Patterns of habitat use and distribution of Ganges river dolphins *Platanista gangetica gangetica* in a human-dominated riverscape in Bihar, India

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By

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Declaration

I declare that the thesis entitled "Patterns of habitat use and distribution of Ganges river dolphins *Platanista gangetica gangetica* in a human-dominated riverscape in Bihar, India" comprises research work done by me under the guidance of Dr. Jagdish Krishnaswamy, and co-guidance of Dr. Sunil Choudhary and Ms. Dipani Sutaria. The work is original and has not been done earlier by anyone else. Part of this work, which is related to or similar to work done by other researchers, has been cited in this thesis at appropriate places. The results presented in this thesis have not been submitted previously to this or any other university for an M.Sc. or any other degree.

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(Dr. Jagdish Krishnaswamy)

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Certificate

I declare that the thesis entitled "Patterns of habitat use and distribution of Ganges river dolphins *Platanista gangetica gangetica* in a human-dominated riverscape in Bihar, India" comprises research work carried out by Kelkar Nachiket Sanjeev at the Centre for Wildlife Studies under my guidance, and the co-guidance of Dr. Sunil Choudhary and Ms. Dipani Sutaria, during the period 2007-2008, for the Degree of Master of Science in Wildlife Biology & Conservation of the Manipal University. The results presented in this thesis have not been submitted previously to this or any other university for an M.Sc. or any other degree.

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Executive Summary

The Ganges river dolphin (*Platanista gangetica gangetica* Roxburgh 1801) is an endangered freshwater cetacean species endemic to the Ganga and Brahmaputra river systems in South Asia. The species is morphologically and taxonomically distinctive, and being the only blind cetacean, is dependent on echolocation for locomotion, sensory perception and feeding. The river systems that this unique mammal inhabits are under threat due to a wide range of human disturbances like reduction and modification of river flows, modification of nutrient and sediment fluxes, and degradation of habitat due to barrage and dam construction, point and diffuse water pollution from urbanization and agriculture, poaching and overexploitation of fish resources. Thus the Ganges river dolphin is, probably more than another riverine large mammal, unique in having to share its prime habitat under conditions of intensive human use. My study aimed to understand the relationship between river dolphin habitat use and ecological, environmental and anthropogenic activity covariates in the Vikramshila Gangetic Dolphin Sanctuary (VGDS), Bihar, India. The Sanctuary, which is the only protected area specifically created for Ganges river dolphins in India, is a biodiversity-rich and highly productive 65-km stretch of the lower Ganga river between Sultanganj and Kahalgaon in Bhagalpur district of Bihar, with an almost intact assemblage of large vertebrates typically associated with the Gangetic floodplain river ecosystem. The Sanctuary comprises an intensively used riverscape and landscape with high levels of human poverty, inadequate law-enforcement and poor governance. Despite this, it is an example of committed civil society effort in ecological monitoring and conservation advocacy.

Much of the published work on Ganges river dolphins largely covers status surveys and conservation planning. Other researches have been focused on molecular phylogenetics,

anatomical description and echolocation studies mainly on captive individuals. Many other studies, including the grey literature (government and institutional reports etc.), are heavily based on incidental field observations unsubstantiated by quantitative or statistical analyses. There is an urgent need to understand the specific habitat ecology of Ganges river dolphins, with quantitative approaches, in order to understand and mitigate threats to long-term conservation. The study had three main objectives:

1. To estimate the distribution and abundance of Ganges river dolphins in the VGDS
2. To study the patterns of habitat use by Ganges river dolphins in the VGDS in relation to ecological, environmental and human use covariates.
3. To assess the extent of overlap between fishing activities by local fishermen and dolphins for fish prey resources as well as space use.

The field work was spread over the dry season months of December 2007 to April 2008. I conducted double-platform surveys in VGDS with help from a local conservation NGO, the Vikramshila Biodiversity Research and Education Centre. Two-sample capture-recapture methods were used in the estimation of abundance. For objective 2, the river stretch of 65 km was systematically divided into 2.5 km segments or transects. Non-random boat transect surveys with a total upstream effort of 1170 km over 54 days, across the Sanctuary stretch, were carried out for estimating dolphin encounter-rates and collecting data on habitat covariates such as water depth, channel width, flow speed and substrate type at dolphin sighting locations along the transects. Due to the expected (and observed) spatially auto-correlated nature of successive, or spatially adjacent data values from linear boat transect surveys as well as the correlation between explanatory variables, the data were analyzed using Classification and Regression Trees (CART). These nested, hierarchical trees were used to explain the variability in dolphin

encounter-rates through rules based on values of ecological covariates. Finally, interviews with fishermen (n=105) helped understand the competition and spatio-temporal overlap between fishing activities and dolphin habitat use, and typical fish catch and dolphin prey. Measures of relative abundance of fish prey were developed using catch data from standardized fishing effort (gillnet passes). Stomach contents data from deceased dolphins collected in the past six years were used to estimate fish prey-size preferences of dolphins. The abundance of Ganges river dolphins across the studied stretch of VGDS was estimated at about 280 dolphins in April 2008 using two-occasion capture-recapture methods. Similar methods were used by Smith et al. (2006) in the Bangladesh Sunderbans, which estimated Ganges river dolphin abundance between 196 and 225 with a sampling effort of 1561 km. The estimates from the VGDS were thus considerably higher. River dolphins were most abundant in specific sites along the river stretch. Dolphins preferred mid-channel depths lower than 16.5 m, with bank depths greater than 1.45 m, and rocky and muddy substrates, had a high degree (almost 90%) of spatial overlap with fishing activity. Interviews with fishermen indicated that they sought out fishing locations largely based on the same characteristics. There was a strong overlap (around 75 %) in sizes of fish sought by dolphins and fishermen, partly due to the fact that fishermen no longer can rely on large fish catches which have declined over time. This study indicates that while dolphin population size is currently healthy in the VGDS, its continued welfare would depend on future trends in local fishing activity. This information would be useful for management decisions regarding human-dominated riverscapes for river dolphin conservation in South Asia.

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I profess my gratitude towards Bihar’s wild lands and waters. The banks and alluvial islands in the Ganga, where I thought several thoughts, watched several dolphins and enjoyed the contemplation on mixing sediments and eroding sand, eddy currents and nutrient flows; can never be forgotten.

I conclude with my favourite line from a poem by John Keats, a note which is reason enough to live, for me.

“The poetry of earth is never dead…”

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General Introduction

Riverscapes and associated freshwater ecosystems in the Indian subcontinent are under threat due to a wide range of intensive human use and developmental activities. Increased population and development pressures have led to depletion of fish stocks, severe pollution from point and diffuse sources, degradation of habitats, sediment load changes and hydrological alterations (Lal Mohan 1989, 1992, Rehana et al. 1995, Ansari et al. 1999, Manel et al. 2000, Dudgeon 2000, Singh 2001, Gergel et al. 2002, Singh et al. 2003, Sinha 2006). These in turn have had detrimental effects on the flora and fauna of the riverine ecosystems, including the Ganges river dolphin, a cetacean endemic the Ganges-Brahmaputra river systems in India and Bangladesh (Smith and Smith 1998, Sinha et al. 2000, Sinha 2006).

River dolphin conservation has become a very critical issue, owing to the recently reported extinction of the Baiji or Chinese River Dolphin *Lipotes vexillifer* Miller 1918 (Turvey et al. 2007, Ghosh 2007). The Ganges river dolphin *Platanista gangetica gangetica* Roxburgh 1801 has been declared an endangered species in the IUCN Red List, 2007. In the Wildlife (Protection) Act, [Government of India], 1972, the species has been listed in Schedule I. The Vikramshila Gangetic Dolphin Sanctuary (VGDS) in Bihar, India, is a 65 km stretch of the Ganga River between the Sultanganj and Kahalgaon, in Bhagalpur district of Bihar and is the only protected area specifically created for this species (Environmental Department Notification No. S.O. 382, Ministry of Environment and Forests, 1991 in. Choudhary et al. 2006). Owing to the large population of people inhabiting the riverbanks and dependent on the riverscape, the Vikramshila Gangetic Dolphin Sanctuary faces severe pressures from human disturbance and fishing.

Substantial proportions of the local people are economically very poor and are socially marginalized (Choudhary et al. 2006). In addition, poor governance and lack of law enforcement has led to continuing exploitation of fishermen communities by criminal gangs. The Vikramshila Biodiversity Research and Education Centre (VBREC), an NGO in Bhagalpur has actively been involved in conservation of river dolphins, along with other aquatic life, and has managed to raise awareness and support for dolphin conservation among fishermen. However, threats still abound, with dolphins facing aggravated competition from fishing activity and deaths occurring due to accidental by-catch due to entanglement in gillnets. My project aimed at understanding patterns of dolphin habitat use and habitat selection in this Sanctuary, to provide a quantitative analysis of relationships between habitat use and ecological covariates and responses to existing fishing and other anthropogenic pressures. Mapping of dolphin distribution in this river stretch is expected to serve as a conservation prioritization tool for Sanctuary management, through either official or civil society engagement, and for awareness among people. This study was conducted with logistic help and guidance from the VBREC team in Bhagalpur. It was funded by Wildlife Conservation Society –India Program and Whale and Dolphin Conservation Society, United Kingdom.

This dissertation work has been organized in three chapters, entitled as follows:

1. Estimating the abundance of river dolphins using double-platform independent-observer surveys in Vikramshila Gangetic Dolphin Sanctuary, Bihar, India.
2. Patterns of habitat use by Ganges river dolphins in a human-dominated riverscape in Bihar, India: implications for conservation

3. Effects of prey availability and anthropogenic pressure on foraging habitat selection by Ganges river dolphins in Vikramshila Gangetic Dolphin Sanctuary, Bihar, India.

The formats of all chapters pertain to peer-reviewed journals. Chapter 2 has been formatted pertaining to guidelines of Conservation Biology, and chapters 1 and 3 as per Ecology.

The basic questions addressed in the study are:

1. What is the distribution and abundance of Ganges river dolphins in Vikramshila Gangetic Dolphin Sanctuary in the dry (low water) season?

2. What are the spatial patterns of habitat use by river dolphins in this river stretch in the low-water season? What biophysical covariates explain river dolphin habitat use?

3. Is there a seasonal redistribution of dolphins influenced by decrease in river discharge?

4. What are the effects of prey availability and fishing pressure on dolphin habitat selection at a local scale, in the dry season?

5. What is the extent of resource competition between fishing activities and dolphins?

Different studies based on observations have proposed that water depth, channel width, direction and velocity of flow, geomorphologic complexities, and substrate type affect habitat use (Shreshtha 1995, Smith et al. 1998, Smith and Smith 1998, Sinha et al. 2000, Sinha 2006, Choudhary et al. 2006). Along with these, prey availability is another factor that can affect population size and habitat selection. River dolphins in the Ganges have been recorded to feed on small fish, and occasionally on crustaceans (Sinha 2006). Published works suggest that river dolphins compete with fishermen for the same fish resources, but no quantitative assessments or tested hypotheses are available. I focus on habitat selection and foraging preferences to test the following hypotheses and their variations. I base my hypothesis on a synthesis of literature on Ganges river dolphins as well as other studies on cetaceans living in similar habitats across the world.

Hypothesis 1. Depth profile, channel width, flow and substrate type influence river dolphin habitat use (Sinha et al. 2000, Sinha 2006, Garaffo et al. 2007). Dolphins prefer deep mid-channel areas close to shallower waters, proximate to banks.

Hypothesis 2. River dolphin distribution is non-random and there is a preference for specific sites along the river stretch. Other studies on riverine, coastal and estuarine cetaceans have shown patterns like clumped distributions and site-specific preferences (Hastie et al. 2004, Daura-Jorge et al. 2005, Wedekin et al. 2007, Garaffo et al. 2007).

Hypothesis 3. Prey availability (Allen et al. 2001, Benoit-Bird and Whitlow 2003) and fishing pressures determine foraging habitat selection (Allen et al. 2001, Kaschner et al. 2004). I test whether habitats are being selected in spite of high fishing pressure.

Hypothesis 4. The prey-size spectrum of dolphins approximates to a lognormal distribution. This has been proved in many vertebrates and may be of importance in understanding specialization in foraging (Hespenheide 1973, Larkin 1978, Munk 1992, Forsman 1996, Floeter and Temming 2005).

Background to the Study

The transition of ancient lineages of cetaceans from shallow epicontinental seas to freshwater over geological time has been attributed to marine transgression episodes (Cassens et al. 2000, Hamilton et al. 2001). In Asia, large river systems like the Yangtze in China, and the Indus, Ganges and Brahmaputra in India-Pakistan-Bangladesh became specialized habitats to some cetacean species. These species are endangered due to large-scale human disturbances across their distribution in Asia. The Baiji or Yangtze River

Dolphin *Lipotes vexillifer* was recently reported as ecologically extinct in Chinese waters (Turvey et al. 2007). The Ganges River Dolphin *Platanista gangetica gangetica*, from the Ganges and Brahmaputra river systems of northern India, Nepal, Bangladesh and the Indus River Dolphin *Platanista gangetica minor* Owen 1853, from the Indus river of Pakistan, are both assessed as 'Endangered' (Smith and Braulik 2004).

Research on *Platanista* sp. has been largely restricted to basic biology and molecular phylogenetics. In the late 1960s and 1970s, a series of descriptive papers on morphology, anatomy and physiology, side-swimming as well as acoustics and sound propagation mechanisms, echolocation, neuro-anatomy, brain development and reproductive biology were published on captive individuals of both species (Herald et al. 1969, Nishiwaki and Mizue 1970, Poulter 1971, Pilleri 1974, Pilleri et al. 1976). The phylogeny of the blind river dolphins has been studied using cytochrome-b gene sequences (Arnason and Gullberg 1996, Cassens et al. 2000, Hamilton et al. 2001, Verma et al. 2004). Pollution studies have been conducted to assess bio-magnification and magnitude of heavy metals, butyltin compounds, and organochlorines in tissues of Ganges river dolphins (Kannan et al. 1993, 1997). The species is known to be mostly solitary, except mother-calf pairs. They are also known to congregate sometimes in shallow water zones for feeding on small fish groups in such areas (Sinha 2006). Accounts have been published on sexual dimorphism, diving behavior, mating, lactation, calving and gestation periods, observations from dead specimens, but overall they are very scattered (see Sinha et al. 1993, Shreshtha 1995, Sinha 2006, Choudhary et al. 2006). For the Ganges river dolphin populations in India, Nepal and Bangladesh, population and threat assessment surveys have been carried out throughout their distribution range in order to assess the conservation status and obtain information on threats (see Hussain and

Chowdhury 1993, Smith et al 1998, Sinha et al. 2000, Wakid 2005, Biswas and Boruah 2006, Choudhary et al. 2006, WWF 2006). These surveys have resulted in preliminary information on encounter-rates of dolphins in different river stretches. In the 1990s, the main threat to the dolphins, especially in Bihar and Assam states, was reported to be direct killing by fishermen for extraction of oil from the blubber, which was used as a fish-bait (Lal Mohan 1989, Sinha 2002). Some novel approaches to prevent further hunting have included the use of fish scrap oil instead of oil from hunted dolphins (Sinha 2002) and owing to awareness and conservation efforts, direct killing has reduced (Sinha 2006, Choudhary et al. 2006). Threats to dolphins and dolphin habitat such as damming (Lal Mohan 1992) have been suspected to cause genetic isolation of dolphin populations (Reeves et al. 1997, Sinha 2006). Accidental by-catch owing to entanglement in gillnets, however, continues to be a threat (Sinha 2006).

Anecdotal observations have speculated on various factors that affect dolphin habitat use such as depth, channel width, water quality, confluence areas, geomorphologic complexities, substrate type, sediment load, hydraulic refuges, eddies and mid-channel island habitats (Shreshtha 1995, Reeves et al. 1997, Smith et al. 1998, Smith and Reeves 2000, WWF 2006, Sinha 2006, Biswas and Boruah 2006, Choudhary et al. 2006). Depletion of major carp fishery over the years has caused greater exploitation of smaller fishes and commercially unimportant fish species, which are considered the main prey of dolphins (Sinha 2006, Choudhary et al. 2006).

Conservation efforts across India, Nepal and Bangladesh have mainly focused on sensitizing fishermen to stop the killing of dolphins, seeking people’s co-operation for prevention of illegal hunting and creating awareness about the adverse effects of dams and barrages on river flows and catchments (Smith et al. 1998, Shreshtha 1995, WWF 2006, Choudhary et al. 2006). Apart from population surveys and threat mitigation measures, the detailed, scientific ecological knowledge about the species is still bereft of empirical information. Considering the high human impacts on the river systems the species inhabits, information regarding population size, space use, and habitat preferences that influence distribution and survival is required to systematically plan conservation strategies.

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Running head: Estimating the distribution and abundance of Ganges river dolphins

Title: Estimating the distribution and abundance of Ganges river dolphins in Vikramshila Sanctuary, India, using double-platform surveys

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Chapter 1

ESTIMATING THE DISTRIBUTION AND ABUNDANCE OF GANGES RIVER DOLPHINS IN VIKRAMSHILA SANCTUARY, INDIA, USING DOUBLE-PLATFORM SURVEYS

ABSTRACT

Ganges river dolphins are under threat in their range in the Ganges-Brahmaputra river basins in South Asia. In the past, most assessments of dolphin abundance at various river stretches have been based on direct counts which do not take into account imperfect detection and have no measure of uncertainty in their estimates. In 2006, Smith et al. used double-platform methods with visual surveys for freshwater cetaceans, and capture-recapture methods for abundance estimation, in the Bangladesh Sundarbans; estimating the abundance of Ganges river dolphins at 196-225 (SE 24.9) with a survey effort of 1561.5 km. I adapted this double-platform technique for replication in working conditions constrained by logistics and funds, as in the Vikramshila Gangetic Dolphin Sanctuary (VGDS), Bihar, India. The sanctuary expanse is a stretch of biodiversity-rich, highly productive riverine habitat. Double-platform boat surveys with independent observer teams were conducted to estimate abundance of Ganges river dolphins *Platanista gangetica gangetica* in the VGDS. Two-sample capture-recapture estimation methods were used for abundance estimation. Dolphin abundance along the 65-km stretch of the river was estimated to be 179 ± SE 7.29 in March and 270 ± SE 7.56 in April 2008, with mean cluster size estimated as 1.4 ± SE 0.06 dolphins. In spite of accounting for bias associated with these estimates, the increase in abundance in the summer season might be due to migration by dolphins from tributaries with decreasing discharge to the deeper main river channels. These estimates are significantly higher than

those obtained by Smith et al. (2006) in the Bangladesh Sundarbans. Comparing with count-based surveys of Ganges river dolphins across other parts of India, Nepal and Bangladesh, it is clear that the VGDS riverscape has one of the highest population sizes of river dolphins and is of extreme importance for river dolphin conservation.

KEYWORDS

Ganges river dolphins, availability bias, perception bias, double-observer surveys, two-sample mark-recapture methods, abundance estimates

INTRODUCTION

Counts of animals usually represent a proportion of the true abundance due to imperfect detectability (Buckland et al. 2001); therefore estimation of detection (or capture) probability is often a key component of modern abundance estimation techniques. Conventional Distance Sampling (CDS) assumes that detection of animals on the line is certain, denoted conventionally as $\hat{g}(0) = 1$. Estimation of the abundance of aquatic diving mammals like cetaceans involves assessing the critical issues of availability bias and detection probability, or perception bias. This requires the estimation of two probabilities: 1) the probability of animals being available for detection (i.e. when they surface above the water), and 2) the probability of being detected by the observer when they are available for detection (Laake and Borchers 2004). Because of these issues of 'perception bias' and 'availability bias' (Marsh and Sinclair 1989), the assumption of certain detection on the line does not hold in the case of cetaceans. Further away from the line, probability of sighting an animal might be conditional on various covariates related to observer attention, weather conditions and animal behavior. Double platform surveys with independent observer teams, where sighting data from each platform, representing an independent capture occasion, can be used in a two-sample capture-recapture framework for estimation of abundance (Laake and Borchers 2004), using the Lincoln-Petersen estimator or the Chapman's bias-corrected estimator (Amstrup et al.. 2005). In such estimation, unmodelled heterogeneity in capture probability (Laake and Borchers 2004) may bias abundance estimates. The heterogeneity in detection probability might be due to individual diving behavior, and the combined effects of covariates like weather, sighting conditions and observer attention on detection probability (Laake and Borchers 2004). Unlike in earlier surveys (see Smith and Reeves 2000, Sinha et al. 2000, Akbar et al. 2004, Choudhary et al. 2006, Braulik 2006) that only employed "direct counts" and obtained "best estimates", double-platform independent observer surveys provide estimates of capture probabilities in addition to those of abundance and estimates of precision. However, in linear stretches with complex riverine and landscape features such as islands, where survey designs with random line-transects cannot be implemented, capture-recapture methods are an alternative, free of assumptions about animal distribution in the study area. Recent estimates of abundance of Ganges river dolphins using double-observer surveys in the Sunderbans of Bangladesh have used similar methods, but with major capital and logistical investments involved (Smith et al. 2006). Due to logistic and financial constraints, large-ship surveys are costly and often beyond most local conservation and research teams in developing countries to afford (Aragones et al. 1997, Smith and Reeves 2000). I conducted double-observer surveys with modifications to suit my requirements within the limited available resources.

METHODS

Study Area

The Vikramshila Gangetic Dolphin Sanctuary is located in the Bhagalpur district of Bihar, India. It is a river-stretch of 65 km length between the towns of Sultanganj (25^o15’15”N, 86^o44’17” E) and Kahalgaon (25^o16’54”N, 87^o13’44”E). Morphology of the river channel is characterised by meanders, wide straight channels, alluvial islands, point and spit bars, rocky mid-channel islands and eddy—counter current pools also being common habitat features. The water depth ranges from 0.2 to 40 m. Owing to the presence of alluvial islands, there are peculiar navigation problems. The variation in channel width is between 150 m to almost 2 km. However, in very wide channels, water depths are very shallow and the channel is cut by various islands. Over my surveys, such places recorded very low numbers or even absence of dolphins, since in many stretches one could wade through. As survey coverage would be low in these sites, I considered only the traversed sub-channel or side-channel as part of the surveyed area.

Field Methods

The surveys conformed to the basic assumption for the double-platform independent observer surveys that animals did not move around in the study area between detection occasions. Owing to logistic and financial constraints that did not permit use of large-shipboards, I used a wooden, diesel-powered country boat for independent-observer surveys. To ensure independence between observer teams, such that no transfer of verbal, symbolic or cue-sighting information takes place a wooden platform was built on the rear end of the boat using locally available materials like bamboo poles and wires. The construction did not cause

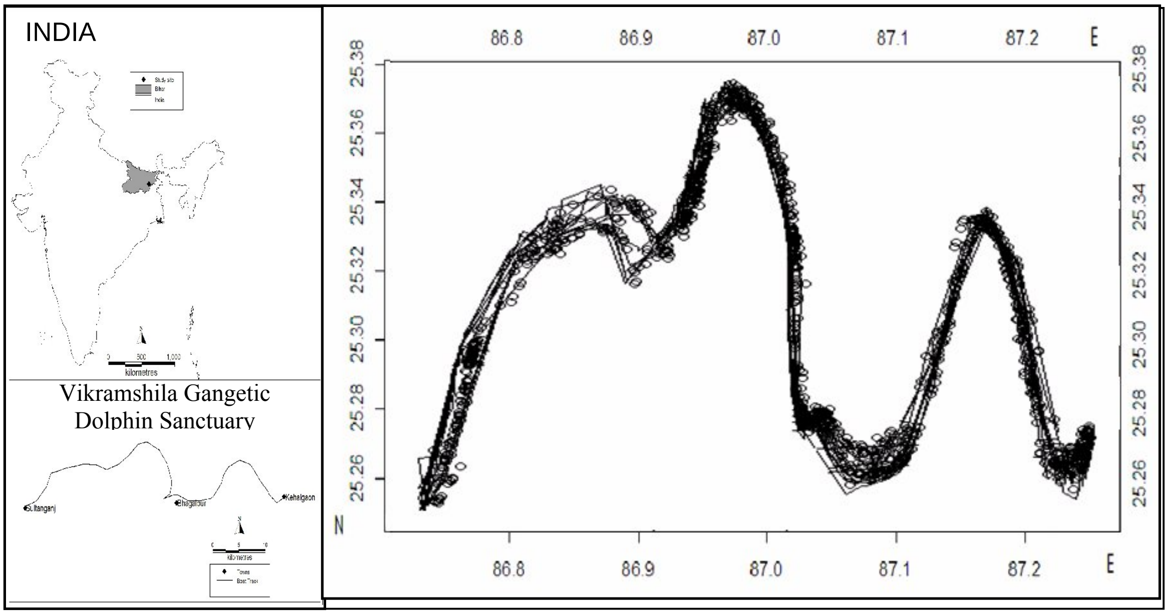

Fig 1.1. Map showing location of the Vikramshila Gangetic Dolphin Sanctuary in India (left). Boat track-line in the river stretch (right). Dark areas indicate high dolphin encounter-rates occurring at periodic intervals across the river stretch. Lines indicate transect track.

platform location and detection to be significantly correlated. Double-observer surveys were done once in early March 2008 and in late April 2008. Each observer team was adequately trained in techniques before implementing the surveys. Teams consisted of 2 observers, with a central data recorder for both the teams. A total of 65 km of survey effort was invested in each of these surveys. Both teams searched for dolphins visually and reported sighting details

to the data recorder. Whenever a dolphin group was sighted, sighting time, approximate perpendicular distance from boat track-line and age-class was recorded. Distances from the boat to the sighted animals were recorded in 10 m classes. Distance estimation was standardized using a Nikon Laser Range Finder 1200 S 7 X 25. It was ensured that $\hat{g}(0)= 1$ in this case by limiting the boat speed to 4.5-5 kmph and based on information that dolphins, on an average, surface once every 1-2 minutes (Shreshtha 1995, Sinha 2006). Regular breaks were taken to avoid effects of observer fatigue. During these breaks, cross-verification of sighting time and distance data from the two teams helped confirm duplicate identifications from sightings data. Due to the almost simultaneous time lag in the observation process by both platforms the same surfacing could be independently detected within a lag of less than a minute. Thus the visual survey could ascertain the correctness of recapture identification.

Analysis Methods

I used the Lincoln-Petersen estimator and Chapman's bias-corrected estimator for data from both surveys (Amstrup et al. 2005). The Lincoln-Petersen estimator is of the form $\hat{N} = n_1 \times n_2 / m_2$ and the Chapman's bias-corrected version of the estimator is $\hat{N} = [(n_1 + 1) \times (n_2 + 1)/(m_2 + 1)] - 1$ .where N = actual population size, n_1 = sample of animals marked on first occasion (first observer), n_2 = sample of animals marked on second occasion (second observer), m_2 = number of animals marked by first observer and second observer both. The capture probabilities for the observer teams is given by $\hat{p}_1 = m_2 / n_2$ and $\hat{p}_2 = m_2 / n_1$. Variance for these estimators is estimated as $\text{var}(\hat{N}) = (n_1 + 1) \times (n_2 + 1) \times (n_1 - m_2) \times (n_2 - m_2)/(m_2 + 1)^2 \times (m_2 + 2)$ (Williams et al. 2002, Amstrup et al. 2005). From the standard deviations of the estimates, 95% confidence intervals were obtained for abundance estimates approximated for a standard normal distribution.

RESULTS

The Lincoln-Petersen (L-P) and Chapman's bias corrected estimators (C-P) yielded estimates of abundance of river dolphins in the Vikramshila Gangetic Dolphin Sanctuary which are presented in table 1.1.

Survey No.	$\hat{N}$ (L-P)	$\hat{N}$ (C-P)	Standard Error	$\hat{p}_1$	$\hat{p}_2$	Averaged C.I. (95 %)
I (March 2008)	180.46	178.99	7.285	0.44	0.63	148—208
II (April 2008)	274.82	270.19	7.56	0.55	0.63	239.62—304.09

Table 1.1. Estimates from two-sample capture-recapture methods

DISCUSSION

Although two-sample mark-recapture methods are free of assumptions related to animal distributions with respect to the track-line, they are not free of other sources of bias. The most important bias is the unmodelled heterogeneity in detection probability due to miscellaneous covariates and not distance alone, as in CDS (Laake and Borchers 2004). Thus, modelling the dependence of capture probability on other factors is not achieved, and detections are thus correlated (Laake and Borchers 2002). Approaches from distance sampling have been integrated for modelling this probability as a function of increasing distance from the track-line, and other environmental covariates. This can be achieved by Mark Recapture Distance Sampling methods. In this case, the estimates for the March 2008 survey show a negative bias, because of weather condition effects for some part of the survey. This 'unmodelled heterogeneity' is the main problem here. If effects of factors like wind and glare would be included, the estimates would be higher. Probabilities for the two observer platforms were also seen to differ significantly. So observer effects might be very important. Also, it might not always be assumed that the 'marking' probability of animals always differs for both observers. In fact, a reasonable assumption to make (provided the nature of animal distribution in the study area is known) is of point independence (Laake and Borchers 2004) where $\hat{p}_1 = \hat{p}_2$ but only at zero distance from the track-line. At all other distances, $\hat{p}_1$ and $\hat{p}_2$ differ and depend on various covariates or their interactions. In my preliminary MRDS analyses, I obtained $\hat{p}_1$ = 0.39 ± SE 0.067 and $\hat{p}_2$ = 0.61 ± SE 0.076. When assumed that the negative bias due to the assumption of point independence is constant for both teams, these estimates hint at the inherent difference between the two observer teams and serve as an indicator of heterogeneity. MRDS estimates were higher than two-occasion capture-recapture estimates, but cannot be discussed owing to the problem of distance assumptions being violated. In the case of full independence, the negative bias increases further due to relaxation of the assumption that both observers sight (or miss) equally well on the track-line. I also stress on the use of methods that either take into account non-random placement (surveys done as if on a ship of opportunity) such as spatial distance models (Hedley 2000, Williams et al. 2006); or zigzag placement of transect lines (wherever possible) (Strindberg and Buckland 2004).

Smith et al. (2006) reported the abundance of Ganges river dolphins in the Sunderbans of Bangladesh using capture-recapture methods, as 196-225 individuals (CV = 12.6 %) with a sampling effort of 1561.5 km. However, they also surveyed the more numerous Irrawaddy Dolphins in that area. Also, the lower estimates for Ganges river dolphins could be due to the estuarine and higher salinity conditions of the habitat, as compared to freshwater habitats. High dolphin abundance in VGDS might be due to high productivity. Best estimates based on counts reported from other surveys, are 174 dolphins in Vikramshila Sanctuary (Choudhary et al. 2006); 144-161 over 250 km from Patna to Sultanganj in Bihar; and encounter-rates mostly range from 10-40 per 100 km of effort in many stretches in the upper Ganga and tributaries (Sinha et al. 2000). Comparing with the above counts and estimates, the density/abundance of Ganges river dolphins seem to be one of the highest in the dolphins' distribution range. Despite estimation bias, the dolphin abundance seems to be much higher in the summer months, due to abstraction of water from the tributaries for irrigation and by immigration into the river main stem. It is possible, that historically the lower Ganga region was the global hotspot for this species. The VGDS stretch can serve as one of the major focal areas for conservation of Ganges river dolphins.

CONCLUSIONS

The above analyses may be considered a useful preliminary tool for getting abundance estimates of river dolphins in a linear sampling area, and is a more robust method instead of only 'direct counts'. It is well-suited for areas with resource constraints such that transect lines can be placed randomly with respect to actual animal distribution, only with great costs or technical difficulties. The methodology involved the use of wooden diesel-operated country boats with constructed platforms using materials like bamboo poles, with help from local fishermen and boatmen. Wooden country-boats can navigate in shallower and constricted channels, are easy to manoeuvre, and are relatively inexpensive. The surveys involved local people in the training and observation process. Implementation of cost-effective methodology based on available local resources might be useful for conservation teams working with various constraints. Therefore, double-observer surveys need to be used regularly for surveys of river dolphins across their range. This would strengthen further conservation efforts by estimation of the target population size of river dolphins across different riverscapes. Reliable abundance estimates obtained over time would allow useful and logical inferences about population trends, providing a sound basis for conservation and management planning.

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Title: Patterns of habitat use by Ganges river dolphins in a human-dominated riverscape in Bihar, India: implications for conservation

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Chapter 2

PATTERNS OF HABITAT USE BY GANGES RIVER DOLPHINS IN A HUMAN-DOMINATED RIVERSCAPE IN BIHAR, INDIA: IMPLICATIONS FOR CONSERVATION

ABSTRACT

The Ganges river dolphin, an endangered freshwater cetacean species, is endemic to the Ganga and Brahmaputra river systems in South Asia. River dolphin populations live in the densest populated floodplain rivers in South Asia and face threats due to intense hydrological alterations, pollution and human extractive uses due to population pressures. In the lower Indo-Gangetic plains, the Vikramshila Gangetic Dolphin Sanctuary (VGDS) in Bihar, India is a 65 km stretch of the Ganga river with relatively high population densities of river dolphins. This highly productive riverscape and habitats are also human-dominated, with local communities from low income groups depending largely on riverine ecosystem services and thus utilising the same space as the dolphins. From December 2007 to April 2008, I used boat-based surveys across this river stretch to collect data on sighting locations and dolphin encounter-rates (as a proxy for habitat use intensity), as well as ecological and anthropogenic activity covariates like water depth, flow, channel width, substrate type, frequency of motorized boats and fishing intensity. Sampling units for data collection consisted of systematically placed segments of length 2.5 km across the river stretch. Change in spatial autocorrelation of dolphin clusters with increasing spatial lag was plotted using a Moran's I correlogram. Using Classification and Regression Trees (CART), a non-parametric approach, variability in river dolphin encounter-rates through rules based on ecological and anthropogenic covariates was explained. To investigate whether dissimilarity in habitat use was correlated with dissimilarity in these covariates, Mantel's tests were used. Dolphin clusters occurred at different sites along the river stretch at regular intervals. Dolphin habitat use was higher in muddy and rocky composite substrates than in homogenous sandy substrates. Mid-channel depths higher than 16.5 m and shallow banks with less than 1.45 m depth were less preferred. The same covariates explained almost 90 % of variation in fishing intensity as well. River depth, flow, substrate type showed a low yet significant correlation with dolphin habitat use. However, number of motorized boats, presence of vegetation and boat noise were not significantly correlated with dolphins.

KEYWORDS

Ganges river dolphins, human-dominated riverscape, habitat use, regression trees, ecological covariates, fishing intensity

INTRODUCTION

River systems of the Indian subcontinent are severely threatened due to habitat destruction, hydrological alterations, pollution and over-fishing (WWF Living Planet Report 2006). An indicator of these severe changes has been the reduction in populations of the Ganges river dolphin, an endangered freshwater cetacean species, which has been under threat owing to human disturbances at local as well as landscape levels across their distribution range in India. Being the main large mammal species of these rivers, conservation of Ganges river dolphins is a major priority issue (Smith et al. 2004). Recently, another river dolphin species of South Asia, the Baiji or Chinese River Dolphin, was declared extinct from the Yangtze river in China (Turvey et al. 2007). Healthy populations of river dolphins might be considered an indicator of the health of the river ecology itself. This study was conducted in the Vikramshila Gangetic Dolphin Sanctuary, Bihar, India, an area with a relatively good population of dolphins (Sinha et al. 2000; Choudhary et al. 2006). The population size of river dolphins might be one of the highest among areas in the distribution range of the Ganges river dolphin (see chapter 1). However, this area also has a large population of people dependent on the river's ecosystem services and living in extremely deprived socio-economic conditions. Therefore, information on patterns in habitat use of the Ganges river dolphins in relation to ecological, environmental and anthropogenic activity covariates can provide important insights for objective conservation and management planning in a human-dominated landscape.

Studies on various estuarine, coastal and riverine dolphin species have shown that dolphins show a marked preference for specific sites (Acevedo-Guttierrez & Parker 2001, Aliaga-Rossel 2002, Compton 2004, Hastie et al. 2004, 2005, 2006, Daura-Jorge et al. 2005, Kreb 2005, Wedekin et al. 2007, Garaffo et al. 2007), across the habitats they use. Population and habitat assessment surveys of river dolphins across their range world have proposed that deep waters, channel width, flow, geomorphologic complexities, substrate type and similar ecological factors affect habitat use by Ganges river dolphins (Shreshtha 1995, Smith and Smith 1998, Sinha et al. 2000, Sinha 2006, Choudhary et al. 2006). In spite of a large number of hypotheses and observational data, few quantitatively rigorous studies have been carried out to study the relationship of dolphins with biophysical covariates. In this study, I ask the following questions:

1. How are dolphin clusters distributed in the river stretch?
2. What is the role played by depth profile, channel width, flow and substrate type in influencing river dolphin habitat use?

3. In a human dominated riverscape, how do fishing intensity and other human disturbance affect dolphin habitat use? Does fishing intensity show a similar pattern as that of dolphin distribution?
4. Are river segments similar in ecological and anthropogenic activity covariates also similar in dolphin habitat use?

The river stretch was systematically divided into 2.5 km long segments used as sampling units for collection of data on dolphin sighting locations and habitat covariates. Anthropogenic disturbance covariates were also recorded at this level. Results show that dolphins prefer deep channels with shallow deposition banks and composite substrates to homogenous sand. Finally I discuss implications of the influence of these covariates on dolphin distribution at the scale of the study and its possible landscape-level implications.

METHODS

Study Area

The Vikramshila Gangetic Dolphin Sanctuary is a 65 km long segment of the Ganges river main stem between the towns of Sultanganj (25^{o}15’15”N, 86^{o}44’17” E) and Kahalgaon (25^{o}16’54”N, 87^{o}13’44”E) situated in the district of Bhagalpur in Bihar, India. The river Sanctuary of VGDS is one of the areas characterized by highest fluvial discharge in the lower Ganga belt and the highest deposition of alluvial mid-channel islands, point bars and spits in the Ganga main stem (Singh et al. 2007). This stretch is characterized by two prominent meanders. Granite outliers called monad nocks are seen in the VGDS in or near the river in the form of rocky hillock islands. The river width varied between 150 m to almost 2 km. River depth showed a high variation (range 0.2-40 m). The Sanctuary was notified by the

Government of India in 1991 especially for protection of the endangered Ganges river dolphins (Kumar and Sinha 2001, Choudhary et al. 2006). Along with the high densities of dolphins, the Sanctuary has remarkable biodiversity. Smooth-coated otters *Lutrogale perspicillata* and turtles *Kachuga spp.* are very commonly seen. Several wintering migratory species of ducks, waders, cranes, terns and skimmers have been recorded. In spite of this high diversity and rich variety of life, scant attention has been paid towards implementation of meaningful conservation measures by the concerned government authorities, such as the Forest Department and Fisheries Department. Untreated sewage from many towns located on the banks of the Ganga is allowed to flow directly into the river channel. Agricultural runoff, embankment detritus and organic wastes are other sources of pollution. There is unregulated, criminal-aided fishing and anti-social activities. The main land uses are agriculture and settlements, with fishing (around 3000 fishermen households) as an important occupation of the area. A local NGO, Vikramshila Biodiversity Research and Education Centre in Bhagalpur, with help from the Whale and Dolphin Conservation Society, has been conducting population assessment surveys and effecting conservation awareness work over the last decade. In the face of high poverty, high crime rate and poor governance, the survival and population success of river dolphins in the Sanctuary, along with the local fishing communities, is a very crucial conservation problem.

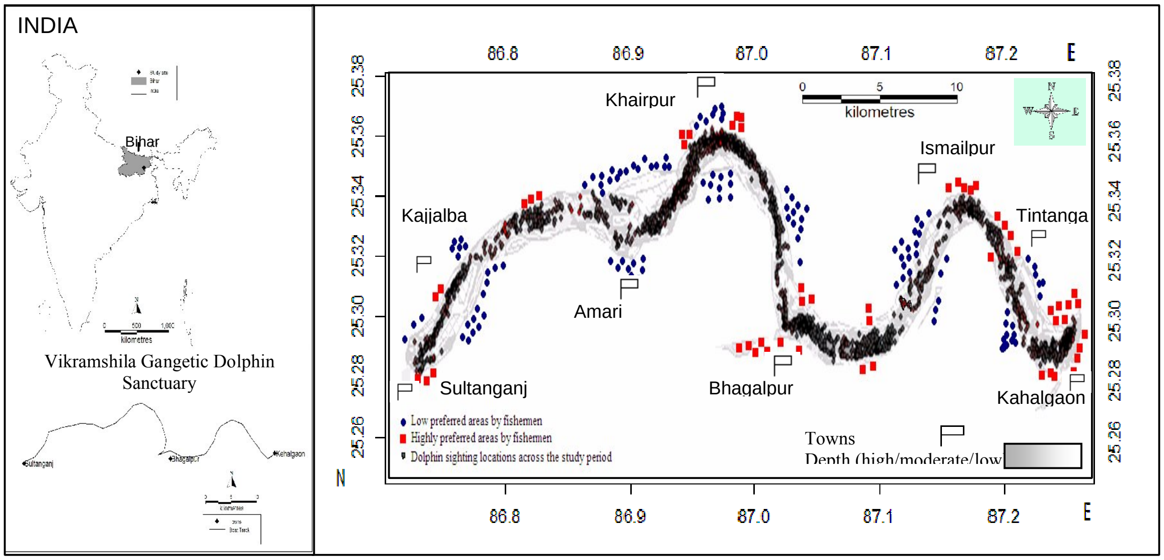


Figure 2.1. Map showing location of Vikramshila Sanctuary in India (top left); river stretch (bottom left); river stretch with dolphin sighting locations and high and low fishing pressure in different areas

Field Methods

Dolphin surveys and marking of sighting locations

I conducted eighteen replicates of twenty-eight systematic or non-random straight-line transects of length 2 or 2.5 km along the river stretch. The total upstream survey effort was 1170 km. This yielded temporal replicates of segment-wise encounter-rates of dolphins across the dry season from December 2007 to April 2008. Surveys were done in both upstream (E-W) and downstream (W-E) directions between Kahalgaon to Sultanganj. Upstream mean boat speed was 5 kilometres per hour (kmph) and downstream speed was 9 kmph. Three observers, (two on the sides and a central data recorder), searched on both sides of the boat track for dolphins. Observers recorded sighting distances (measured using a Nikon Laser Range Finder 1200 S 7 x 25) and angles were measured using a magnetic compass (between 0° and 90° on either side of the observer) with respect to boat, when a cluster was sighted. Boat locations were logged in a Global Positioning System (Garmin 12 XL GPS) each time a cluster was sighted. Age-classes of dolphins were recorded as adult, sub-adult and calf based on Smith and Reeves 2000. Latitude and longitude data on locations (in degrees decimal) were converted to Universal Transverse Mercator (UTM) – zone 45, Northern Hemisphere in the datum World Geodetic System (WGS 84) to visualize points in a 2-dimensional-space, and approximate x- and y- coordinates could be obtained (with the software MN DNR Garmin 5.1.1 (Minnesota Department of Natural Resources 2001)) for each dolphin cluster based on sighting distances and angles. Dubious surfacing events were not recounted, especially with respect to animal sightings exactly perpendicular to the track-line, if a group had just been left behind. Inter-observer communication ensured cross-verification of possible double-counts. Responsive or evasive movement by dolphins to the boat track-line was found to be negligible. Estimation of cluster sizes and group composition was based on careful observations on resurfacings of individuals within close vicinity of each other. Low boat speed in upstream surveys (<5 kmph) provided sufficient time to carefully correct for possible double counts in recording.

Ecological covariates

Collected data on habitat properties like water depth, channel width, substrate type and flow pattern type for each 2.5 km segment is shown below (see table 2.1). I recorded depths (using a hand-held Hondex Digital Depth Sounder 3394), along with GPS locations, at random locations or at regular intervals of 200 m, at various locations where dolphins were frequently seen and valley-type cross section-depths across each segment at regular intervals. Channel width in each segment was recorded at regularly spaced (200 m) locations using a Nikon Laser Range Finder 1200 S 7 X 25. I graded substrate types from physical collection of sediment samples under broad categories like mud, sandy or rocky substrate for each segment and recorded presence of aquatic submerged macrophytic vegetation. River profile was characterized based on transverse depth cross-sections. Presence of confluences, alluvial islands, alluvial floodplains, sand and spit bars, levees, ghats and rocky mid-channel islands was recorded. Indices of water quality (nitrates, phosphates and chlorides in parts per million) were calculated from collected water sample, but these data were not used owing to lack of any variation in the values obtained.

No.	**Variable**	**Categorical/ Ranked/Continuous**	**Covariate used (abbreviated as)**
1.	Water depth	Continuous	Midchannel depth (Depth 1), Depth at deposited banks (DBD), Depth at eroded bank (EBD)
2.	Channel width	Continuous	Mean channel width
3.	Substrate type	Categorical	Major substrate type (MST); coded as Sand=1, Mud =2, Sand + Rock =1.5, Rock + Mud = 2.5 and Sand + Mud = 3.
4.	Flow speed	Categorical	Slow (0), moderate (1) and rapid (2)
5.	Presence of vegetation	Binary	Present/Absent
6.	Channel Type	Categorical	Wide straight, wide meandering, channel with rocky mid-channel islands
7.	River profile	Categorical	Graph of transverse cross-sections Uniformly shallow areas—Trough-shaped (T) valleys,very deep areas—U-valleys Deep areas with shallow banks—D valleys Areas with alternation of deep and shallow water—W shaped valleys, typically with mid-channel islands.
8.	Habitat diversity and evenness	Continuous	Shannon-Weiner index for habitat types within each segment (H), and Evenness index (E) based on Magurran, 1986.

Table 2.1. Table explaining details of habitat covariates measured

Anthropogenic disturbance

Sketch-maps for locating villages were prepared from Survey of India topographic maps (scale 1: 25,000) of the area. I obtained segment-wise data on various anthropogenic activity covariates (see table 2.2) and recorded GPS locations of ghats, embankment constructions, settlements, boat stops, fishing vessels, industry areas, effluent and waste outlets. One hundred and five fishermen were interviewed to record preferred fishing habitats, types of nets and gear used, amount of effort expended in fishing (in terms of time and distance traveled) along with basic information like name of village, experience in fishing, socio-economic and criminal problems related to exploitative fishery (see appendix 1) in order to assign a composite fishing pressure rank based on net types, net use intensity and number of fishing boats in each segment.

No.	Variable	Categorical/ Ranked/Continuous	Covariate used (abbreviated as)
1.	Motorized boats	Continuous	Number per segment
2.	Fishing boats	Continuous	Number per segment
3.	Boat Noise	Ordinal	High , medium or low
4.	Net use intensity	Ordinal	Ranked 1 to 4 based on fishermen interviews
5.	Fishing intensity	Ordinal	Ranked based on preferred fishing locations, number of boats, net types used, other related activities and fishermen perceptions

Table 2.2. Table explaining details of anthropogenic activity covariates measured

Data Analysis

Covariates data collected in linear and continuous river systems would have a pronounced effect of spatial dependence, as proximate points would be more similar (Fortin and Dale 2005). In order to test for spatial autocorrelation, I used a Moran's I correlogram. One would expect dolphin encounter-rates closer to each other to be similar in relation to spatial lag (with increasing difference in geographical distance classes). The Moran's I statistic was computed using the Ecodist library of R 2.7.0 software (R Development Core Team 2008). Euclidean distance was computed as the square root of the sum of squared differences of the geographical co-ordinates of all points.

As explanatory variables were mostly riverine geophysical characters, they were often correlated with each other (e.g.—river width and river depth). Therefore, we used a non-parametric approach of rule-based, hierarchical splitting of the heterogeneity in the response variable of interest (dolphin encounter-rates in this case) to analyze habitat use. This method, called Classification and Regression Trees (CART) could be used without any parametric assumptions of statistical independence between all explanatory covariates (De'ath & Fabricius 2000, Boyce et al. 2002). At each level in the tree-building, heterogeneity in the response variable is partitioned by selecting the covariates which minimize this variation at that level. The heterogeneity basically refers to lack of fit between the split in the tree model and the response variable values, and is called 'deviance'. The tree model which splits the data such that deviance is minimized is chosen as the best. The advantage of using tree models is that they can handle multiple covariates of any type, and possible non-linear relationships. A CART algorithm was used to explain encounter-rates with the help of rules based on ecological and anthropogenic activity covariates.

I also used Mantel tests to correlate pair-wise dissimilarity in environmental and ecological variables with dissimilarity in encounter-rates, as a support for rules obtained from regression tree analyses. This also addressed the question of whether pair-wise similarity (or dissimilarity) in dolphin encounter rates across segments was correlated with (pair-wise) similarity in the covariates like depth, flow, substrate type, fishing intensity (Urban et al. 2002, Snelder et al. 2007, Krishnaswamy et al. in press).

RESULTS

Moran's I correlograms

Moran's I correlograms showed a quasi-periodic pattern in spatial autocorrelation over the range of geographical distance classes. This indicates a quasi-periodic occurrence of similar and dissimilar encounter rates of dolphins across increasing spatial lag. The correlogram indicates a regular occurrence of preferred and non-preferred sites along the river stretch (see fig. 2.3).

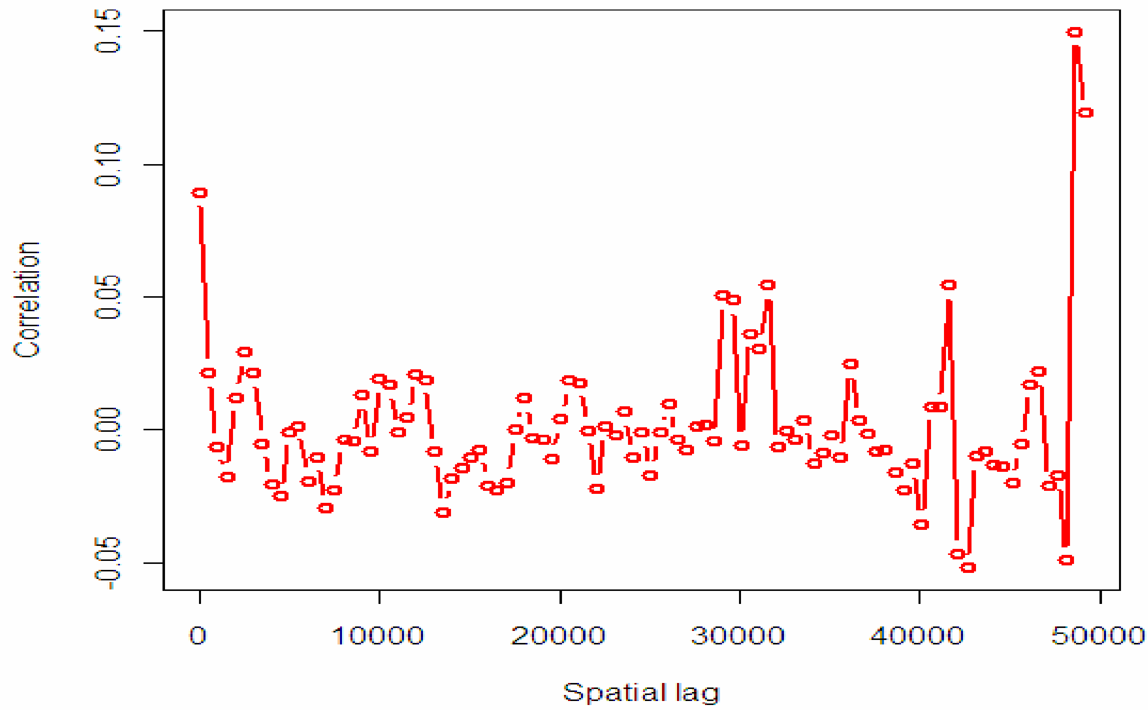


Figure 2.3. Moran's I correlogram showing quasi-periodic pattern in autocorrelation of dolphin encounter rates with increasing spatial lag (in metres).

Regression trees

Fishing intensity was an important factor in explaining dolphin habitat use at the spatial scale of 2.5 km river segments. Dolphin encounter-rates were greater in high fishing intensity areas. This suggests an overlap in space use by dolphins and fishermen. In high fished areas, much of the variation in encounter rates was explained by deposited bank depth which shows a threshold value of 1.45 m. Dolphins preferred deposited bank areas with depth greater than 1.45 m to bank areas with lower depths. In low preferred areas for fishing, mid-channel depths were 16.5 m or above, which were also less preferred. Below 16.5 m, the most important variable was substrate type. Very shallow deposited banks were less preferred. Number of motorized boats did not seem to significantly affect dolphin encounter-rates across segments. Habitat use by dolphins and fishermen was explained by similar habitat covariates. Regression trees showed river depth profile, substrate type and flow to be common preferences to both dolphins and fishermen.

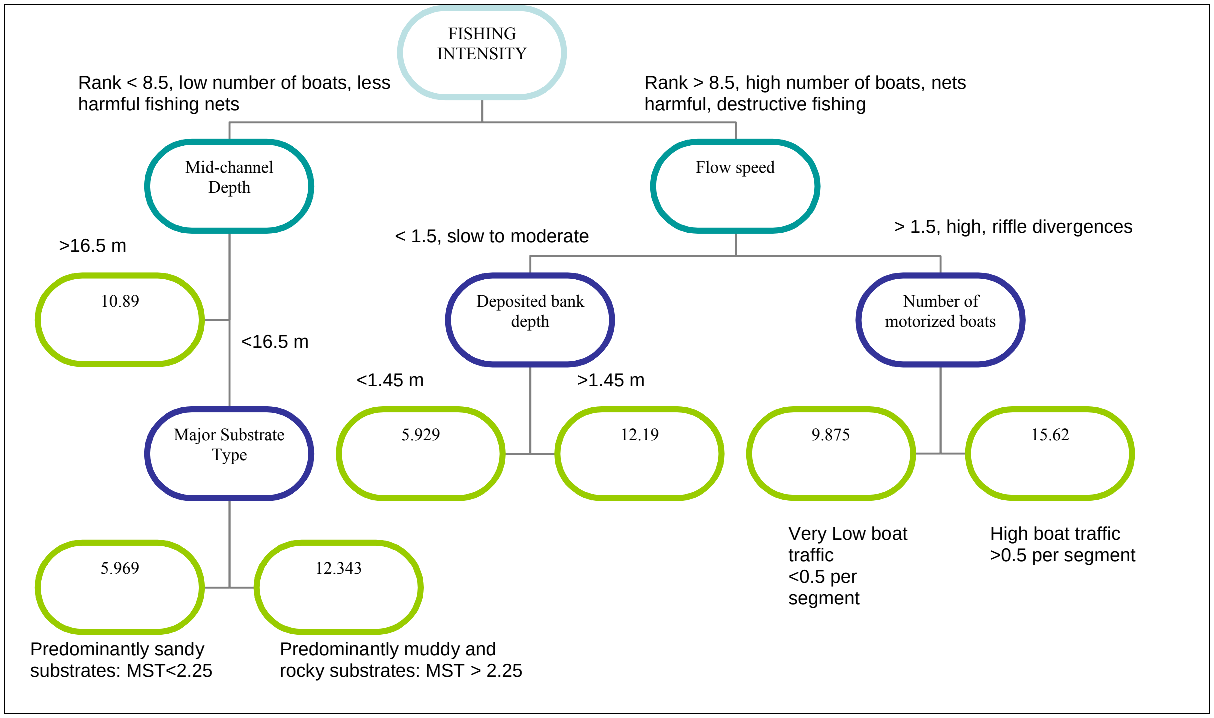
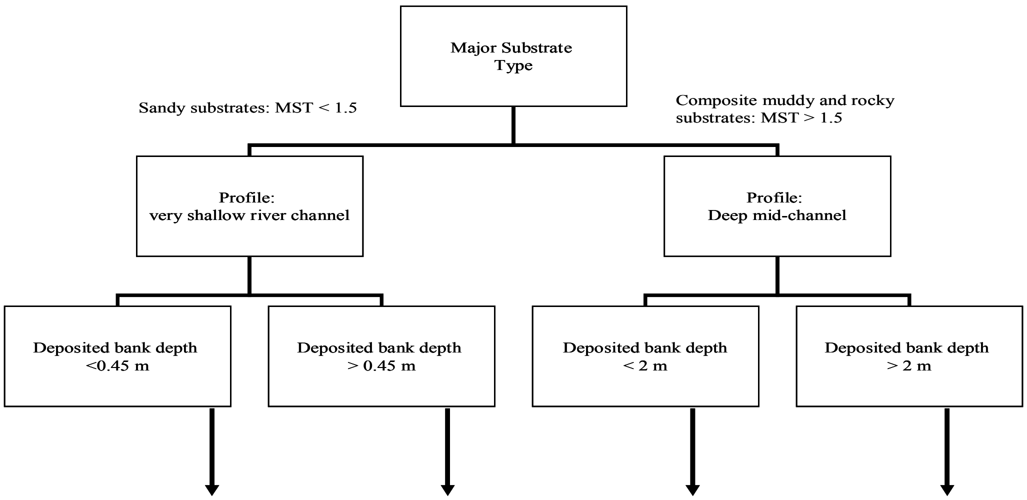


Figure 2.4. Regression tree (with minimum deviance) showing ecological and anthropogenic activity covariates explaining dolphin habitat use.



Fishing Intensity	2.83	5.67	37.69	15.31
Dolphin encounter rates	2.00	4.22	43.21	6.83

Figure 2.5. Schematic representation showing sum total of responses (fishing intensity and dolphin encounter-rates) obtained from two regression trees. Almost 90 % overlap in terms of habitat choice.

Mantel tests

Used as a support to CART, Mantel's tests showed low to moderate correlation between the dissimilarity matrix of dolphin encounter-rates and the corresponding matrices in river geo-physical characteristics between sites (see table 2.4.). Although counterintuitive, I did not find any effect of motorized boats and other human use on dolphin encounter rates. As expected, segments with similar fishing intensity showed significant, yet low correlation with dolphin encounter rates across sites. Similarity in substrate type and depth showed up as significant, but low correlation with similar encounter-rates. However, net intensity or vegetation type on their own did not show significance effects or correlations.

S. no.	Independent variable	Mantel's r	p-value	C.I. (Mantel's r)
1.	Mid-channel depth (Depth 1)	0.15	0.001	0.14—0.17
2.	Deposited bank depth (DBD)	0.12	0.001	0.10—0.13
3.	Eroded bank depth (EBD)	0.15	0.001	0.13—0.16
4.	Flow	0.12	0.001	0.11—0.13
5.	Major Substrate Type	0.21	0.001	0.20—0.22
6.	Fishing Intensity Rank	0.11	0.001	0.09—0.11
7.	No. of motorized boats	-0.014	0.67	NS
8.	Net use intensity	-0.007	0.76	NS
9.	Vegetation	-0.02	0.84	NS

Table 2.4. Mantel's tests showing correlation between differences in dolphin encounter rates and differences in ecological and anthropogenic activity covariates across segments. (NS = Non-Significant)

DISCUSSION

The results of this study describe dolphin habitat use in terms of river depth, substrate types and provide evidence for site specificity of dolphin clusters over the dry season. Also, it clearly shows the spatial overlap between fishing and dolphin habitat use. The preferred habitat variables for dolphins as well as fishermen, as seen from the results, might strongly affect fish relative abundance, and therefore, prey availability, which has been suggested as the main driver of dolphin habitat utilization in various studies (Shreshtha 1995, Acevedo-Gutierrez & Parker 2000, Allen et al. 2001, Benoit-Bird & Whitlow 2003, Miller 2003). At a segment scale, used in the present communication, there might be limited interpretation of certain specific interactions, such as fluctuation in prey availability, which happen to be very important, but whose effects cannot be seen at the scale of sampling.

River systems are continuous over very large scales, and changes in hydrological patterns at the source-areas seriously affect the floodplain areas (Dudgeon 2000, Manel 2002, Wiens 2002, Twidale 2004, Singh et al. 2007). Species restricted to rivers have adapted, over evolutionary time, to the dynamic nature of these systems (Dudgeon 2000). Flood pulse theories (Gunderson 1968, Medeiros 2004) propose an enrichment of the river flow not just by sediment flow dynamics but also by increased availability of prey for different organisms (Medeiros 2004, Dudgeon 2005). In the low water season, i.e., from November to May, upstream diversion of water for agriculture on the floodplains causes reduction in river discharge, which implies a consistent reduction in depth along the downstream stretches. Following the recession of the flood, the river depths stabilize and start decreasing slowly. Ganges river dolphins, thought to be migrating in the flood season, depending on hydrologic fluctuations or in search of concentrated prey areas, might prefer conditions where deep areas are near shallow banks, perhaps due to local prey availability or relative richness of resources. I suspect that dolphin individuals or clusters might actually be monopolizing different sites within the river channel in the low-water months. Studies on river dolphins in other parts of the world have shown roughly similar patterns or trends, especially in habitat use and distribution across a riverine gradient (Geise et al. 1999, Aliaga-Rossel 2002, Hastie et al. 2004, Daura-Jorge et al. 2005, Garaffo et al. 2007, Guilherme-Silveira and Silva 2007, Wedekin et al. 2007). Site-specific preferences suggest the influence of specific combinations of covariates on dolphin habitat use, and a case-by-case discussion of each habitat variable with respect to management implications is imperative. In the wake of large-scale, landscape-level changes such as river-linking, barrage constructions, inland waterways development and even, global climate change that might affect these river systems in the near future; these implications might be important.

Threats like large-scale channel dredging for creation of inland waterways might prove to be disastrous for dolphins, owing to the obvious reduction in prey availability due to change in river profile (Lal Mohan 1992, Reeves et al. 1997, Smith & Smith 1998, Sinha et al. 2000). Dolphin preference for geologically older and more mature, non-sandy substrates, has implications in regulating minimum base flow regimes of flood plain rivers and stopping siltation of river channels. Increase in new sandy beds or islands, might cause significant fluctuations in fish communities (Edds 1993, Bunn & Arthington 2002). Also, altered flow regimes could seriously affect substrate maintenance and affect dolphins in turn. Since dolphins show a clear preference for deeper areas near shallow areas, it is very important to ensure that large-scale changes of river hydrology do not alter these depth combinations. River-linking projects, if implemented without environmental flow considerations, will not only cause irreversible damage to flow regime maintenance but also will affect dolphin populations across its distribution range (Smakhtin & Anputhas 2006). A high increase in depth at deposition banks, for example, owing to large-scale increases in fluvial discharge due to global warming and glacial death, might create difficulties for dolphin foraging and might have serious implications for fish recruitment (Bunn & Arthington 2005). Embankment construction near villages for preventing bank erosion has increased multifold just recently in the VGDS. This has caused an increase in transport boats and the degree of underwater noise, causes of serious disturbance to dolphins. Although my results showed no relationship between motorized boat traffic and dolphin encounter rates, it might not mean that dolphins are free of constant disturbance, especially in relation to boat noise masking acoustic clicks. The embankment construction and resulting detritus affect hydraulic refuges near deep eroded banks, which dolphins prefer (Smith et al. 1998). Rocky islands formed by collapsed embankments, at least on a short-term, seem to provide foraging areas for dolphins in the VGDS. However, this also increases vulnerability of dolphins due to proximity to pollution point sources around embankments or boat stops, or solid waste dumping into the river. Within the Sanctuary area, other threats like algal blooms and solid waste dumping near Bhagalpur need serious attention. Impacts of plastic, untreated sewage and other harmful wastes need to be quantified. Aquatic organisms come in direct contact and show greater vulnerability with respect to organic, inorganic and synthetic chemical pollution of river water (Sinha et al. 2000, Manel et al. 2002). Especially, impacts of pollutants such as pesticides and heavy metals (Kannan et al. 1993, 1997) might be particularly harmful.

Global climate change causing increased glacial melt in the Himalayas might affect the Ganges flood pulse dynamics. Among other local threats, since the Sanctuary area has few industrial areas near the river banks, harmful sources might be less, compared to other stretches of the Ganges. The Bhagalpur district is an arsenic and fluoride pollution belt (Acharyya 2005) due to geogenic processes. Arsenic has been detected in surface river water, possibly due to synthetic wastes, and this serves as just an indicator to the hazardous effects of pollution on dolphins. There is a large body of work on land-use changes on banks and pollution of a diverse nature affecting the Ganges river water and aquatic life (Rehana 1995, Ansari et al. 1999, Manel et al. 2000, Singh 2001, Gergel et al. 2002, Singh et al. 2003, Sinha 2006). The synthesis of such studies is required with respect to dolphin welfare and for mitigating these unseen hazards.

CONCLUSIONS

1. River dolphins occur at more or less regularly spaced sites across the VGDS river stretch and show a marked preference for specific sites over the dry season.
2. They show a distinct preference for deep water areas with shallow deposited bank areas at nearby distances.

3. Fishing intensity appears to drive dolphin habitat use. Dolphins and fishermen seem to have a high level of spatial overlap (almost 90 %) due to competition between dolphins and fishermen for fish prey resources.
4. There is a considerable influence of substrate type on dolphin habitat use. Composite, non-homogenous muddy or sandy substrates seem to be preferred over homogenous, predominantly sandy substrates.

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Running head: Prey availability and fishing effects on dolphin foraging

Title: Effects of prey availability and fishing pressure on foraging habitat selection by Ganges river dolphins in Vikramshila Sanctuary, Bihar, India

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Chapter 3

EFFECTS OF PREY AVAILABILITY AND FISHING PRESSURE ON FORAGING HABITAT SELECTION BY GANGES RIVER DOLPHINS IN VIKRAMSHILA SANCTUARY, BIHAR, INDIA

ABSTRACT

Studies have shown that availability of prey affect foraging habitat selection by dolphins over different spatiotemporal scales. Human fishing pressure, within different habitat types, could drive selection to a considerable extent by modifying the degree of locally available resources or foraging areas. I investigated hypotheses about the prey availability and preferences of Ganges river dolphins (*Platanista gangetica gangetica*) in the Vikramshila Gangetic Dolphin Sanctuary, Bihar, India. Ecosystem services in this river stretch are used by a large number of fishermen, belonging to low income groups and living in extremely deprived socio-economic conditions. Owing to decline of large-sized fishes, net mesh diameters used by fishermen are showing a negative trend, capturing smaller and smaller fish, causing an increase in conflict with dolphins. Based on bootstrapping estimation of fish sizes, from stomach contents obtained from available secondary data, dolphins were found to prefer mainly small-sized fishes. I conducted prey sampling in different habitat types, like confluences, eddies, alluvial floodplain banks and rocky islands. Sampling sites were selected on the basis of dolphin encounter-rates, and classified as 'highly preferred' and 'non-preferred'. Information from fishermen interviews, on preferred fishing areas, net types used and perceptions about prey availability was integrated with preference and prey availability data for dolphins. The results indicate a high overlap (90 %) of between dolphins

and fishermen, in habitat use with respect to relative benefits in prey procurement as well as in sizes of fish captured (almost 75 %). Increased competition for fish prey in recent years, suggests that river dolphins in the Sanctuary area might have become more vulnerable to fatal risks such as entanglement in gillnets. Alternative livelihoods for poor fishermen, whose gains from fishing have reduced substantially, might be a potential solution in minimizing impact of fishing on dolphin prey availability.

KEYWORDS

Ganges river dolphins, Vikramshila Dolphin Sanctuary, *prey availability, human fishing pressure, foraging and prey-size preferences, degree of overlap*

INTRODUCTION

The Ganges river dolphin is a unique, endangered, freshwater cetacean species found in the Ganges-Brahmaputra river systems of India, Nepal and Bangladesh. It is a blind dolphin, without a crystalline eye-lens, which uses only echolocation for feeding on fish prey and for locomotion. The Ganges river dolphin has been under severe threat due to human extraction pressures on river ecosystem services, hunting and poaching, damming of rivers and barrage construction, modification of hydrologic and nutrient flow regimes and pollution of water. The Ganges river system has one of the most extensive floodplain and is one of the most densely populated areas of the world. The Vikramshila Gangetic Dolphin Sanctuary, Bihar, India, has a considerably high human population dependent on the river and living in extremely deprived socio-economic and governance conditions (Choudhary et al. 2006). Fishermen (about 3000 households) form a significant component of this population, and owing to their fishing activity, compete for similar resources as river dolphins. Adequate foraging spaces and availability of food resources are crucial for the survival of any species. Studies have shown that prey variables affect dolphin foraging habitat selection over different spatiotemporal scales (Allen et al. 2001, Benoit-Bird and Whitlow 2003, Hastie et al. 2004). Foraging habitat selection by dolphins needs to be studied not just with respect to ecological factors, but also with respect to changes brought about due to over-harvesting of fish prey. In recent years, the selectivity in fishing has decreased due to considerable depletion of large-sized, commercially important fishes. Smaller-sized fishes, which were thought to be the main prey of dolphins (Sinha et al. 1993, Kumar and Sinha 2001), are being exploited to a much greater extent, corresponding to the reduction in net mesh diameters. Also, the social conditions of fishermen in the river have worsened over the years, due to poverty, criminal brutalities and extortion and government apathy.

In this study, I examined the role of prey availability and fishing intensity in affecting dolphin foraging. The degree of overlap between river dolphins and fishermen across different habitat types was estimated from prey sampling and dolphin stomach contents data as well as fishermen interviews, to address potential solutions for minimization of adverse effects of conflict.

METHODS

Study Area

The Vikramshila Gangetic Dolphin Sanctuary (VGDS, hereafter) is a 65 km segment of the Ganges river main stem between the towns of Sultanganj (25^{o}15'15"N, 86^{o}44'17" E) and Kahalgaon (25^{o}16'54"N, 87^{o}13'44"E), situated in the district of Bhagalpur in Bihar state, India. The Sanctuary was notified by the Bihar State Government in 1991 especially for protection of the endangered Ganges river dolphins (Choudhary et al. 2006). The river Sanctuary of VGDS was characterized by highest fluvial discharge and highest deposition of alluvial mid-channel islands, point bars and spits in the Ganga main stem (Singh et al. 2007). It had two prominent meanders in this stretch. Granite outliers called monad nocks are seen in or near the river in the form of rocky hillock islands. The channel width varied between 150 m to almost 2 km. River depth also varied greatly (range 0.2-40 m). Important habitats in the river stretch include eddies and counter current pools, alluvial islands, confluence zones, eroded zone hydraulic refuges and shallow pools. The main land uses are agriculture and settlements, with fishing as an important occupation of the area. The Sanctuary has a dense human population. The Sanctuary has no management or threat mitigation measures being implemented, owing to lack of political will, corruption and criminal movements in the area. In turn, fisheries in the river are unmanaged and there are neither bans nor restrictions, in spite of the protected area status of VGDS.

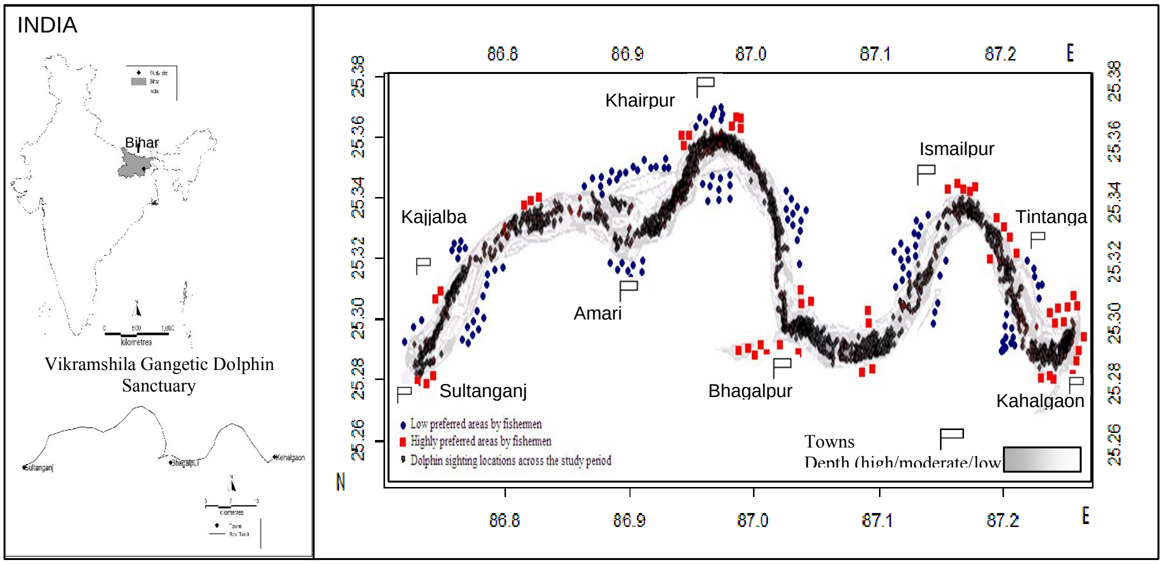


Figure 3.1. Map showing location of Vikramshila Gangetic Dolphin Sanctuary in Bihar, India (left). Map showing dolphin distribution across the study area, with high and low fishing pressure in different segments (right).

Data Collection

I conducted field work from December 2007 to April 2008. These months represent the dry (non-flood) season period over winter and summer. Sampling was conducted from 0600 hours to 1700 hours.

Field Methods

Prey sampling

With help from local fishermen, I sampled fish prey using 50 m long, 1.8 m wide monofilament gill nets (mesh-size 20 mm), for 30 minutes at a time, in selected areas under varied habitat types and human use regimes. I rotated sampling for ensuring constancy in time and weather conditions, mostly from morning to noon hours in the following habitat types: 1. confluences and inlets 2. alluvial floodplain and low-flow banks 3. counter-current pools and eddies 4. rocky islands and ghats 5. alluvial islands. Due to net placement constraints, very deep waters like mid-channel areas could not be sampled, and also that bottom-dwelling fish could not be sampled. For each habitat type, I recorded details like depth, substrate type and presence of vegetation, number of fishing boats, gear and net-types used. After removing the fish from the nets, I weighed them using a Pesola 100 g spring balance and measured their standard lengths (snout to base of caudal fin) with a measuring tape. Fishes were subjected to taxonomic identification unto species level using standard literature (e.g. Jayaram 1994, Ranjit Daniels 2001). I counted number of individuals for each species. In all 52 gill net passes were conducted in different areas.

I summarized the characteristics of actual dolphin prey using data from opportunistic carcass analyses collected between 2001 and 2006, by the Vikramshila Biodiversity Research and Education Centre, Bhagalpur (see details in Choudhary et al. 2006). I also obtained unpublished data on stomach contents of two individuals, until 2008. Species and lengths obtained in the stomach contents were recorded and specimens preserved in 4 % formalin, by the team.

Anthropogenic pressure

I obtained segment-wise data on number of fishing boats, nets used and human activities during dolphin surveys from systematically placed segments of 2.5 km in length across the entire stretch. I prepared sketch-maps for locating villages based on Survey of India (1: 25,000) topographical maps. I conducted interviews with fishermen in different villages in all segments (n=105) to record preferred fishing locations, preferred habitats for fishing, types of nets and gear used, amount of effort expended in fishing (in terms of time and distance traveled) along with basic information like name of village, degree of experience in fishing, socio-economic and criminal problems related to exploitative fishery (see appendix 1). Based on ratings given by fishermen to different fishing areas and observed intensity of fishing activities, I assigned preference ranks (read fishing intensity ranks) to segments, on the ordinal scale of 1 to 14. Also, based on frequency of occurrence of different types of nets across segments, I divided segments into net use intensity types (ranked 1 to 4 in ascending order of net use). Different net types were rated by fishermen with respect to catch per unit effort (CPUE) and net capacity to catch small fishes. Carpet and basket nets, Chinese lift-nets, hook-line fishing, monofilament gill nets, beach seine nets and mosquito nets were rated in ascending order from 1 to 7 respectively, based on harvested fish catches. Mosquito-nets and beach-seines could harvest the smallest fish, and were rated as high impact nets. For analyzing degree of overlap I grouped nets used by fishermen across the Sanctuary stretch into mesh diameter classes. The intervals were decided on the basis of the net-type classes available in local fish markets and on feedback from fishermen interviews.

Data Analysis

Prey sampling data

I calculated fish species diversity indices for each gill-net pass using the Shannon-Weiner Diversity Index (Magurran 1986). In various habitat types and fishing pressure regimes, student's t-test, Mann-Whitney U-test and Wilcoxon's rank-sum test (Conover 1999) were used to compared fish counts, diversity and lengths based on high and low dolphin counts around fish sampling sites (Allen et al. 2001) in a hypothesis testing framework. I used bootstrapping estimation to obtain confidence-intervals and means for fish sizes obtained from standardized fishing effort and for sizes of fish obtained from stomachs of deceased dolphins. I compared the confidence intervals for estimating degree of overlap between dolphin prey and fish catch.

Anthropogenic pressure data

I obtained indices for fishing pressure and net types based on fishermen's assessment of net risk and destructive potential of fishing methods used, as well as recorded information on number of nets owned by fishermen and number of boats seen involved in fishing. I ranked segments based on interviews data and observed fishing effort, and used ranks in analyzing impact. I performed statistical analyses using the software R 2.7.0 (R Core Development Team 2008) and Microsoft Excel—2003.

RESULTS

Prey availability

There was a significant difference in both fish counts and species diversity (which reflect higher relative abundance) for high and low preferred areas by dolphins, (species diversity: Mann-Whitney $U = 243$, $p < 0.0001$, counts: Wilcoxon's Rank-Sum $W = 252.5$, $p < 0.005$). Also, lengths of fish in these two treatments were found to be significantly different (Mann-Whitney $U = 25.5$, $p < 0.0001$). In dolphin preferred areas bootstrapped mean length (cm) was 7.867 ± SD 2.29, and in non-preferred areas it was 9.673 ± SD 2.7574 and mean fish counts in preferred areas were 2.5 fold higher than those in non-preferred areas. Among habitat types, consistently higher fish catch counts were recorded by eddies, rocky islands and ghats, than other habitat types. Alluvial floodplain banks recorded moderate prey availability, while confluences showed decreasing prey availability with decrease in dry-season discharge. Preference for confluence habitats and eddies as well as eddy-counter current pools was high in spite of their low availability.

Prey-size preferences

Frequency of bootstrapped estimates of fish lengths obtained from stomach contents of deceased dolphins (bootstrapped mean = 6.2 cm, SD = 3.09 cm, iterations = 10000) was compared to the bootstrapped estimates (see above) from fish catch data in dolphin-preferred and non-preferred areas. Approximated distributions to the re-sampled means and standard deviations of fish sizes showed that dolphins exhibit a lognormal distribution of prey size preferences in feeding.

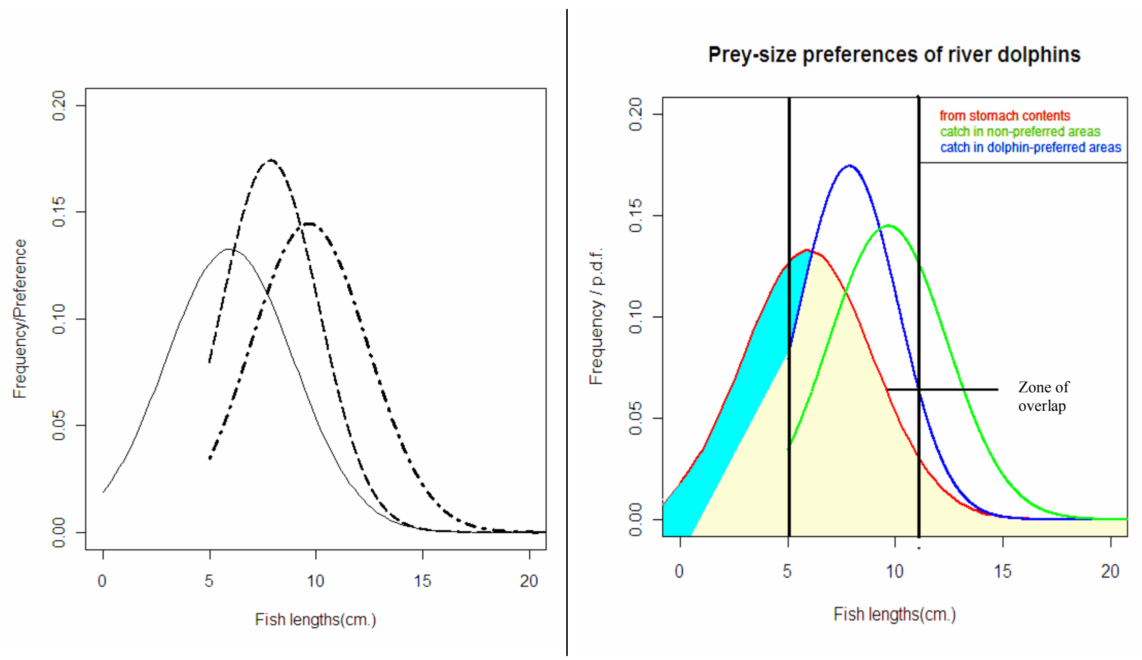


Figure 3.1. Curves showing overlap between dolphin prey sizes and fish sizes obtained from small-sized mesh-nets (20 mm diameter). Left figure shows the lognormal nature of prey-size preference: smooth line—fish sizes in dolphin stomach contents; dashed line: fish sizes from catches in dolphin-preferred areas; dashed-and-dotted line: fish sizes from catches in non-preferred areas. Figure placed on right side is a diagrammatic representation of overlap between prey-size preference distributions of fine mesh sized nets and dolphins.

Overlap between mesh sizes used and dolphin prey preference

As many as 90 % (n = 92) fishermen mentioned that there was a decline in fish catch, sizes of individual fishes, as well as mesh sizes. The histogram of mesh size frequencies indicates that fishermen mostly use small mesh-sized nets. The most commonly used mesh diameter class was 12 to 24 mm (n =124) followed by the 24 to 40 mm nets (n =66). Frequency of wider-meshed nets was low (range n = 10 to n = 30). Use of nets below 12 mm, accounting for a great loss to fish fingerling recruitment, was relatively high (n=47) (see fig. 3.4).

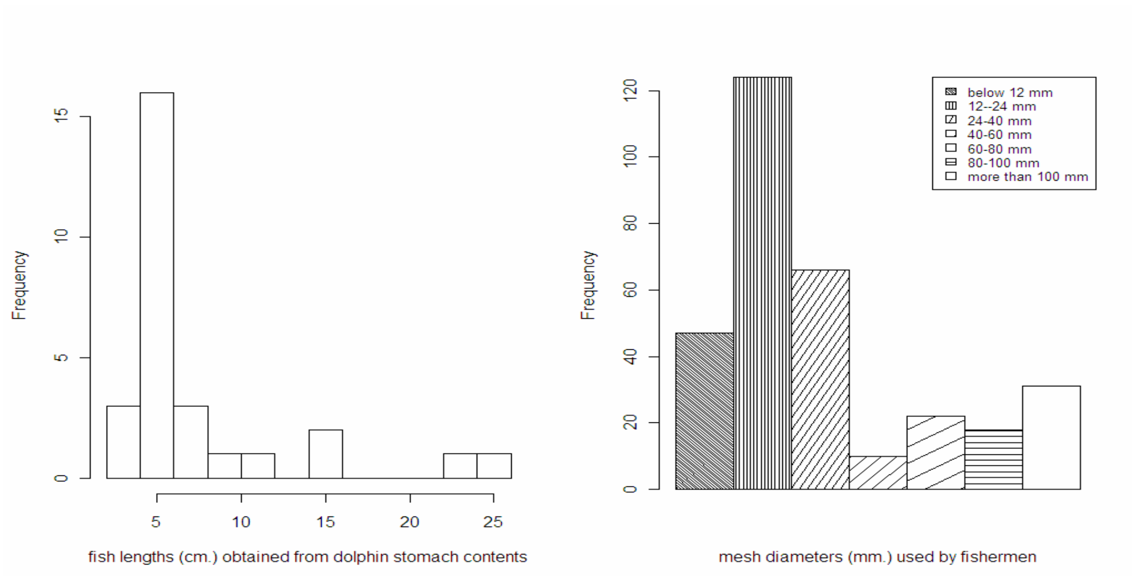
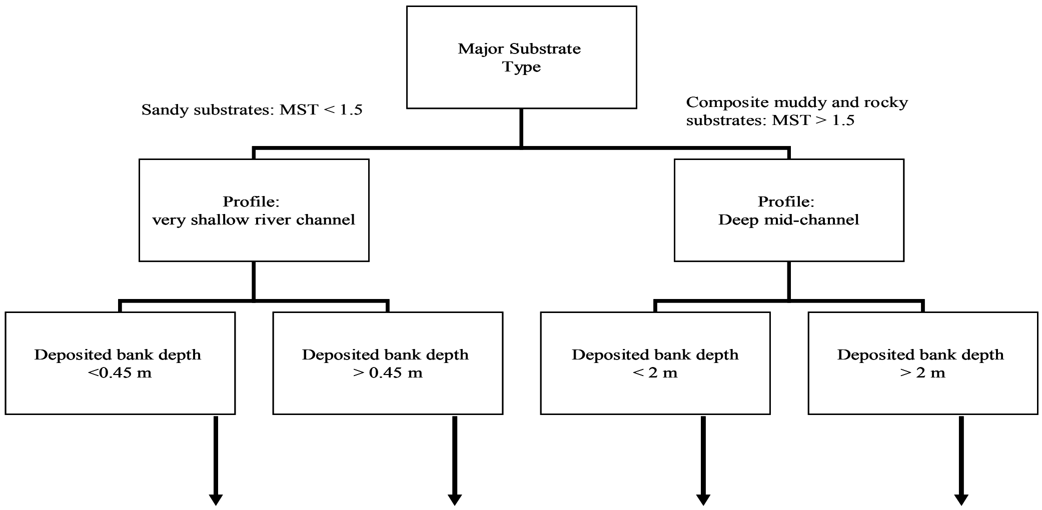


Figure 3.3. Distribution of fish sizes obtained from dolphin stomach contents (left) and frequencies of mesh-sizes used by fishermen in VGDS (right). The overlap between actual dolphin prey and nets fishing the same is seen to be very high.

Overlap between dolphins and fishermen across different habitat types

Major substrate type, mid-channel depth and deposited bank depth were found to be habitat variables chosen both by fishermen and dolphins. Observation data on dolphins and interviewed fishermen both, showed a preference for composite muddy-rocky substrates, rather than sandy substrates. Also, shallow bank areas near deep mid-channel waters were more preferred. Encounter-rates of dolphins were consistently higher in high fishing intensity areas than low fishing intensity areas (see fig. 3.3). This overlap did not change irrespective of habitat type and was clearly dependent on prey availability. The important exception was the relatively higher preference of dolphins for eddies and counter-current pools, where fishermen did not invest much effort owing to problems involved with placing nets.



Fishing Intensity	2.83	5.67	37.69	15.31
Dolphin encounter rates	2.00	4.22	43.21	6.83

Figure 3.4. Schematic representation showing total responses (fishing intensity and dolphin encounter-rates).

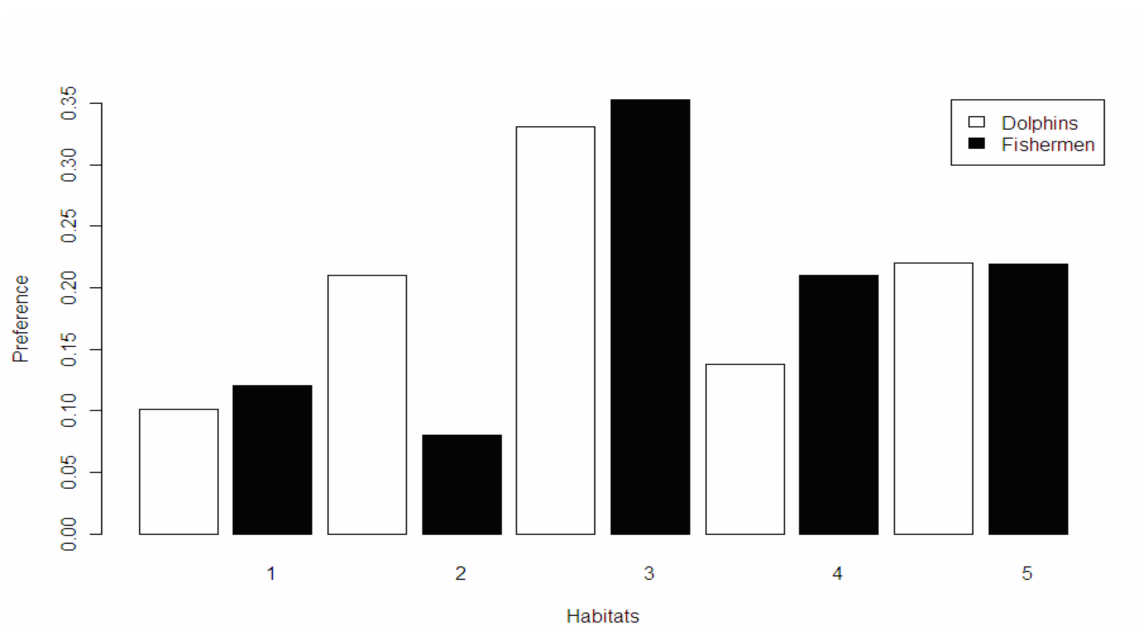


Figure 3.5. Comparative habitat use by dolphins and fishermen across different habitat types.
Habitat types: 1. Rocky islands and Ghats. 2. Eddies and counter currents. 3. Alluvial floodplain banks. 4. Wide river pools. 5. Confluences and inlets.

Fishing effort invested by fishermen

From the interview data, the mean distance traveled for fishing per occasion across all fishermen was calculated at 13.84 km ± SE 3.203. The mean time spent per day in fishing was 12.154 ± SE 1.47. Fishermen, typically, set gillnets in river areas from 1700 hours to 0600 hours the next day. The number of net-types owned by an average fisherman was calculated at 2.62 ± SE 0.11 nets. The effort invested by the fishermen, according to them, was not justified for whatever returns they get in the form of fish. Percentage of fishermen who wanted to discontinue fishing if given any better alternative deal, like construction labourers, or as labourers in pond fishery culture, was as high as 72 % (n=75). The reasons stated were mainly due to low returns in spite of high effort. Also, criminal threats, extortion and deprivation of fishing areas by fishery mafia were commonly cited threats. Criminals indirectly affected traditional fishermen by concentrated use of mosquito nets (4 mm mesh size). Mosquito-nets placed across inlets and confluence mouths, excluded poor fishermen as well as dolphins, from such areas.

DISCUSSION

Over-fishing by humans, is indicated by loss of selective fishing, as well as generalization in fishing nets and methods used There is a progressive reduction in average fishing net mesh-sizes, and smaller fish size-classes are progressively over-harvested (Murawski 1996). In the Ganges river system abundance of large fishes has declined over the years (Natarajan 1996, Dudgeon 2005, Choudhary et al. 2006, Sinha 2006). In the Sanctuary area, the fishing has lost its choices and fishermen are compelled to harvest the most abundant size-classes available. This reduction also causes changes in the spatial concentration and distribution of fisheries. Studies have shown that fishes themselves, change their habitat or location as their prey size spectrum increases with increasing body-size (Munk 1992, Floeter and Temming 2005, Duplisea 2005). Since fish breeding and spawning grounds are located mostly in low-flow river channels or floodplain wetlands near the banks, there is a process of succession in the way fishes move to deeper, main-channel areas as their body sizes increase (Gunderson 1968, Medeiros 2004). Fishing activity, with reduction in targeted sizes over time, might shift to shallower areas. In such resource-limited situations, higher fishing effort might in fact indicate low prey availability as against the inverse (Larkin 1978, Murawski 1996).

Foraging animals might be constrained by several factors related to prey choice and prey availability (Griffiths 1975). These factors are related to size of prey available, size of prey that can be handled effectively and consumed (due to morphological or physiological constraints), specialization in prey types or species eaten, access to habitats with higher prey and even energetic and allometric constraints, such as predator-prey body size ratios (Gunderson 1968, Hespenheide 1973, Griffiths 1975, Larkin 1978, Forsman 1996, Medeiros 2004, Floeter and Temming 2005, Duplisea 2005). In aquatic systems, trophic models are said to be size-structured, a system where large eats small (Christensen and Pauly 1993, Kaschner et al. 2004). Thus, aquatic species might consume prey based on metric and shape criteria rather than taxonomic preferences.

The results prove conclusively that dolphin prey-size preference approximates to a lognormal distribution. Due to this characteristic preference for smaller fishes, the dolphin appears to be an ecological generalist, and to adopt a locational, eclectic mode of feeding (Larkin 1978). The spatial location of the preferred prey size spectrum of river dolphins therefore, must be mostly concentrated near the shallow-water banks. Thus, I suggest that for river dolphins, number maximization by feeding on many smaller fishes, might be a better strategy than energy maximization by eating few larger, and thus, more difficult-to-handle (and perhaps beyond capacity) prey (Griffiths 1975). Foraging might be energetically less costly when concentrated near depositional or shallow banks, than deeper areas where prey-encounters might be fewer (Acevedo-Gutierrez and Parker 2000, Miller 2003, Hastie et al. 2006). Chance foraging in deeper waters might be dependent only on eels, (of which 40 cm long individuals have been occasionally found in dolphin stomachs) but is not discussed here.

The distribution of fish sizes (dolphin stomach contents data) was very similar to fish size distribution from prey sampling. Thus, prey sampling catch data were usable for indicating overlap between catch from smaller mesh-size nets and dolphin prey-sizes. This proves the high degree of overlap between fishermen nets and dolphins across different habitat types within the study area, and that both select similar habitat conditions for foraging or fishing. However, river dolphins might have better access to and be more capable of utilizing certain habitats than other fishermen. A distinct selection for such habitats, deeper habitats like eroded zone hydraulic refuges, eddies and counter-current pools, in spite of their low availability, might be reducing the vulnerability of dolphins due to fishing nets or other threats. These are not used by fishermen much, due to constraints in net or boat use, and might be intensively selected by dolphins. It is possible that dolphins adopt different feeding strategies under different regimes of fishing pressure and combinations of ecological covariates (Weiss 2004). It is also possible that dolphins might consider active foraging at intermittent times between specific foraging peaks as an alternative strategy, in order to maximize net energy optimization. Thus, foraging behavior of river dolphins might include intermittent feeding during travel or local movement (Arditi and Dacorogna 1988).

Fishing also overlaps temporally with dolphin foraging. Small cetaceans are known to have at least two, or three feeding peaks in one circadian rhythm: a morning peak, a late afternoon and a midnight peak (Shane et al. 1986, Allen et al. 2001).

In conclusion, if there are many large fish in the river, we should not expect such competition. Since resource depletion in large-fish stocks forces overlap and competition, dolphins have to select foraging habitats in spite of intense human fishing pressure. In turn, they might be getting more risk-prone to other threats like incidental by-catch in monofilament gill nets. The excessive use of fine-mesh, nylon monofilament gill nets instead of hand-woven thick-sinew nets might lower acoustic reflection, causing decreased detection of nylon nets by dolphins and risking death by entanglement (Jefferson et al. 1992, Trites et al. 1997, Fertl and Leatherwood 1997, Kaschner 2004). The recruitment of smaller fish prey in the river seems a vital necessity for ensuring the ecological security for river dolphins. This emphasizes the need to overthrow human barriers that hamper these source-flows of fish by illegal and destructive netting practices such as beach-seine nets and mosquito-nets.

CONCLUSIONS AND RECOMMENDATIONS

I note here that in the rule gazette of the State Fisheries Department (Choudhary et al. 2006), it is stated that fishing in the river using nets of diameter below 40 mm is illegal. The observed trend in mesh size use is not only because of illegal fishing by criminal mafia, but is enhanced because of marginalized fishermen communities facing depletion in fish catch. Lower limit restrictions for mesh sizes in order to avoid direct competition for certain fish prey have been suggested as a potential solution (Choudhary et al. 2006, Sinha 2006). However, the optimality in terms of the resulting socio-economic costs to user fishermen has been considered to a limited extent. Further, there has been no suggestion for restriction of an upper limit of mesh sizes, which in its turn might be detrimental to adult large fish having the highest reproductive value. Regular patrolling of the Sanctuary area to curb illegal netting is essential. Management of the Sanctuary by the related governmental agencies like the Forest and Fisheries Department is non-existent. I reiterate that enforcing the ban of criminal-operated illegal nets like mosquito nets and beach-seine nets, as well as large hooks and lines is necessary for reducing, if not resolving, the conflict in habitat choice by dolphins and fishermen. Yet, fishing mafia, criminals and political nexuses linked with the destructive fishing practices make direct action measures very difficult. Another potential solution exists in the regulation of fishermen numbers and providing alternative livelihoods, but this is difficult given the low socio-economic conditions prevalent in the area. Fishermen do not earn enough to sustain their families. Fishing in the river is more of a compulsion than a means to earn daily bread. For conservation, this is an opportunity; and provision of alternatives like sustainable pond fishery, can ease the pressure off the Sanctuary, utilizing the fishermen's traditional skills. Protection of river dolphins will depend on strict, effective and regular management of the co-existence relationships and fishing thresholds that need to be realized in order that subsequent impacts on river dolphins could be minimized.

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Conclusion

The conclusions from this dissertation work are mainly about the relationships between dolphin relative abundance and different ecological and anthropogenic disturbance covariates. Abundance estimation using double-observer surveys and with two-sample capture-recapture estimation was used for addressing precision issues in estimation of population size. The method is an example of a low-cost survey technique for river dolphin surveys in the face of resource constraints, but still useful in estimating uncertainty about the population size. I describe the habitat use of dolphins within the Sanctuary across the low water season from December 2007 to February 2008. There is a considerable influence of major substrate type and river channel profile on dolphin habitat use. Composite, non-homogenous substrates seem to be preferred above homogenous, predominantly sandy substrates. This might have conservation implications for dolphins, in relation to maintenance of environmental flow regimes, siltation and depth fluctuation control, in the face of engineering changes like large dams, barrages and linking projects that threaten fluvial hydrology. This indicates a distinct preference for deep water areas with shallow deposition banks at nearby distances. River dolphins were most abundant at specific sites along the river stretch. Dolphins preferred mid-channel depths lower than 16.5 m, with bank depths greater than 1.45 m, and rocky and muddy substrates, had a high degree (almost 90%) of spatial overlap with fishing activity. Interviews with fishermen indicated that they sought out fishing locations largely based on the same characteristics. There was a strong overlap (around 75 %) in sizes of fish sought by dolphins and fishermen, partly due to the fact that fishermen no longer can rely on large fish catches which have declined over time. Fishing intensity and human disturbance appear to drive dolphin habitat use on a broad spatial scale and not just by local-level disturbance. Dolphins and fishermen seem to have a great degree of overlap due to competition for fish prey resources. Fishery has become resource-limited, and the progressive reduction in mesh diameters has led to increased competition between dolphins and fishermen across habitat types, times of day, and size of prey causing the former to become more vulnerable to threats like by-catch, entanglement or exposure to polluted areas.

This study indicates that while dolphin population size is currently healthy in the highly productive, biodiversity-rich riverscape of VGDS, its continued welfare would depend on future trends in local fishing activity. This information would be useful for management decisions regarding human-dominated riverscapes for river dolphin conservation in South Asia.

Appendices

Appendix 1

Questionnaire used in fishermen-interview surveys

INT # Time: Date:

Name:

Age:

Village name:

Extent of fishing: 1. Km traveled 2. Amount of time usually spent

Frequented villages/places in VGDS for fishing:

Preferred fishing areas:

1. Confluences and inlets 2. Ghats 3. Eroded banks 4. Deposited banks

5. Deep mid-channel 6. Near rocky islands 7. Alluvial islands and point-bars

Profile: T/D/U/V/W

Substrate preferred: Muddy / Sandy / Rocky

Types of nets used + mesh sizes

Years since starting fishing:

Opinion on trend of fish populations over these years:

Threats or problems faced in the Sanctuary: