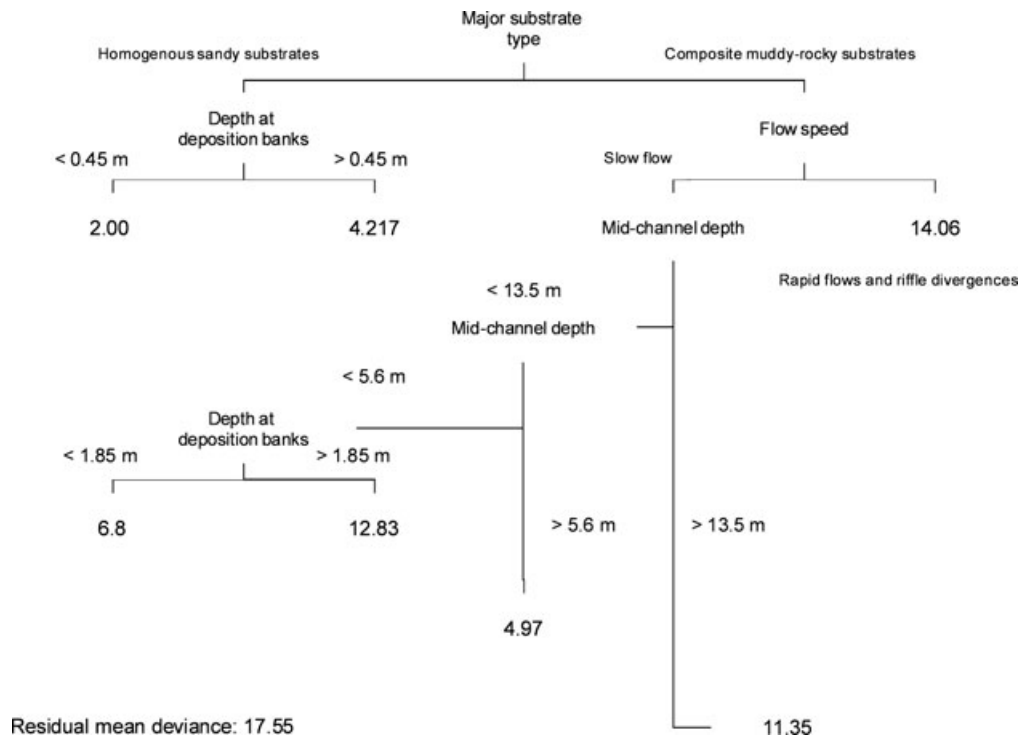


Figure 1. Regression tree explaining variation in dolphin habitat use. Numbers at terminal nodes indicate mean dolphin encounter rates influenced by different combinations of ecological covariates (e.g., depth, flow, substrate).

respectively. Detectability ranged from 0.44 to 0.63 for observer teams. During these seasons, the average depth of the main channel declined over 1.5 m.

Dolphins preferred channels with muddy and rocky substrates (rather than homogenous sand deposits), deep midchannel waters (5.6–13.5 m), and shallow waters near sediment deposition areas over 1.85-m deep (Fig. 1). In most habitats highly preferred by dolphins fishing intensity was moderate. Fishing intensity was high in very shallow areas, which were not preferred by dolphins (Figs. 1 & 2). Areas with rapid flow, such as confluences and eddy countercurrents, were highly preferred by dolphins, but fishing was higher in areas with moderate flow (Figs. 1 & 2). On the basis of mapped locations of dolphin sightings, fishing nets, and boats, their spatial overlap was estimated at 85%. Covariates of tree models (except motorized boat traffic) were significantly correlated (in terms of pairwise dissimilarity) to dolphin encounter rates (Table 2).

Distribution of length of fish in stomach contents (mean [SD] = 6.2 cm [3.09]) overlapped more closely with length of fish sampled from dolphin-preferred areas (7.87 cm [2.29]) than with distribution of fish lengths from unpreferred areas (9.673 cm [2.7574]). Our comparisons of mesh-size frequency distribution and distributions of sampled fish lengths showed that 75% of the fish targeted by fishers were within the size range preferred by dolphins (Supporting Information). Estimated mean proportion of small fish in the total catch was 0.743 (SD 0.05, 95%CI 0.69–0.79) (Table 3). Dolphin preference

was positively related to fish counts, species richness, and fish-catch weight and negatively related to fish length (Table 4). In moderately fished sites fishes weighed significantly more, had higher species richness, and were more abundant than in highly fished sites (Fig. 3).

Discussion

Estimated dolphin abundance in VGDS was higher than in any area where the dolphin is known to occur. Previous surveys from river stretches in the Ganga and Brahmaputra systems (Sinha et al. 2000) also indicated lower abundance. An increase in dolphins since 2001 has been reported in VGDS (Choudhary et al. 2006) after initial baseline surveys in 1998 (Sinha et al. 2000). Nevertheless, these surveys did not incorporate estimation of detectability and may have underestimated abundance. Estimates derived from capture–recapture studies in the Bangladesh Sunderbans (Smith et al. 2006) suggest lower dolphin abundance than in VGDS. Intentional killing of dolphins in VGDS has declined through conservation-awareness programs (Choudhary et al. 2006) and may have played a role in maintaining the population in this high-priority area.

Increase in abundance in peak dry season was likely due to congregation of dolphins in the main channel, where there was sufficient depth and flow volume. Ganges river dolphins migrate into tributaries in the

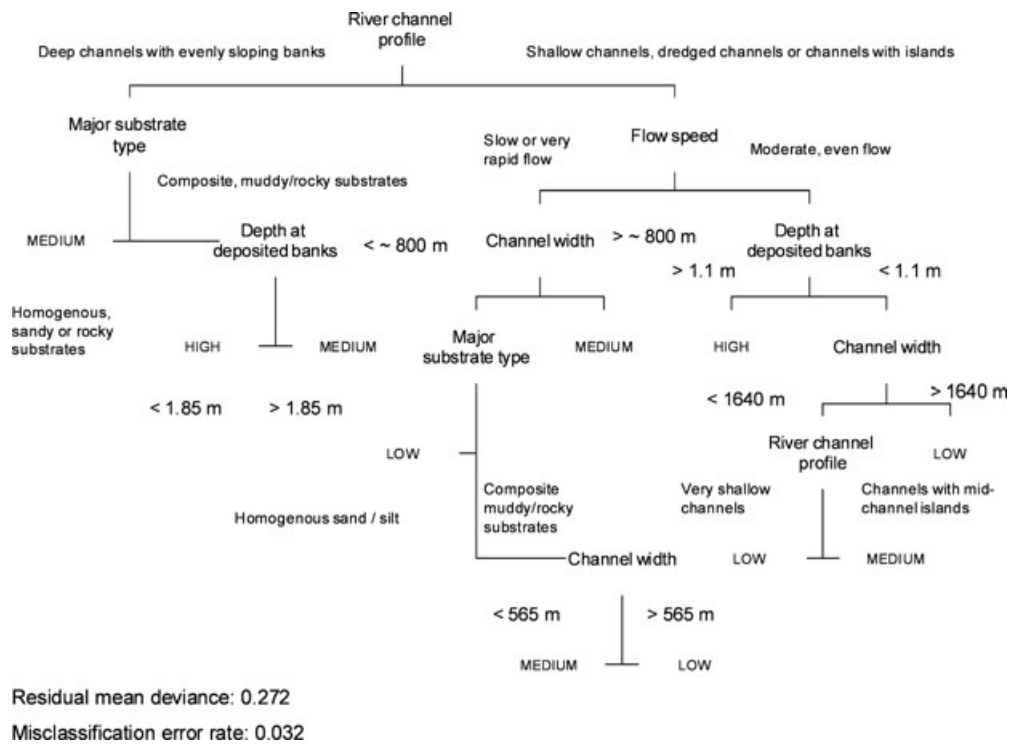


Figure 2. Classification tree explaining variation in intensity of fishing. Text in uppercase (at terminal nodes) represents fishing intensity levels (low, medium, high) influenced by different combinations of ecological covariates (e.g., depth, channel width, flow, substrate).

high-water flood season (Smith et al. 1998; Sinha 2006). Reduced upstream and tributary water volume, through diversion of water for agricultural use, may cause immigration of dolphins into larger main channels. Changes in flow volume in river basins (Dudgeon 2000b) may thus intensify competition among dolphins and between dolphins and fishers. This may cause fishers and dolphins to congregate at certain productive sites in the main channel far from their preferred areas in tributaries. Our results highlight the importance of maintaining adequate dry season river flows in tributaries (Bunn & Arthington 2002;

Richter et al. 2003) to sustain dolphin populations and reduce competition in the main river channel.

Ganges river dolphins (Smith et al. 1998) and other riverine and estuarine dolphins (Aliaga-Rossel 2002; Wedekin et al. 2007) occur at very specific locations. Aggregations of dolphins tracking the availability and concentration of local fish prey may choose certain sites (Hastie et al. 2004). Fishing activity was concentrated mostly at dolphin foraging sites, and it appears fishers and dolphins select sites with similar ecological conditions and higher fish availability. Dolphins with better

Table 2. Results of Mantel tests showing correlation between differences in dolphin encounter rates and differences in ecological and anthropogenic activity covariates across river segments.

Independent variable*	Mantel's <i>r</i>	95% CI
Midchannel depth	0.15	0.14-0.17
Deposited bank depth	0.12	0.10-0.13
Eroded bank depth	0.15	0.13-0.16
Flow	0.12	0.11-0.13
Major substrate type	0.21	0.20-0.22
Fishing intensity	0.11	0.09-0.11
No. of motorized boats	-0.014	-
Submerged vegetation	-0.02	-

*Significant at $p = 0.001$, except for no. of motorized boats ($p = 0.67$) and submerged vegetation ($p = 0.84$).

Table 3. Estimated posterior proportions of small-sized fishes of total caught derived from prior distributions of assumed proportions to indicate exploitation status.

Prior distribution parameters	Posterior mean	CI (2.5% - 97.5%)	DIC ^a
Beta (1,9)	0.726	0.676-0.772	8.421
Beta (1,3)	0.739	0.689-0.785	7.946
Beta (1,1)	0.744	0.695-0.789	7.921
Beta (3,1)	0.745	0.694-0.79	7.913 ^b
Beta (9,1)	0.75	0.702-0.795	7.938

^aDeviance information criterion.

^bMost likely candidate model assuming proportion of 75% in total catch.

Table 4. Parameter estimates for Bayesian generalized linear models for dolphin habitat preference as a function of covariates indicating availability of fish.

Covariate (effect on dolphin preference)	Model prior ^a	Intercept (mean)	Credible interval (intercept)	Slope (mean)	Credible interval (slope)	DIC ^b
Fish count (+)	U	-0.7835	-1.588- -0.0242	0.1151	0.046-0.1997	73.531
	I	-0.7805	-1.574- -0.0363	0.1143	0.0487-0.1959	73.392
Fish length (-)	U	2.051	0.5039-3.927	-0.223	-0.4349- -0.0495	80.203
	I	2.707	0.981-4.787	-0.3005	-0.5342- -0.1069	80.878
Fish weights (+)	U	-0.4948	-1.25-0.2352	0.00647	0.00163-0.0122	79.716
	I	-0.6524	-1.394-0.0488	0.00814	0.0036-0.01371	79.825
Fish species richness (+)	U	-0.9203	-1.853- -0.0425	0.3782	0.1362-0.6567	76.776
	I	-0.8173	-1.834- -0.1087	0.3407	0.113-0.6114	76.741

^aAbbreviations: U, uninformative prior; I, informative prior.

^bDeviance information criterion.

access to rapid-flow habitats that are not fished much because of constraints in net or boat use, may have a small advantage over fishers. Because these habitats are uncommon in the river, spatial overlap cannot decrease beyond a particular level. Therefore, dolphins may select heavily fished sites. At these sites, numerous small-mesh gillnets and mosquito nets are often set across channels, which may make foraging dolphins vulnerable to accidental entanglement.

Spatial overlap of marine mammals and fisheries is regarded as a useful indicator of resource competi-

tion (Matthiopoulos et al. 2008). High spatial overlap in resource-rich regions can be misconstrued by policy makers and conservationists as evidence of coexistence. Overlap in itself does not provide a complete picture of competition or direct effects of fishing on dolphins. High levels of fishing cause a decline in fish availability over time and may affect dolphins. In the least-productive sites dolphin abundance was low, as was fishing intensity. Dolphin habitat use overlapped primarily with moderate fishing intensity. Moderately fished sites were less productive than heavily fished sites, but seemed to provide

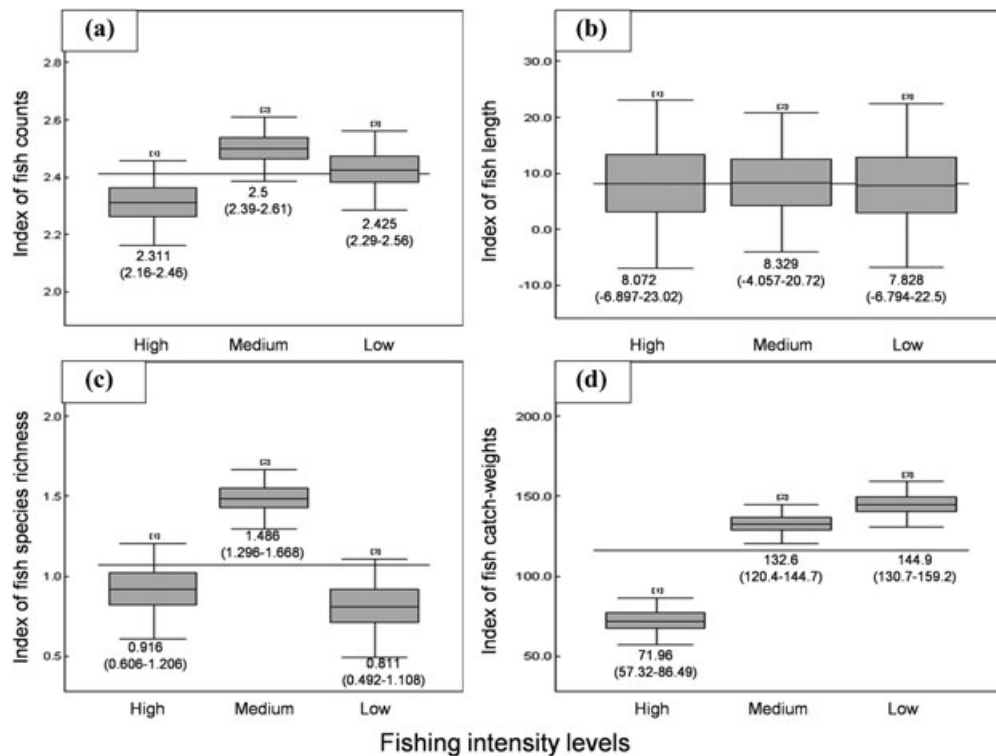


Figure 3. Influence of fishing intensity levels (high, medium, and low) on the (a) abundance of fishes, (b) length of fishes, (c) fish species richness, and (d) fish-catch weights. Numbers indicate parameter mean with 95% CI in parentheses for the corresponding level (e.g., index of species richness with high fishing intensity is 0.916 [0.606–1.206]). Line in the middle of graph indicates global mean across all levels.

more opportunities for foraging dolphins. Thus, moderately fished sites with high dolphin abundance may offer a threshold reference condition for fisheries.

Sites preferred by dolphins had higher biomass of small fishes, which supports previous observations of a predominance of small fishes in the stomach contents of dolphins (Sinha et al. 1993). Information on the feeding ecology of river dolphins comes exclusively from studies of stomach contents and observations of bottom feeding (e.g., Reeves & Brownell 1989; Sinha et al. 1993). An understanding of the functional mechanisms (e.g., feeding morphology and behavior) influencing prey selection by dolphins is important to predict how intensity of competition may change under different scenarios of fish availability. On the basis of our findings we estimated high overlap in fish sizes preyed on and harvested. Two explanations of this high overlap are likely. If small fishes are preyed on by dolphins because larger fishes are no longer available, both dolphins and fishers will compete for small fishes and take the suboptimal sizes available. Alternatively, mechanical restrictions on feeding imposed by weak jaw muscles or narrow esophagi of long-snouted piscivores (Endo et al. 2002), such as dolphins, can limit prey selection. Size-dependent prey selection (Layman 2004), higher encounter rates of locally abundant small fishes, and lower energetic costs (less diving effort) may cause foraging dolphins to select shallow areas. There are fewer large fishes, so fishers are also targeting smaller fishes, which are more abundant in shallower waters (Duplisea 2005). This shift to smaller fishes may have intensified competition between dolphins and fisheries over the years.

Restoration of the original size-class structure of fish populations to reduce competition should be a priority of both fisheries management (Dudgeon 2005; Link 2005) and dolphin conservation efforts. Severe declines of large predatory fishes that compete with dolphins for fish prey could be the reason for persistence of river dolphins in overexploited systems. Resilient and opportunistic predators such as river dolphins (preferring small fishes) may thus mask rather than reveal depletion of fish resources, whereas fishers will suffer more from the decline in the abundance of large fishes.

Overall, the trajectory of decrease in the abundance of commercial species follows the pattern of "ecosystem overfishing" (Murawski 2000). The existence of this condition is supported by catch data from landing sites within the sanctuary (S.C., unpublished data). The state fisheries department specifies a minimum mesh size of 40 mm (Choudhary et al. 2006); thus, about 75% of fishing, including that for subsistence, is illegal. Criminals threaten and banish fishers from their preferred fishing areas (Choudhary et al. 2006) and use destructive practices such as beach seines, mosquito nets, and poisons, which cause mass mortality of newly recruited fishes. Elimination of destructive fishing practices needs to be

the first step in restoration (Biswas & Boruah 2000), and the continued presence of regulatory authorities is necessary. Regulating fishing intensity in dolphin hotspots can ensure prey availability to dolphins. Our results provide baseline information for future assessments and identify monitoring targets for fisheries and river dolphin conservation. Our results demonstrate that developing easily measurable indicator variables for monitoring (e.g., fishing effort in moderately fished sites) (Link 2005) can help detect ecologically sustainable fishing thresholds. Nevertheless, scientific fish-stock assessments and long-term monitoring of community-level changes (Piet & Jennings 2005), lacking in this region (Dudgeon 2005), are urgently needed to define management goals.

Alternative livelihoods such as cooperatively managed aquaculture or ecotourism could ease pressure on the depleted fisheries. Such comanagement initiatives can economically benefit fishers through application of their traditional ecological knowledge and fishing skills. An economic safety net against the depleting resource base is needed to avoid marginalization of fishers by recognizing and securing their tenure rights. Schemes such as the National Rural Employment Guarantee Scheme can help generate alternative employment opportunities for some people dependent on protected areas for resources. Local fishers could be made important stakeholders in dolphin conservation and sanctuary management via incentives to monitor and regulate their fishing practices. Long-term restoration programs can keep both fisheries and dolphins alive. Effective conservation of river dolphins could thus help revitalize local fisheries rather than end them.

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Supporting Information

A map of the study area showing dolphin locations and land-use types (Appendix S1) and a figure of fish lengths

in dolphin stomach contents and of fish sampled by nets (Appendix S2) are available as part of the online article. The authors are responsible for the content and functionality of these materials. Queries (other than absence of the material) should be directed to the corresponding author.

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