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The Endangered Ganges River dolphin *Platanista gangetica gangetica* in Nepal: abundance, habitat and conservation threats

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ABSTRACT: Conservation of the last remaining Ganges River dolphins *Platanista gangetica gangetica* in Nepal will require robust population estimates and better information on suitable habitat characteristics. To gain a better understanding of these parameters, we conducted boat-based surveys in the 3 major river systems (Karnali, Sapta Koshi, and Narayani) of Nepal. We recorded covariates at high spatial resolution and utilized these data to inform occurrence and abundance models. We allowed for detection bias by applying occupancy and N-mixture models that account for imperfect and heterogeneous detection. Occupancy results indicate that dolphin site use varies among the different river systems, across 2 seasons, and increases with river depth. River effects received nearly 100% of the model support and had the strongest influence on dolphin occurrence and abundance. The seasonal influence on dolphin occurrence in the systems ($\Sigma\omega_i = 0.997$) revealed that occupancy probabilities were heightened during the pre-monsoon season. Deep pool habitat was also identified as a predictor of dolphin habitat use, which accounted for 41.02% of all dolphin sightings occurring in this habitat. Although estimates vary depending on season, we estimate that there are between 37 and 42 (95% CI: 28 to 52) Ganges River dolphins distributed in the rivers of Nepal. Results suggest that seasonality and each specific river affect dolphins and their habitat in Nepal; we strongly recommend site and season-specific conservation actions. Further research on the integration of additional and alternative abundance techniques, behavioral studies, and pursuit of a conservation genetics approach are all important steps in the management of this endangered species.

KEY WORDS: Ganges River dolphin · Endangered species · Abundance · Habitat · Distribution · Nepal

INTRODUCTION

The Ganges River dolphin (GRD) *Platanista gangetica gangetica* is one of the most threatened freshwater dolphins in the world. It is native to the major lowland rivers and tributaries of Nepal, India, and Bangladesh (Shostell & García 2010). This subspecies has been categorized as Endangered by the IUCN since 2004; however, a panel of experts registered the dolphin as Critically Endangered (locally) due to significant declines in population and range (Janawali & Bhuju 2000), with an estimated population of fewer than 20

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adults in Nepal (Jnawali et al. 2011). Anthropogenic activities, including development, fishing and alteration of natural water flow processes have all been implicated in the apparent decline in abundance (Smith et al. 1994, WWF-Nepal 2006). Perhaps the greatest threat to dolphin persistence is the segregation of the entire population into small sub-populations separated by structures including dams and dikes (e.g. barrages), in which only limited migration is likely possible during the monsoon period (Smith 1993).

Despite some notable actions by independent conservation leaders, the river dolphin has received less attention than other charismatic megafauna of Nepal. Past efforts to monitor the species have primarily involved boat-based counts of individuals, which were used to estimate historical encounter rates and abundances (Shrestha 1989, Smith 1993, WWF-Nepal 2006, Chaudhary 2007, Kelkar et al. 2010). The general trend across all areas is that these small, isolated populations have declined (Smith 1993, WWF-Nepal 2006, Wakid 2007, Khatri et al. 2010), some at alarming rates (e.g. 26% over 12 yr in parts of the Brahmaputra; Wakid 2007). Sparse sightings of 1 or 2 individuals indicate that suitable hydro-physical habitat is rare in the river systems of Nepal (Smith 1993, Paudel 2012).

While protected areas overlap with the dolphin's distribution in Nepal (e.g. Bardia National Park, Koshi Tappu Wildlife Reserve, and Chitwan National Park), their numbers and distribution have still declined significantly since monitoring began (Shrestha 1989, Smith 1993, Smith et al. 2006, WWF-Nepal 2006), with the species vanishing completely from some rivers (i.e. present in 4 rivers in the 1980s, now found only in 3; Leatherwood & Reeves 1994). Because of the critical status of this group of GRDs, it was suggested that regular monitoring be undertaken (Leatherwood & Reeves 1994). Here, we provide detailed population estimates and describe the ecological factors associated with their occurrence in 3 river systems in Nepal where the dolphins have been documented. This is the first attempt in Nepal to obtain detailed estimates of dolphin abundance and habitat characteristics, accounting for detection bias during 2 critical seasons (pre- and post-monsoon) in 3 major rivers.

MATERIALS AND METHODS

Study area

We conducted surveys on the 3 largest river basins in Nepal where the river dolphins have been historically documented: the Karnali (28.630329° N, 81.274830° E), Sapta Koshi (26.722925° N, 87.083357° E) and Narayani (27.563377° N, 84.064135° E) (Fig. 1). The Government of Nepal, Department of National Parks and Wildlife Conservation, Kathmandu granted permission for this project along these 3 river systems. All of these rivers are located downstream of the Siwalik foothills of the Nepalese Himalayas. This study area represents the extreme upstream limit of GRD distribution in southern Asia. With headwaters in the southern slopes of the Himalayas of Tibet, seasonal melting of snow results in fluctuating water levels in these river systems. The surveyed areas along the rivers consisted of 42 km along the Karnali from the Karnali bridge to the Nepal/India border; 36 km along the Sapta Koshi from the Srilanka Tappu to the Nepal/India border; and 37 km along the Narayani from the Amaltari post to Treveni Ghat. Surveys were restricted to Nepal (in all river systems) due to security concerns in India. All 3 river basins are characterized by relatively high velocity flows in comparison to downstream waters, large seasonal and year-to-year variations in stream flow and sediment transport with mixed-use riparian areas. Most of the local people living close to the river systems are illiterate, with agriculture and fishing as their major occupations. Hence, immense pressure from the local people has increased the spatial overlap between dolphins and fisheries in the river systems.

These river systems are all large tributaries of the Ganges River in India, where relatively high numbers of GRDs have been reported. The rivers are affected by the barrages at the Nepal–India border (Narayani) or just above (Sapta Koshi: 7 km north of border) or below the border (Karnali: 20 km south of border), which are used to divert water for irrigation and to control flooding in India. Upstream dolphins may move downstream through the barrages during flood periods, potentially resulting in permanent loss of individuals from Nepal.

Dolphin surveys

Surveys occurred during low water seasons (pre-monsoon: March to May 2013 and post-monsoon: November to January 2014). During each season, we surveyed all 3 rivers on 3 separate occasions with an interval of 2 wk between surveys. We only sampled during clear weather conditions, and all surveys were completed over the course of 1 d. We considered dolphins within a distance of 200 m from each other to be a single group. We followed the survey

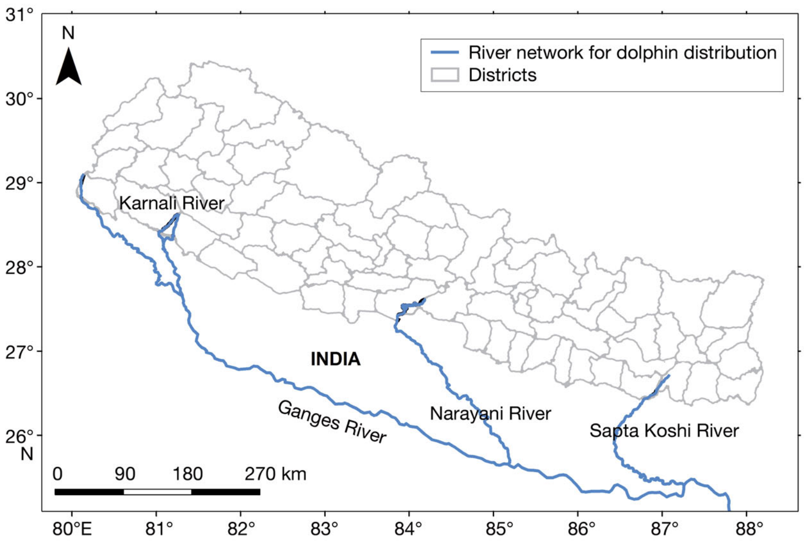

Fig. 1. The 3 surveyed rivers and their location within the Ganges River watershed and the protected areas they traversein Nepal

methods recommended by Smith & Reeves (2000b) for narrow channel habitat. It was assumed that allowing a dolphin to surface at least once within our range of detection would avoid double counting, which was achieved by maintaining a boat speed of 5 km h^{-1} (Kelkar et al. 2010, Richman et al. 2014). Teams typically consisted of 6 individuals, representing researchers, park officials and NGO members on a single platform (eye height 1.5 m), with 2 primary observers and 1 rear observer. Surveys began at 09:00 h and ended at 16:00 h during clear weather conditions. The 2 primary members were positioned at the front of the vessel, left and right of a data recorder, and continually searched for dolphins using binoculars and occasionally with unaided eyes. Individual dolphins were classified as newly born, juvenile or adult based on size and color. The data recorder documented sighting time, position (latitude and longitude), observer number, group size, distance from the dolphin to the nearest river bank, and a code for habitat type. Positions were rotated to minimize perception bias at an interval of 2 h. The single rear observer was responsible for counting individuals (if any) missed by primary observers.

During surveys, we also collected habitat data along 300 m river segments that we considered to be the sites of the subsequent occupancy analysis. Habitat characteristics included measures of water depth using a depth finder (Leatherwood et al. 2000, Akbar et al. 2004, Smith et al. 2008), river width using a range finder (Smith et al. 2006, 2008) and habitat structure of the river. While measuring river depth, the boat remained midway between the banks in order to standardize these values. We classified habitat as either meandering (M), river confluence (CF), deep pool (DP; >3 m in depth) or straight channel (SC; <3 m in depth), following previous guidelines (Biswas & Boruah 2000). We compared mean depths and widths between seasons and among rivers and habitat types using *t*-tests (seasonal) and ANOVA and Tukey's HSD post hoc test (habitats and rivers), with a significance level of $\alpha = 0.05$.

Habitat occupancy model

From the survey data, we formulated binomial detection histories of dolphin detections and non-detections for integration into occupancy models (Mackenzie et al. 2002). Occupancy models are hierarchical, and estimate species occurrence or site use (ψ) while also estimating a detection nuisance parameter (p) (Royle & Dorazio 2008). This class of models is useful because it allows us to estimate occurrence (site use) probabilities as a function of habitat covariates via the logit-link. Detection histories were based on the 3 separate survey occasions for each river (e.g. history 101 = detected on first survey, not detected on second survey, detected on third survey). Since there were 2 wk between each survey, and the sites (300 m river segments) in the analysis were relatively small in comparison to individual dolphin movements, we considered ψ to represent dolphin site use. We first modeled detection as either a function of time (such that each survey had a different probability of detecting dolphins), as a function of season, river depth, river width, an additive model with both depth and width, or as constant across all surveys (6 detection models while keeping ψ constant, similar to Cove et al. 2014). We then selected the top-ranking detection covariates and included those in all further occupancy models assessing site use. Although detection could also be affected by other covariates, we did not consider any additional effects because sampling only occurred during favorable weather/visibility. Based on current ecological knowledge of GRDs, we formulated 14 *a priori* hypotheses of dolphin site use based on habitat, season, river, and depth and width profiles (see Table 1). We also included a constant model in which all sites had equal use probabilities, and a global model which included additive effects of all covariates. We executed the occupancy models using the freely available software PRESENCE v.8.0 (Hines 2012). For model selection, we adopted the information-theoretic approach and ranked each hypothesis based on its relative Akaike information criterion (AIC) and the information distance to the top model in the set (Burnham & Anderson 2002). Furthermore, we calculated the cumulative Akaike weight ($\Sigma\omega_i$) of model support for each covariate to determine its relative importance to other covariates, with higher weight suggesting more influence (Burnham & Anderson 2002).

Dolphin abundance model

To estimate global abundance, we utilized *N*-mixture models, which are explicit process hierarchical models that account for imperfect and heterogeneous detection (Royle & Dorazio 2008). Each river was broken down into what we considered independent segments, which were often separated by a barrage or other structure preventing migration. There were a total of 8 river segments of variable length among the 3 rivers (3 in Karnali, 3 in Sapta Koshi, and 2 in Narayani). We modeled the detection parameters as constant over time since the surveys were only conducted on optimal visibility days and we did not consider there to be any detection concerns at the scale of the *N*-mixture model sites based on relatively high detection probabilities from the site-use models (see 'Results'). We analyzed dolphin abundance in these segments as being independent between seasons (16 sites in the model) since the monsoon season connects them with flash floods, allows some migration and alters the rivers' physical attributes. We first modeled the abundance with a Poisson distribution and then a negative binomial distribution to account for over-dispersion. We compared multiple *a priori* models in which we modeled GRD abundance as a function of river, habitat, season, constant and additive variations of those covariates (see Table 3). We then utilized the most supported model distribution for the covariate models using function 'pcount' in library 'unmarked' (Fiske & Chandler 2011), within the computational software R v.3.0.2 (R Development Core Team 2013). To determine covariate effects, the logit-link informs the detection component of the model (as in occupancy models), while the log-link function informs the abundance component. We compared the candidate models via a model selection approach similar to the occupancy analyses, using AIC and Akaike weights (Akaike 1973). We estimated mean abundance estimates and standard errors through back-transformation of values given by the most supported model and the most supported constant-model for comparison to observed counts.

RESULTS

Depth, width and dolphin habitat characteristics of river systems

The mean (±SD) depth and width of the rivers differed between the post-monsoon (width: 236.53 ± 121.67 m; depth: 1.60 ± 1.24 m) and pre-monsoon seasons (width: 251.97 ± 119.03 m; depth: 3.55 ± 3.50 m): width: $t = -2.798$, df = 1004.47, $p = 0.005$; depth: $t = -13.51$, df = 650.85, $p < 0.001$. Similarly, the mean depth and width of the river sections measured at 300 m intervals differed between river systems (width: $F = 81.834$, df = 2, $p < 0.001$, Karnali: 187.16 ± 78.55 m, Sapta Koshi: 258.04 ± 132.59 m, Narayani: 197.11 ± 56.36 m; depth: $F = 712.209$, df = 2, $p < 0.001$, Karnali: 5.55 ± 4.13 m, Sapta Koshi: 1.40 ± 1.10 m, Narayani: 2.65 ± 1.56 m). Mean depth varied between all pairs of river systems (Tukey's test, $p < 0.001$ for all pairs) but the mean width between Narayani and Karnali was not different (Tukey's test, $p = 0.267$). Mean width (DP: 231.88 ± 99.52 m; SC: 220.50 ± 99.42 m; CF: 266.41 ± 142.04 m; M: 247.06 ± 131.11 m) and depth (DP: 4.60 ± 2.92 m; SC: 1.59 ± 0.98 m; CF: 2.94 ± 3.26 m; M: 1.27 ± 1.06 m) differed among habitat types for all river systems (width: $F = 10.38$, df = 3, $p < 0.001$; depth: $F = 463.18$, df = 3, $p < 0.001$). Mean depth and width differed between all pairs of habitat types ($p < 0.001$ for all pairs) except for width between DP and SC ($p = 0.128$). There was a significant interaction between the effects of river systems and season on the depth of river systems (univariate test, $F = 77.37$, df = 2, $p < 0.001$) but not for width of river by the same interaction effects ($F = 1.472$, df = 2, $p = 0.230$).

Occupancy and abundance

The additive detection model with river width and depth received the most model support, so we included those positive detection covariates in all further site-use models (Table 1). The mean (±SE) probability of detecting dolphins for each independent survey was 0.563 ± 0.045. Of the 14 *a priori* models that we compared to predict river dolphin site use, only 2 models received nearly all of the model support ($\Sigma\omega_i$ = 0.997; Table 1). River effects received 100% of the model support and had the most influence on dolphin occurrence. The 3 rivers had different occurrence probabilities; both Karnali and Sapta Koshi were similar and significantly more likely to be used by river dolphins than the baseline Narayani River (Table 2). Models incorporating a seasonal influence on dolphin site use in the river systems ($\Sigma\omega_i$ = 0.997; Table 1) increased occupancy probabilities during the pre-monsoon season (Table 2). All other covariates that we examined received support from the global model, each with $\Sigma\omega_i$ = 0.332 (Tables 1 & 2). The deep pool habitat was the only significant predictor (CI excluded 0) of dolphin site use from the remaining covariates (Table 2). Mean (±SD) depth and width of the dolphin sighting locations was 4.24 ± 1.98 and 225.93 ± 96.63 m, respectively. The greatest proportion (41.02%) of sightings occurred in deep pool habitat, followed by confluence (28.20%) and meandering (12.82%).

We initially examined the Poisson and negative binomial distributions for river dolphin abundance. The negative binomial distribution received more support and was used for further mixture models to predict the abundance of dolphins. Similar to the occurrence models, only 2 of the *N*-mixture models received the majority of the model support ($\Sigma\omega_i$ = 0.998; Table 3). The different river systems once again had different effects on dolphin abundance (Table 3). The suitable habitat/connectivity covariate also received support, but the β-coefficient estimates were highly variable, with CIs strongly overlapping 0. We used the top-ranking model to estimate dolphin abundance across all surveyed segments of the 3 rivers (Table 4). Since the β-coefficients were not all significant, we also included the negative binomial constant model estimates and the maximum count observed per survey for conservative estimates of abundance. Since the pre- and post-monsoon seasons were independent, we provided season-specific estimates for all the segments, as well as a global abundance estimate for all of Nepal (Table 4). We estimate that 28 to 52 (95% CI) of Ganges River dolphins are currently distributed among the 3 rivers in Nepal. Observed mean (±SD) dolphin group size was 2.25 ± 1.75, with the largest group size (6 dolphins in a single group) recorded in Sapta Koshiat.

Table 2. Estimates of untransformed coefficients (β) (±SE) of habitat and seasonal covariate effects on occurrence of Ganges River dolphins *Platanista gangetica gangetica* derived from survey data from the Karnali, Sapta Koshi and Narayani Rivers, Nepal. Estimates are from the top-ranking model in which the covariate was supported; $\Sigma\omega_i$ is the cumulative weight of support for that covariate. Confidence intervals (CI) were calculated assuming a normal distribution. **Bold** indicates parameters significant for occupancy (at $p < 0.05$)

Covariate / Substructure	β	SE	CI (%) 2.5	CI (%) 97.5	$\Sigma\omega_i$
Detection parameters					
River width	0.35	0.20	−0.05	0.74	1.000
River depth	0.12	0.28	−0.43	0.67	1.000
Site-use parameters					
River					
Karnali	**3.59**	**1.03**	**1.56**	**5.61**	**1.000**
SaptaKoshi	**3.35**	**1.02**	**1.35**	**5.36**	**1.000**
Narayani	**−5.35**	**1.02**	**−7.35**	**−3.34**	**1.000**
Season					
Pre-monsoon	**1.13**	**0.32**	**0.50**	**1.76**	**0.997**
Habitat					
Deep pool	**1.23**	**0.55**	**0.15**	**2.30**	**0.332**
Straight channel	0.17	0.55	−0.91	1.24	0.332
Confluence	0.55	0.57	−0.57	1.67	0.332
River width	−0.19	0.17	−0.53	0.15	0.332
River depth	−0.15	0.19	−0.53	0.23	0.332

Table 1. Model selection statistics for all occurrence models, as well as initial detection models with constant ψ, for the Ganges River dolphin *Platanista gangetica gangetica* derived from survey data from the Karnali, Sapta Koshi and Narayani Rivers, Nepal. AIC: Akaike's information criterion; ΔAIC: AIC information difference, ω_i: Akaike weight; *K*: no. of model parameters; *p*: detection nuisance parameter

Model	AIC	ΔAIC	ω_i	*K*	−2log-likelihood
ψ(river + season),*p*(width + depth)	514.12	0	0.665	7	500.12
ψ(global),*p*(width + depth)	515.51	1.39	0.3319	12	491.51
ψ(river),*p*(width + depth)	524.84	10.72	0.0031	6	512.84
ψ(season),*p*(width + depth)	546.34	32.22	0	5	536.34
ψ(depth),*p*(width + depth)	552.99	38.87	0	5	542.99
ψ(depth + width),*p*(width + depth)	554.98	40.86	0	6	542.98
ψ(.),*p*(width + depth)	558.81	44.69	0	4	550.81
ψ(.),*p*(width)	559.32	45.2	0	3	553.32
ψ(.),*p*(season)	559.53	45.41	0	3	553.53
ψ(width),*p*(width + depth)	560.24	46.12	0	5	550.24
ψ(.),*p*(depth)	560.39	46.27	0	3	554.39
ψ(habitat),*p*(width + depth)	560.56	46.44	0	7	546.56
ψ(.),*p*(time)	561.21	47.09	0	4	553.21
ψ(.),*p*(.)	561.28	47.16	0	2	557.28

Table 3. Model selection statistics for all models with untransformed coefficients of habitat and seasonal covariate effects on abundance estimates for the Ganges River dolphin *Platanista gangetica gangetica* derived from *N*-mixture models applied to survey data from the Karnali, Sapta Koshi and Narayani Rivers, Nepal. Δ_i: Akaike's information criterion (AIC) difference; ω_i: Akaike weight; *K*: number of model parameters. Entries in **bold** are significant in that confidence intervals exclude zero. Models follow a negative binomial distribution unless otherwise noted. (–) not applicable

Model	Δ_i	ω_i	*K*	Untransformed coefficients of covariates (SE)				
				Intercept	Karnali	Sapta Koshi	Habitat	Season (post-monsoon)
River + habitat	0.00	0.690	6	−10.53 (18.88)	**1.99 (0.77)**	**3.13 (0.76)**	10.56 (18.87)	–
Global	1.65	0.300	7	−9.67 (12.72)	**1.99 (0.77)**	**3.13 (0.76)**	9.77 (12.70)	−0.15 (0.25)
Habitat	11.83	0.002	4	−8.84 (29.60)	–	–	11.03 (29.60)	–
Constant negative binomial	28.17	0.000	3	1.48 (0.61)	–	–	–	–
River	29.77	0.000	5	−0.67 (1.20)	2.19 (1.47)	2.63 (1.46)	–	–
Post-monsoon	30.16	0.000	4	−0.82 (0.40)	–	–	–	−0.15 (1.14)
Post-monsoon + river	31.53	0.000	6	−0.58 (1.22)	2.34 (1.52)	2.84 (1.54)	–	−0.53 (1.09)
Constant Poisson	103.57	0.000	2	1.16 (0.143)	–	–	–	–

DISCUSSION

The Karnali and Sapta Koshi Rivers had higher occurrence probabilities and abundance estimates for GRDs than the Narayani River. Higher occurrence probabilities suggest that these 2 rivers are more vital to river dolphin conservation in Nepal than the Narayani. The northern sections of the Narayani are not favorable in terms of the ecological needs of the dolphins due to habitat fragmentation and high competition pressure from buffer zone communities (Choudhary et al. 2012). Our results also suggest that even though portions of the Narayani lie within the core area of Chitwan National Park, the variability of the water level (and hence deep pools) is largely dependent upon the barrage gates, limiting habitat suitability in that river segment (Smith et al. 1998, Smith & Reeves 2000a). Seasonal flows characterize the rivers of Nepal (Chalise et al. 2003). Furthermore, during monsoon seasons, dolphins move into tributaries to reduce the risk from floods and floating debris, suggesting that vital tributaries are absent in the northern Narayani sections. Barrage management seems to be one of the most important factors for recovery of dolphin populations in the Nepalese sections of the river systems. Thus, successful river dolphin conservation requires effective water management in the rivers of the region (Smith et al. 1998).

The site-use models also revealed a strong relationship between dolphin habitat use and deep pools in those segments. River confluences have been suggested as high quality habitat for river dolphins in Asia (Timilsina et al. 2003) and South America (McGuire & Winemiller 1998), yet our results suggested that dolphin occurrence was more probable in river segments with deep pools. Deep pools have also

Table 4. Abundance estimates for Ganges River dolphins *Platanista gangetica gangetica* derived from *N*-mixture models applied to survey data from the Karnali, Sapta Koshi and Narayani Rivers, Nepal. Included are maximum observation counts (Max obs), season-specific estimates (N-est) (with 2.5 and 97.5% confidence intervals, CI) from the top-ranking model, and the constant negative binomial model estimates (Constant NB) for comparison

River Segment	Pre-monsoon					Post-monsoon				
	Max obs	N-est	CI (%) 2.5	CI (%) 97.5	Constant NB	Max obs	N-est	CI (%) 2.5	CI (%) 97.5	Constant NB
Karnali										
1	0	0.00	0	0	0	0	0.00	0	0	0
2	4	5.80	4	8	5	2	3.77	2	6	3
3	8	11.49	9	14	11	5	9.23	7	12	8
Sapta Koshi										
1	0	0.00	0	0	0	0	0.00	0	0	0
2	0	0.00	0	0	0	0	0.00	0	0	0
3	14	22.96	19	27	20	14	24.37	21	28	21
Narayani										
1	0	0.00	0	0	0	0	0.00	0	0	0
2	2	2.04	2	3	2	0	0.03	0	1	0
Total	28	42.28	34	52	38	21	37.39	30	47	32

been identified as preferred habitat by river dolphins and their fish prey in the upper stretches of the Ganges River in India (Bashir et al. 2010). The depth and width recorded in our investigation were lower than the observed threshold for dolphin survival during the post-monsoon period (Akbar et al. 2004, Smith et al. 2008) and, as a consequence, abundance was likely reduced compared to the pre-monsoon season. Akbar et al. (2004) did not observe any dolphins in river stretches with a depth of less than ~1.5 m, so the pre-monsoon season might be the most critical period for the dolphins in Nepal and other northern stretches of their range, particularly with climate change having the potential to affect water levels. Similarly, the drawdown of water levels in the Cinaruco River in Venezuela resulted in the abandonment of flooded Amazonian forests by botos *Inia geoffrensis* (Amazon River dolphins; McGuire & Winemiller 1998). Our results reveal the importance of river morphology and seasonal ecology to dolphin occurrence and abundance and are therefore useful for the development of site-specific conservation actions throughout Nepal.

Although detection seems to be an issue for surveying river dolphins, the detection estimates from the occupancy models were encouraging. River width and depth both positively affected dolphin detection. This effect might be a result of dolphins surfacing more often in wide river segments because there is sufficient space for them to not feel threatened by the survey boats. It might also be a consequence of deep pools (depth) being a preferred habitat. Dolphin counts did, however, vary among the different surveys, suggesting a substantial detection bias. Other cetacean studies have also observed detection probabilities <1 (Shrestha 1989, Smith et al. 1994, Timilsina et al. 2003, WWF-Nepal 2006, Paudel et al. 2014) and it is appropriate and important to account for these biases when determining population estimates, particularly for rare and endangered species (Nicholson et al. 2012). We suggest that future surveys in an *N*-mixture model framework might benefit from measuring additional detection covariates at the scale of the sites. The derived abundance estimates from our surveys are the first to account for such bias and robustly estimate the global population for Nepal, which is likely why our estimates are slightly higher than any previous surveys (e.g. 7 individuals, Smith 1993; 16 individuals, WWF-Nepal 2006). We estimate that we failed to detect between 6 and 24 dolphins during the surveys. This result is most likely a consequence of dolphins (1) travelling into tributaries and being temporarily unavailable for sampling, (2) hiding amongst debris, or (3) failing to surface within sight of the observation crew. Similar behavior has been shown to occur in the botos of the Amazon, where sexual segregation occurs during seasonal floods (McGuire & Winemiller 1998, Martin & da Silva 2004). Our methodology provides a standardized protocol, and should be applied to future surveys monitoring the status of the Critically Endangered Nepalese dolphin population. Additionally, the use of visual-acoustic surveys (Akamatsu et al. 2001, Wang et al. 2006, Mellinger et al. 2007) might aid in more accurately estimating the population by accounting for missing individuals in visual surveys. This approach is appropriate for species that are rarely spotted because they spend long periods of time under water.

The 2 lower stretches of the Karnali River where dolphins were observed have low water speeds and adequate amounts of deep pool habitats. Additionally, 20 km below the India/Nepal border there is a barrage, which is a stronghold for dolphins because of conservation efforts made by the Indian Government. We detected 12 dolphins in the 2 southern sections and estimated there were likely 16 individuals in the entire section of the river within Nepal. In contrast, only 3 or 4 dolphins were observed in the Karnali River over a decade prior to our study. It is probable that the low detections from the 2003 study (Timilsina et al. 2003) were due to detection bias (which we accounted for), so it is difficult to determine if there was a significant change in abundance.

The Sapta Koshi River had the highest number of river dolphins and is likely the largest sub-population in the country. Khatri et al. (2010) observed 11 dolphins along the length of the Koshi River after a major flood in 2008. Similarly, Limbu & Subba (2011) counted 11 dolphins in the Koshi River during the same time period. The maximum observed count (minimum known alive) in our surveys of Koshi was 14 individuals with detection bias-adjusted estimates ranging from 19 to 27 individuals (95% CI). These numbers are encouraging because they suggest an increase in abundance in the Koshi since the flood of 2008. However, all of the individuals were counted in the southern section of the river (on the Nepal/India border) and none were detected in the northern 2 segments, which are north of a barrage that severely limits the distribution of the dolphins. Dams are known to serve as barriers to movement for river dolphins (Smith & Smith 1998, Smith et al. 1998, Dudgeon 2005, Dudgeon et al. 2006). Furthermore, the southern extent of the Koshi population is connected to the Indian population so individuals can emigrate and disperse to India and possibly be lost from the Nepalese population. Even as the largest sub-population in Nepal, the dolphins of Sapta Koshi are not likely a genetically viable population without immigration from India and potential translocations of individuals (Smith et al. 1998, Zheng et al. 2005).

River geometry (and geomorphics) and development structures constructed at the India/Nepal border (developed in all river systems) pose the greatest threat towards the extinction of the river dolphin due to the dramatic changes in river flow characteristics (Paudel et al. 2014). Anthropogenic pressures such as the presence of fishing boats, stone quarries and motorboats used for local transportation along ghat areas (local transportation points across the rivers) are the other associated threats—all of which appear to be more localized, yet they are likely compounding effects in the decline of the GRD in Nepal. Changing the natural course of river systems (e.g Sapta Koshi and Geruwa to western flow in Karnali) with fluctuating depth profiles and fragmented deep pools greatly affects dolphin occurrence. Additionally, large numbers of local ghat areas (i.e. 4 ghats over the study stretch in Karnali, but not in Narayani or Sapta Koshi) are likely factors contributing to the decrease in the dolphin's distribution (46 km in 1986; 32 km in this study; also see WWF-Nepal 2006) in Nepal.

Although our results reveal a severely limited river dolphin population with low abundance and fragmented sub-populations, our global estimate for all of Nepal (95% CI = 28 to 52 individuals) is higher than the estimated population of 20 individuals in 2011 (Jnawali et al. 2011), likely due to our inclusion of adjustments for detection bias. We are somewhat encouraged that the population of dolphins in Nepal is likely larger than previously appreciated; however, we believe that it is imperative that these data are used to develop local and global recovery strategies for the management of this Critically Endangered species.

CONCLUSIONS

Our population estimates and details of habitat use are the first attempt in Nepal to generate detailed science-based information, and serve as an important baseline for conservation planning, further study, and comparison to other dolphins of the Ganges River watershed in Nepal. This small remaining population of river dolphins is at the brink of extinction due to river geometry and human developments at the Nepal/India border. Conservation interventions (e.g. translocation in Sapta Koshi or extension of the Koshi Tappu Wildlife Reserve boundary; some artificial tributaries in southern sections of Narayani) are essential in Nepal's river systems, as are site-specific conservation action plans. The post-monsoon season is critical for dolphin survival in Nepal, therefore seasonal attention from the respective authorities is also important. Dolphins can be difficult to detect, so integration of additional technologies could enhance the accuracy and precision of estimates for the Nepalese population. Continued investigations of dolphin abundance and occupancy as well as their behaviors in relation to ecological components are strongly recommended to assess the population trend and risk of extinction of the dolphins of Nepal.

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