Abundance and distribution modelling for Indus river dolphin, *Platanista gangetica minor* in River Beas, India

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The present study was conducted between April 2011 and May 2013 in an approximately 70 km long stretch of River Beas to estimate the abundance and distribution pattern of Indus river dolphin along the Beas, as an initial step towards its better conservation. Based on the line transect method for wide channel, seven vessel-based collinear line transects of 10 km each were surveyed once every month. A total of 33 sighting frequencies were possible during the study. The studied isolated sub-population was found to be extant in very low abundance of 0.047 dolphins/km. The distribution of the dolphins was found significantly different in all flow seasons. The dolphins were found migrating towards upstream during high flows as the increased water levels create new suitable habitat patches, whereas low flows restrict them to the only remaining habitats downstream. Persistence of dolphins, even in low density in this isolated small stretch of River Beas is indeed a good sign, but intensive fishing and increasing pollution remain a matter of concern. Hence it is suggested that the government withdraws fishing contracts throughout its range of distribution.

Keywords: Abundance, distribution modelling, freshwater ecosystem, *Platanista gangetica minor.*

FRESHWATER ecosystems support extraordinarily high proportion of the earth's biodiversity. In terms of area, freshwater ecosystems occupy only 0.8% of the earth's surface, but they are estimated to harbour at least 100,000 species, which is about 6% of all described species[1]. Unfortunately, these ecosystems are the hotspots of endangerment as well and are experiencing a greater decline in their biodiversity compared to other ecosystems[1,2]. In tropical Asia with the most dense human population and highest deforestation rate, the modification of river flows, alterations in sediment and nutrient fluxes, river pollution from industrialization, urbanization and agriculture, boat traffic, illegal intentional hunting, and over-exploitative fishing threaten the biodiversity and ecosystem in floodplain river systems[3]. Similar to their habitat, Asian freshwater dolphins are also among the world's most threatened animals. The functional extinction of Yangtze River dolphin, *Lipotes vexillifer* in 2006 clearly demonstrates the paucity of appropriate approach for cetacean conservation and also questions the surviving ability of the remaining freshwater dolphins in future[4].

Freshwater dolphins are distributed within nine river systems or brackish lagoons in Asia, and most of them are categorized as endangered or critically endangered[5]. The South Asian river dolphins, *Platanista gangetica* belong to a monotypic genus that includes the Indus river dolphin, *Platanista gangetica minor* found in the Indus river system in Pakistan and India, and the Ganges river dolphin *Platanista gangetica gangetica* found in the Ganges–Brahmaputra–Meghna and Karnaphuli–Sangu river systems in India, Bangladesh, and Nepal[6]. Both the subspecies are listed as endangered in IUCN Red List of threatened taxa[7,8], as their population is declining rapidly throughout their range of distribution[9].

Indus river dolphins were found in the Indus and its tributaries from the foothills of the Himalaya to the limits of tidal zone in undivided India (now India and Pakistan), a linear range of around 3500 km (refs 7, 10). This historical range of the Indus river dolphin has been fragmented by barrages into 17 river fragments, including 15 fragments in Pakistan and 2 in India[11]. In Pakistan, Indus river dolphins now occur in five subpopulations in the Indus main stem, separated by Jinnah, Chashma, Taunsa, Panjnad, Guddu, Sukkur and Kotri barrages[11]. In India, a recently rediscovered sixth subpopulation occurs in the River Beas[12,13], upstream of Harike barrage. Informal interviews with local riparian community confirm that the stretch of the River Sutlej on the India–Pakistan border between Harike and Hussainiwala barrages has no dolphins.

Populations of river dolphins have declined dramatically in the past two decades. This trend still continues and much of their distribution range has already been lost[9,14–16]. The Indus river dolphin now occupies only 20% of its former range in the form of six isolated subpopulations[17] and approximately 99% of the population occurs in only 690 km stretch of River Indus[11]. Dolphins are already extinct from all the tributaries of the Indus in Pakistan[11]. However, River Beas, upstream of Harike barrage in India is the only tributary having a small subpopulation of the Indus river dolphin. This subpopulation lives about 500 km distance from the Indus (main stem) subpopulations and is secluded through five barrages, namely Harike (India), Hussainiwala (India), Suleimanki (Pakistan), Islam (Pakistan) and Panjnad (Pakistan)[11]. Furthermore, the river downstream of Harike barrage is virtually dry and there is connectivity with the rest of the river system only for a few days each year during the monsoon floods.

This subpopulation is of high conservation importance, as all other dolphin subpopulations are found in a single river (i.e. Indus). Any catastrophic event in relation to climate change of the vulnerable River Indus could wipe out all five subpopulations of the dolphins in the main stem[18–20]. In that situation only dolphins of River Beas would survive and serve as the genetic reserve for future propagation and conservation of species. Indeed,

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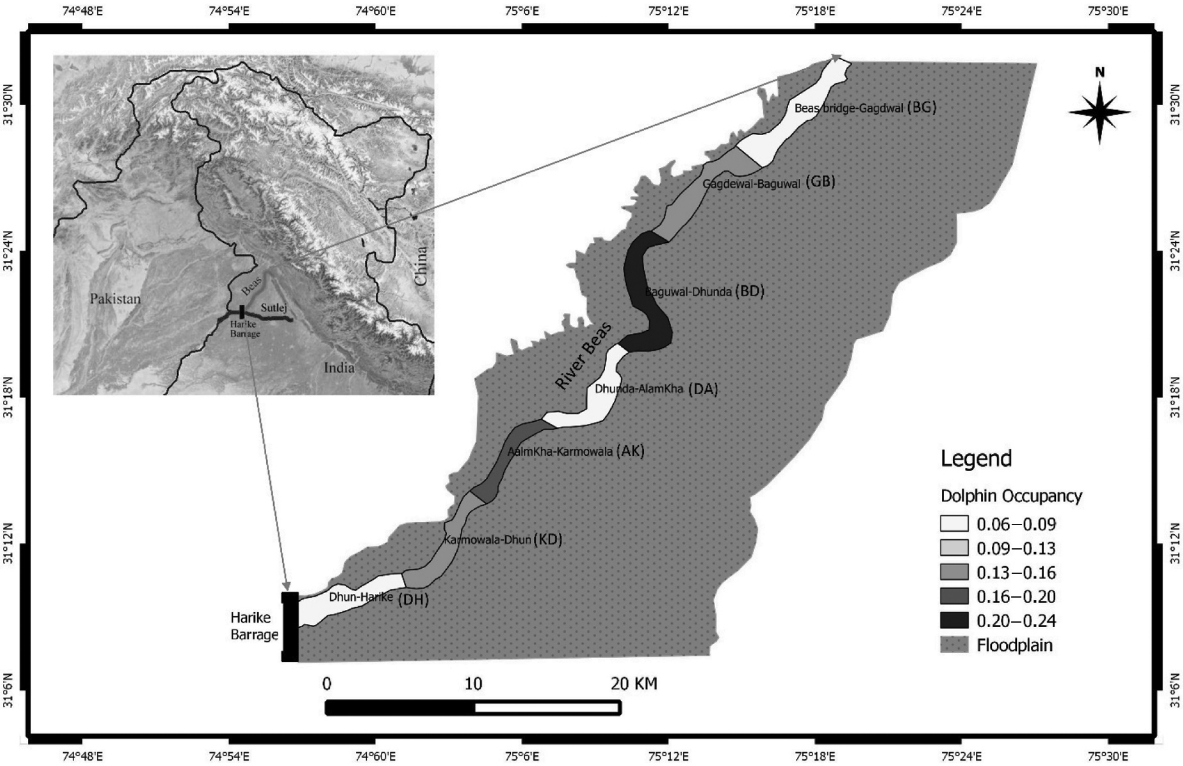

Figure 1. Map of study area showing study sections and proportion of dolphin sightings (i.e. dolphin occupancy) in each section.

Table 1. Abbreviations for the study sections of River Beas

River section	Abbreviation
Beas bridge–Gagdewal	BG
Gagdewal–Baguwal	GB
Baguwal–Dhunda	BD
Dhunda–Alamkha	DA
Alamkha–Karmowala	AK
Karmowala–Dhun	KD
Dhun–Harike	DH

occurrence of species in different rivers divides the risk of being totally extinct through environmental catastrophies, such as flooding or pollution that might wipe out an entire population if present only in a single river[21]. Furthermore, being a small subpopulation, it is susceptible to random demographic stochasticity, environmental catastrophies, inbreeding depression and loss of genetic diversity that can all contribute to increased extinction risk[22–24]. Therefore, it is imperative to study the population dynamics and ecological requirements of this subpopulation to ensure its future survival through informed species management and conservation. The present study estimates the status and abundance of Indus river dolphin in River Beas towards its better conservation. In particular, the following research questions are addressed: (i) sighting records and estimated abundance of Indus river dolphins present in the study stretch and (ii) distribution pattern of these dolphins in the study stretch.

The study was conducted from April 2011 to May 2013 along an approximately 70 km long stretch of River Beas from Beas city (31°30′30.5″N, 75°18′2.5″E) to Harike Wildlife Sanctuary (31°9′6.8″N, 75°57.8′6.5″E), Punjab, India. River Beas represents the freshwater ecosystem in the semi-arid bio-geographical zone. All through its course, a strip of shallow alluvial soil fringes its banks which are subject to inundation during the rainy season[25]. The main channel of the river is broad, dotted with islands and wide pools. The average depth of water varies from about 1.5 m during the dry season to about 4.5 m during the rainy season[25]. Seven vessel-based collinear line transects of 10 km each were surveyed, once every month (Figure 1 and Table 1).

Line transect method for wide channel was adopted for estimating the abundance and distribution pattern of Indus river dolphins in the entire river stretch[26–29]. Observations were made in the morning (0600–1200 h) and evening (1400–1800 h) sessions on a boat moving at a speed of 8–10 km/h in the downstream direction along the deepest part of the channel[29]. Boat surveys were aided by three observers, two stationed in front searching in 90° left to right arc and one rear-facing observer searching up to 180° behind the survey vessel[27,29]. The rear-facing observer records the sightings missed by the front observers, reducing the chances of animals being missed or undetected[30,31] by the front observers. Furthermore, the speed of the vessel was reduced in the preferred dolphin microhabitats, viz. confluences, meanders, downstream of mid-channel islands and where there is large aggregation of fishermen or waterfowls[32]. A 20 min stoppage was made in areas of high dolphin abundance to make a more accurate group size estimate. Care was taken to eliminate the bias of double counting of individuals in a group considering their spatio-temporal array, body size and snout morphology (long and up-curved in female individuals) with the aid of additional observers[29,33,34]. Sighting of individual dolphins or groups was recorded as a single. Corresponding to each sighting distance, sighting angle, GPS location, time, age and sex category of the each individual was recorded.

Based on the data of rainfall received and glacier melting, the seasons were categorized into high (June–August), medium (March–May, September and October) and low (November–February) flow respectively. Furthermore, the river stretch is divided into seven study sections of 10 km each (Table 1)[29].

The spatial distribution pattern of dolphins during different flow seasons was recognized following Bonferroni confidence intervals in combination with chi-square goodness of fit test[35,36] using the following equations. Bonferroni confidence interval equation

$$\bar{P}_i - Z_{\alpha/2k}\sqrt{\bar{P}_i(1-\bar{P}_i)/n} \le P_i \le \bar{P}_i + Z_{\alpha/2k}\sqrt{\bar{P}_i(1-\bar{P}_i)/n},$$

where P_i is the proportion of direct sightings in the ith study section, n the sample size, k the number of categories of habitat studied (river sections in this case), α the confidence interval and Z is the tabular value of standard curve.

Chi-square equation

$$\chi^2 = \frac{\Sigma(O_i - E_i)^2}{E_i},$$

where O_i is number of dolphin (individual/group) sightings in the ith study section and E_i the expected number of dolphin (individual/group) sightings in the ith study section.

The software program DISTANCE[37] (version 5.0) was used to estimate the encounter rate (ER), effective strip width (ESW), density (D), expected cluster size (E(s)) and cluster density (DS) from the line transect method (Table 2).

The Akaike Information Criterion (AIC) values generated by DISTANCE for various models in the analysis were used to select the best fit model[38]. AIC values offer a compromise between quality of fit and increased number of model parameters and are important in selecting a particular model.

Models with high AIC value were selected[26,39]. Further, the goodness of fit test generated by DISTANCE was used to select the fitness of model with observational data, which serves as another important cue that could be generally exercised while selecting a particular model.

A total of 33 sighting frequencies (f) were possible during the study. These sightings were largely concentrated in the study section BD ($f = 8$) followed by AK and KD with sighting frequency (f) = 6 in each; five sightings were recorded in the GB section. Three sightings ($f = 3$) were recorded from sections BG and DH, whereas study section DA was least used by the species with only two sighting frequencies (Figure 1). The distribution of the dolphins was found significantly different in all flow seasons. The dolphins were found moving upstream during high flows as the increased water levels create new habitat, whereas low flows restrict them to the only remaining habitats downstream. During the high flow season, study sections BG ($-0.09 \le 0.33 \le 0.75$), GB ($-0.15 \le 0.22 \le 0.59$) and DA ($-0.15 \le 0.22 \le 0.59$) were found to be preferred, while during medium flows the sections GB ($-0.16 \le 0.19 \le 0.53$), BD ($-0.10 \le 0.31 \le 0.72$), AK ($-0.14 \le 0.25 \le 0.64$), and KD ($-0.16 \le 0.19 \le 0.53$) were used more by the species than that of the proportion they share in the distribution range (Table 2). Section BD ($-0.14 \le 0.25 \le 0.64$), AK ($-0.14 \le 0.25 \le 0.64$), KD ($-0.14 \le 0.25 \le 0.64$) and DH ($-0.14 \le 0.25 \le 0.64$) were found as the sites of preference during the low flows (Table 2).

Dolphins were found to occupy the study stretch with an estimated density of 1.44 ± 0.27 individuals/km^2, which includes the density of adult dolphins 1.06 ± 0.19 individuals/km^2. Further the respective densities of sub-adults and calf were also calculated as 0.34 ± 0.19 and 0.22 ± 0.13 individuals/km^2 respectively. As observed by Braulik[7], the dolphin individuals were found in loose groups of two or sometimes three, with an estimated cluster size of approximately two (1.94 ± 0.14). The total number of individuals was also estimated by projecting the calculated density of sampled area over the available suitable area using DISTANCE 5.0. The estimated number of dolphins was 35 ± 19 (individuals ± SE) at 95% confidence. Although, through the best group estimate method[29] the number comes close to the lower confidence limit, i.e. 18 individuals. The encounter rate for adults and overall (all life stages together) dolphins was estimated as 0.47 individual per length of transect (i.e. 10 km). The encounter rate for sub-adults and calves was 0.11 and 0.10 individuals/length of transect respectively (Table 3).

Local abundance and size of geographic range are both inversely proportional to the probability of extinction of species from the local area and distribution range respectively[40]. Low local abundance plays an important role in the case of local extinction of the species due to demographic and stochastic environmentally hazardous

Table 2. Spatio-temporal distribution pattern of Indus river dolphin along the study stretch of River Beas

Study section	Number of sampling plots	Proportion of total sampling plots (P_{io})	Number of dolphin (individual/group) sightings (O_i)	Expected number of sightings (E_i)	Proportion of sightings at each study section (P_i)	χ^2 distribution	Bonferroni	Conclusion
High flow season								
BG	6	0.14	3	1.29	0.33	2.29	$-0.09 \le P_i \le 0.75$	P
GB	6	0.14	2	1.29	0.22	0.40	$-0.15 \le P_i \le 0.59$	P
BD	6	0.14	1	1.29	0.11	0.06	$-0.17 \le P_i \le 0.39$	A
DA	6	0.14	2	1.29	0.22	0.40	$-0.15 \le P_i \le 0.59$	P
AK	6	0.14	0	1.29	0.00	1.29	$0.00 \le P_i \le 0.00$	A
KD	6	0.14	1	1.29	0.11	0.06	$-0.17 \le P_i \le 0.39$	A
DH	6	0.14	0	1.29	0.00	1.29	$0.00 \le P_i \le 0.00$	A
Medium flow season								
BG	12	0.14	0	2.29	0.00	2.29	$0.00 \le P_i \le 0.00$	A
GB	12	0.14	3	2.29	0.19	0.22	$-0.16 \le P_i \le 0.53$	P
BD	12	0.14	5	2.29	0.31	3.22	$-0.10 \le P_i \le 0.72$	P
DA	12	0.14	0	2.29	0.00	2.29	$0.00 \le P_i \le 0.00$	A
AK	12	0.14	4	2.29	0.25	1.29	$-0.14 \le P_i \le 0.64$	P
KD	12	0.14	3	2.29	0.19	0.22	$-0.16 \le P_i \le 0.53$	P
DH	12	0.14	1	2.29	0.06	0.72	$-0.15 \le P_i \le 0.28$	A
Low flow season								
BG	8	0.14	0	1.14	0.00	1.14	$0.00 \le P_i \le 0.00$	A
GB	8	0.14	0	1.14	0.00	1.14	$0.00 \le P_i \le 0.00$	A
BD	8	0.14	2	1.14	0.25	0.64	$-0.14 \le P_i \le 0.64$	P
DA	8	0.14	0	1.14	0.00	1.14	$0.00 \le P_i \le 0.00$	A
AK	8	0.14	2	1.14	0.25	0.64	$-0.14 \le P_i \le 0.64$	P
KD	8	0.14	2	1.14	0.25	0.64	$-0.14 \le P_i \le 0.64$	P
DH	8	0.14	2	1.14	0.25	0.64	$-0.14 \le P_i \le 0.64$	P
Over all seasons								
BG	26	0.14	3	4.71	0.09	0.62	$-0.16 \le P_i \le 0.35$	A
GB	26	0.14	5	4.71	0.15	0.02	$-0.17 \le P_i \le 0.47$	P
BD	26	0.14	8	4.71	0.24	2.29	$-0.14 \le P_i \le 0.62$	P
DA	26	0.14	2	4.71	0.06	1.56	$-0.15 \le P_i \le 0.27$	A
AK	26	0.14	6	4.71	0.18	0.35	$-0.16 \le P_i \le 0.52$	P
KD	26	0.14	6	4.71	0.18	0.35	$-0.16 \le P_i \le 0.52$	P
DH	26	0.14	3	4.71	0.09	0.62	$-0.16 \le P_i \le 0.35$	A

P_i represents theoretical proportion of observation of dolphin and is compared to corresponding P_{io} to determine if hypothesis of proportional use is accepted or rejected, i.e. $P_i = P_{io}$ at $P < 0.05$ based on Byers simultaneous confidence interval.
Bonferroni, Bonferroni confidence interval proportions; P, Used more than available; A, Used less than available.

Table 3. Abundance of different life stages of Indus river dolphin along the study stretch of River Beas

Life stage	Model	AIC	ESW (m)	ER (n/l)	Cluster density (SE)	Cluster size (SE)	Density (SE)
Overall	Un	380.3	318.2	0.47	0.74 (0.13)	1.94 (0.14)	1.44 (0.27)
Adult	Un	380.3	318.2	0.47	0.74 (0.13)	1.42 (0.98)	1.06 (0.19)
Sub-adult	Un	85.7	212.1	0.11	0.27 (0.15)	1.25 (0.16)	0.34 (0.19)
Calf	Un	75.8	225.0	0.10	0.22 (0.13)	1.00 (0.00)	0.22 (0.13)

Un, Uniform model; AIC, Akaike information criterion; ESW, Effective strip width; SE, Standard error.

events[41–43]. Whereas small or restricted range of distribution makes the species more prone to extinction from habitat loss[44]. Though these two causes of species extinction are independent of each other, if in case both the range size and local abundance influence the risk of extinction, the species with small range may avoid extinction if it has high local abundance, whereas the species with low local abundance might avoid extinction if it is widespread. In the same way, species like Indus river dolphin with both small range and low local abundance must be at highest risk[40].

Compared to the abundance of the main population (encounter rate = 6.23 dolphins/km) which is surviving between Guddu and Sukkur barrage in Pakistan[7], the studied isolated population was found to be extant in very low abundance of 0.047 dolphins/km. The recorded encounter rate was also much less than those recorded for the closely related Ganges river dolphin (0.52–1.36

dolphins/km) in Ganga–Brahmaputra river system[29,45,46]. This isolated subpopulation, which is locally rare, is expected to disappear more rapidly in response to any adverse stochastic change. Moreover, the subpopulation found in the upstream periphery of its distribution range is more vulnerable to such changes as the impact of human-controlled hydrological activities are more strapping in these stretches[17].

The high flow provides an opportunity to the dolphins to move around in the adjoining sections which were not feasible to visit during low or medium flow seasons. Increase in the availability of feasible habitat allows the dolphins to choose where to live and where not to. Since the availability of suitable habitat is not an issue, other factors such as anthropogenic disturbances and prey availability play a vital role in deciding their distribution during this period. Therefore, further studies on their prey population assessment and prey–predator relationship are recommended. River dolphins are thought to be most vulnerable during the low flow season, since the habitat gets shrunk into small patches of suitable habitat within the river[47]. These patches are almost isolated from each other, mainly because of very low water depths. Therefore, during the low flows, the physical features of rivers are the major determining factors for dolphin distribution. Medium flow provides the moderate and comparatively easier situations to live. Since this flow is maintained by the rivers for about half of the year, it is important to study and understand the distribution of dolphins during this time. In spite of all other factors, over the period of a year, the dolphins will spend most of their time at these locations (suitable habitat during medium flow season) only. The seasonal movement pattern of dolphins can provide a biological rationale for determining which areas should be given immediate high priority for conservation. However, dolphins move constantly between suitable patches of habitat and even these patches may migrate gradually in upstream or downstream directions. Thus, definition of fixed spatial boundaries for river dolphin protected areas may not be an effective conservation measure.

Therefore it is imperative to continuously monitor the distribution pattern of the dolphins and recommend large enough areas for their protection to encompass multiple high-use areas. Persistence of dolphins, even in low density (1.44 ± 0.27 individuals/km^2) in this isolated small stretch is indeed a good sign, but intensive fishing and increasing pollution remain a matter of concern[13]. The fishing contractor system still exists in the area in which the rights to fishing grounds were auctioned by the Fisheries Department of Punjab, India and purchased by the politically influential fish contractors. The reckless fishing has added stress to the existing small population of dolphins[13]. It is recommended that the government withdraws fishing contracts throughout its range of distribution. The stretch of River Beas from Beas city to Harike Wildlife Sanctuary needs urgent protection measures to reduce the risk of further decline in the dolphin population and improve conservation efforts. The species importance awareness should be encouraged within the local community in order to ensure the continued survival of this population in the Beas. Otherwise, dolphins here would share the same fate with the now functionally extinct Yangtze river dolphin.

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