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Conservation planning for Gangetic dolphin (*Platanista gangetica*) in smaller rivers of the Ganga River Basin, India

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A R T I C L E I N F O

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A B S T R A C T

The complex and dynamic networks of river system, vital for the maintenance of biodiversity and ecosystem services, are under pressure due to human-induced water stress disrupting ecological processes. Recognition of the importance of rivers as source of life though has led to efforts towards protecting large rivers, nevertheless the conservation and management of smaller rivers remained mostly neglected, creating significant gaps in ecological restoration initiatives. In the present study, we assess the distribution and population status of Gangetic dolphin (*Platanista gangetica*) in the small rivers in the Ganga River Basin for integrating it into the basin wide river conservation strategy. We observed that the Gangetic dolphin inhabited most tributaries and sub-tributaries of the Ganga River, with a naïve occupancy rate of $\Psi = 0.68 \pm 0.04$ (mean ± SE) having 606 ± 142.77 (mean ± SE) individuals and accounts for 15% of the total Gangetic dolphin population in the Basin. The results of *N*-mixture and MaxEnt models demonstrate that channel depth, presence of meanders and water discharge were key predictors of distribution in these rivers, and the proximity to confluences were identified as a critical predictor. About 54%

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(620 km) of 1150 km of the surveyed river stretches exhibited suitability for dolphins in the Basin, indicated by a probability distribution score of ≥0.50. Combining this data with the available information, we delineated a total of 2850 km stretch covering entire Ganga River System suitable for Gangetic dolphins within the Basin. Notably, the 620 km of suitable stretches identified in smaller rivers represent 22% of the overall suitable stretches across the entire basin. These stretches were translated to conservation priority stretches for systematic conservation planning involving various stakeholders for improved river conservation in the Basin.

1. Introduction

The network of river systems, sustained by the interplay of biotic and abiotic components, functions as biodiversity hotspots and offer essential services for human needs (Carpenter et al., 2011; Grill et al., 2019; Meybeck, 2003; Ripl, 2003). The spatial and hierarchical structure, as well as the longitudinal connectivity of the river system, hold together the most diverse composition of flora and fauna globally (Collen et al., 2014; Dudgeon, 2000; Reid et al., 2019). In this complex network, each hierarchical order of streams plays a pivotal role, indispensably contributing to the ecological processes that heavily rely on biodiversity (Bouska et al., 2023; Pracheil et al., 2013). As per the classic stream order or Hack's stream order, existence of large rivers is greatly dependent on the vital contributions of their tributaries and sub-tributaries (Rodriguez-Iturbe and Rinaldo, 1997) and these are crucial for strengthening the hydrological network of the river basins (Nel et al., 2007). The small rivers are often characterized by a mosaic of diverse habitats, which support rich biodiversity, serve as migration routes, sources of nutrients, contributors to climate resilience, and significant refuges for macrofauna (Davis et al., 2013; Gido et al., 2016). The small rivers facilitate connectivity, creating a network that allows for the movement of aquatic species essential for maintaining metapopulations. This, in turn, enables the creation of a metapopulation structure, ensuring genetic exchange and preventing isolation of populations, enhancing the resilience of aquatic species to environmental changes and disturbances (Allendorf et al., 2012; Tonkin et al., 2018). Unfortunately, the fundamental attributes that maintain the integrity of riverine networks are increasingly undermined by human-induced stressors such as the construction of dams, reservoirs, canals, and irrigation systems. The evident decline in freshwater biodiversity underscores the urgent need for conservation actions to halt biodiversity loss and deteriorating ecological processes in these vulnerable ecosystems (Dudgeon et al., 2006; Grill et al., 2019; Vörösmarty et al., 2010).

Until recently, the predominant focus of conservation and restoration efforts has been on large rivers, often overlooking the importance of small rivers (Palmer and Ruhi, 2019). The vital contributions of these lesser known small rivers to the health and resilience of larger river systems are increasingly being recognized in the literature, demanding a shift towards more comprehensive and inclusive conservation strategies that adopt basin-wide approach and prioritize the interconnected nature of riverine ecosystems (Dudgeon et al., 2006; Saunders et al., 2002; Thorp et al., 2010).

The Ganga River, one of the most biodiverse subtropical rivers of India, is currently confronting unprecedented threats from various human-induced stresses (Hussain et al., 2020; Kumar, 2017). The tributaries and sub-tributaries of the Ganga River, hereafter called as small rivers, are pivotal in enriching the hydrological processes and ecological health of the entire Ganga River Basin (henceforth GRB) (Singh and Singh, 2020). The biodiversity of these small rivers is declining rapidly and the paucity of robust ecological information has impeded river conservation efforts (Dudgeon, 2000; Hughes, 2017). This dearth of information poses a significant challenge in understanding the intricate dynamics of these ecosystems, thereby hindering the development of effective conservation strategies. In such a scenario, the utilization of the widely-recognized umbrella-species approach can be fundamental in shaping the future conservation strategies for these lesser known small rivers (Branton and Richardson, 2011; Roberge and Angelstam, 2004). The umbrella-species concept operates on the premise that providing adequate space for species with more extensive spatial needs will also serve as protection for an entire assemblage of species with more modest spatial requirements (Wilcox, 1984; Andelman and Fagan, 2000; Roberge et al., 2008). Hence, large-bodied organisms, often vertebrates, particularly large mammalian carnivores, have been favored as potential umbrella species (Carroll et al., 2001; Roberge and Angelstam, 2004). Consequently, the umbrella species approach can play a crucial role in delineating protected areas, assuming that conserving these species will confer adequate protection to coexisting species (Roberge et al., 2008; Roberge and Angelstam, 2004; Sergio et al., 2008). Indeed, this approach aligns with the goal of 'bending the curve of freshwater biodiversity loss' and is instrumental in garnering public support, thereby increasing the likelihood of conservation actions (Kalinkat et al., 2017; Tickner et al., 2020).

Gangetic dolphin (*Platanista gangetica,* Lebeck, 1801), is an obligatory river cetacean endemic to the Indian subcontinent (Kelkar et al., 2018, 2022; Anderson, 1879). It plays a crucial role in stabilizing ecosystems, regulating energy flows and maintaining the prey base (Behera et al., 2014; Gomez-Salazar et al., 2012; Turvey et al., 2012). While the GRB hosts numerous long-ranging large aquatic vertebrates, such as gharial, mugger, otters, and freshwater turtles, the presence of dolphin throughout the basin, along with its specific hydro-geomorphological requirements, renders it an exemplary candidate as an umbrella species. Utilizing the Gangetic dolphin in this role provides valuable insights into the extent of human pressures and aids in prioritizing conservation efforts within the basin (Hussain et al., 2013; Roff, 2013; Sinha and Kannan, 2014). In recent years, the distribution range of the Gangetic dolphin in various rivers has dwindled, particularly in the upstream stretches (Das et al., 2022, Sinha and Kannan, 2014). The species is now believed to be extirpated from the Son, Ken, Betwa, and Sind rivers, the middle and upper stretch of the Sharda River, and the upper stretch of the Yamuna River (Sinha and Sharma, 2003, Behera et al., 2014). Additionally, several tributaries north of the Ganga River, including the Babai, Bagmati, and Sharda rivers, lack updated information on the status of the Gangetic dolphin (Kelkar et al., 2022), while Rapti

River was surveyed a decade back (WWF-UPFD, 2015). Hence, a comprehensive study is essential to assess the current population status, distribution, and perceived threats, with the goal of integrating this information into basin-wide river conservation strategies.

In this study, we assessed the distribution, population status, and habitat suitability of Gangetic dolphin in small rivers within GRB. Through the study we addressed following research questions, (i) What is the extent of current distribution range? (ii) What is the population status and occupancy? (iii). What are the spatial and environmental factors influencing the distribution and abundance of dolphins in small rivers, and how can this information be utilized to prioritize conservation efforts in these rivers?

2. Methodology

2.1. Study area

The study was carried out in the tributaries and sub-tributaries of the Ganga River. We carried out boat-based visual encounter surveys in ten rivers, covering a total linear stretch of 1290 km, *viz* Girwa (20 km), Kauriyala (15 km), Babai (75 km), Sharda (220 km), Rapti (500 km), Bagmati (60 km), Mahananda (230 km), Ken (40 km), Betwa (90 km), and Sind (40 km) (Fig. 1 **and** Table S1). The survey of the upstream of the Bagmati River was omitted due to navigability concerns. Of the rivers surveyed, Bagmati, Babai, Girwa, Kauriyala, Mahananda, Rapti, and Sharda are northbound Himalayan rivers, partially snow-fed. Whereas the Ken, Betwa, and Sind are rain-fed and have their origins in the Deccan Peninsula (Singh, 2017). The surveys were carried out during the post-monsoon seasons (November -February) of 2022 and 2023 using an inflatable rubber boat fitted with 25 hp Yamaha engine.

2.2. Data collection

We employed a boat-based visual encounter method to record Gangetic dolphin sightings (Smith and Reeves, 2000; Qureshi et al., 2021). All surveys were conducted using inflatable boats, with two independent observers stationed at the front and rear ends of the boat to simultaneously record Gangetic dolphin sightings. The observers did not maintain visual contact and were instructed to adhere to the same survey protocol described in Das et al. (2022). The boat was kept at an average speed of 6–8 km/hr to minimize the likelihood of missing any surfacing event of the Gangetic dolphin (Smith et al., 2006; Das et al., 2022). The least concurrent sighting records obtained by two independent observers were then fitted into -the occupancy framework.

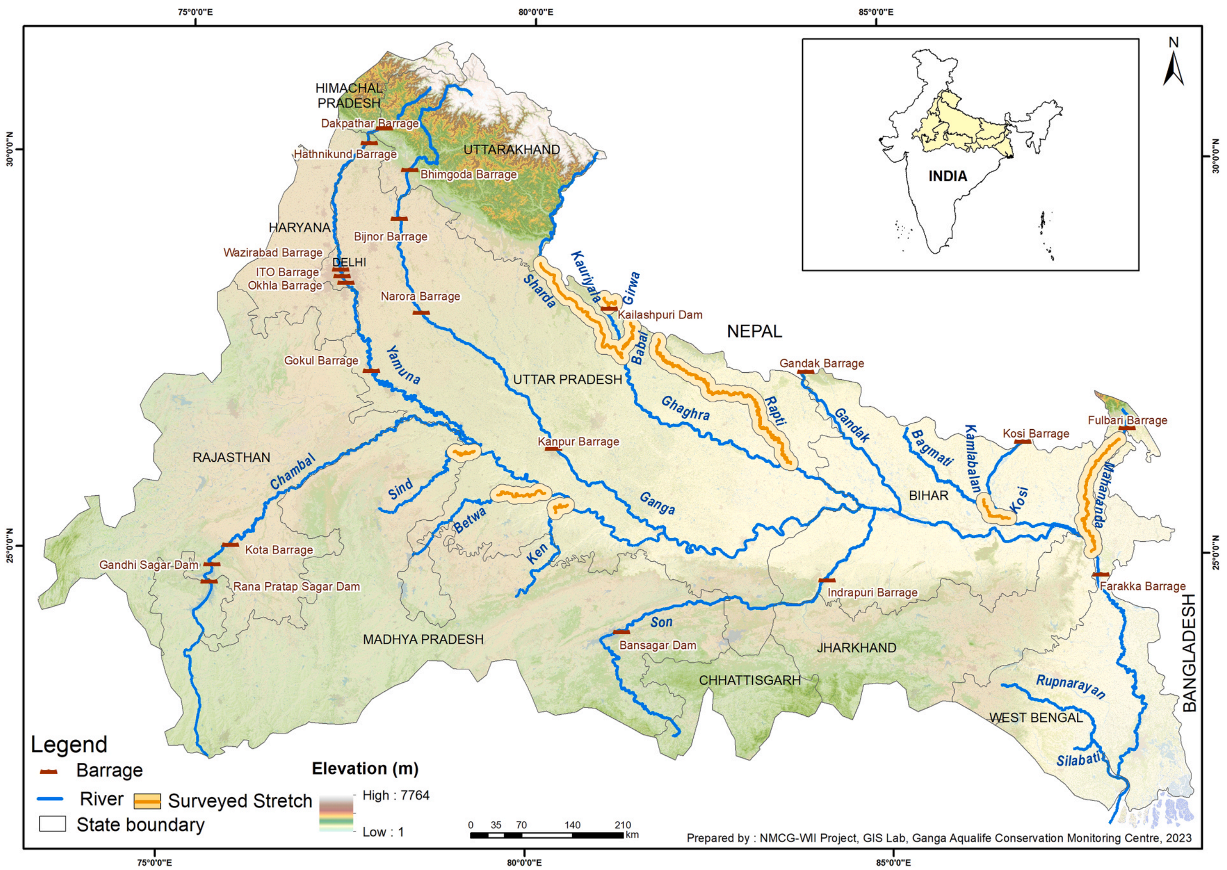

Fig. 1. Location map of the rivers surveyed for recording Gangetic dolphin (*Platanista gangetica*) presence in the Ganga River Basin, India.

In addition to Gangetic dolphin occurrence records across these rivers, we also collected data on (i) hydro-morphological variables (n=5) *viz.* slope, discharge, channel width, channel depth, presence of meanders, (ii) physiochemical parameters (n=5) *viz.* water temperature, dissolved oxygen (DO), pH, salinity, Total Dissolved Solids (TDS) and (iii) human induced stressors (n=5) *viz.* ferry intensity and fishing intensity (number of active nets), sand mining intensity, water extraction pumps and human presence. To mitigate the impact of shallow and unnavigable river sections, the boat-based direct count method utilized the thalweg, or the deepest section of the river channel, to estimate dolphin abundance (Smith and Reeves, 2000; Smith et al., 2006; Braulik et al., 2012; Richman et al., 2014). Leveraging these hydro-geomorphological features and adhering to the assumptions outlined by Charbonnel et al. (2014), we standardized our spatial units to 5 km, in accordance with the methodology proposed by Das et al. (2022). The 1290 km linear stretch was segmented into 258 Biodiversity Evaluation Units (BEUs) (Table S1), and data were collected at 1 km intervals within each BEU. Subsequently, the collected data were averaged and incorporated into the occupancy and N-mixture framework, following the study design outlined in Das et al. (2022). The length of the sampling site i.e. 25 km (five spatial replicates of 5 km segment/BEUs) was selected to meet the assumptions critical for the hierarchical-N mixture model and is based on the following criteria. First, we utilized the mean home range of *Platanista minor* (Toosy et al., 2009) as a surrogate to select the length of the sampling sites for this study, as *Platanista gangetica* and *Platanista minor* both share identical physiological and biological attributes (Smith and Braulik, 2009). Therefore, based on the information, we assumed a maximum daily movement of approximately 25 km for the Gangetic dolphin, considering the intermittent shallow and deep pools in the river stretches. Secondly, the length of the sampling site chosen to meet the closure assumption Royle, (2004), detect the presence of a species, and the requirement for more than three spatial replicates, as recommended by Hines et al. (2010). As the aim of the present study was to assess the abundance and distribution of Gangetic dolphins in the lesser-known rivers of the Ganga Basin, surveys were conducted in narrow channel habitats from November 2022 to February 2023 (low water season). We implemented single observer method, which builds upon the foundation of multiple observers stationed in a single boat, following a thalweg path in the river, are ideal for detecting dolphin sightings (Smith and Reeves, 2000; Paudel et al., 2015; Qureshi et al., 2021). The single observer method always remains a cost-effective survey option for monitoring (Richman et al., 2014). However, unlike the double-observer method, it cannot account for detectability (McConville et al., 2009). To address this, we compared the findings from our study with a correction factor derived utilizing the mean detection probability from double-observer methods (Das et al., 2022).

2.3. Data analysis

2.3.1. River habitat assessment

For habitat assessment, the average values of each variable were computed for a total of 258 Biological Evaluation Units (BEUs). While the presumption was that various rivers possess unique attributes because of their distinct origins and passage through different biogeographical provinces, we employed one-way ANOVA (Analysis of Variance) to assess whether there were significant variations between these BEUs and across rivers.

2.3.2. Encounter rate (ER) and site occupancy

We calculated the Gangetic dolphin encounter rate (sightings per km of linear stretch) for each spatial unit and employed ANOVA to examine variations in encounter rates across the rivers. Gangetic dolphin presence and absence data was pooled from each spatial unit to fit into the occupancy framework (MacKenzie et al., 2002, 2017). We utilized data from repeated visual encounter surveys to fulfill the requirements of single-season occupancy analyses. Key assumptions in single-season occupancy analysis include: (1) closure, assuming the population is demographically closed during surveys, (2) site independence, assuming species detection at one site is independent of detections at others (Fiske and Chandler, 2011), (3) no-false positives, requiring correct species identification and disregarding doubtful detections, and (4) constant probability of occupancy and detection, wherein the default model assumes uniform probability of occupancy and detection across all sites or adjusts for site and observation-level covariates (Mackenzie, 2006). The site occupancy of Gangetic dolphin in the surveyed river was estimated using the *occu ()* function in the "*unmarked*" package (version 1.3.2) in R version 4.3.0, with R Studio version 2023.04.21 (Fiske and Chandler, 2011; RStudio Team, 2022). First, we assessed factors e.g., time spent on each spatial unit (effort), time of the day during survey (time) and channel width influencing the likelihood of detecting Gangetic dolphin (p), while keeping the probability of their presence (Ψ) constant following MacKenzie et al. (2017). Continuous variables were z-standardized, and categorical variables (Table S2) were dummy-coded in order to prevent numerical optimization of the likelihood following Hines, (2006) and Sunarto et al. (2012). To ensure the reliability of our results, we checked for potential multicollinearity among variables using the Pearson correlation test (Graham, 2003). Variables with a Pearson correlation coefficient higher than 0.70 were excluded from the analysis.

2.3.3. Abundance estimation

2.3.3.1. Gangetic dolphin abundance estimation using N-mixture model. We used Binomial *N*-mixture models to estimate the dolphin abundance and factors influencing their distribution (Royle, 2004; Kéry and Royle, 2020; Kéry, 2018). The N-mixture model accounts for imperfect detection and evaluates the likelihood of an event occurring as well as the likelihood of detecting a species (Mackenzie, 2006; MacKenzie et al., 2002; Rota et al., 2009). These models are known to yield more reliable abundance estimates of rare and cryptic species compared to traditional direct counting (MacKenzie and Bailey, 2004; Rota et al., 2009). This method has been successfully used to assess Gangetic dolphin abundance in major rivers of the Ganga basin and the Karnali River in Nepal (Das et al., 2022;

Paudel et al., 2015). We used dolphin sighting records per spatial unit as baseline data and employed the N-mixture model using the '*pcount*' function available in the "*unmarked*" package in R version 4.3.0, with R Studio version 2023.04.21 (Fiske and Chandler, 2011; R Development Core Team, 2023; RStudio Team, 2022). We administered the spatial counts data into the Negative Binomial distributions as it effectively models abundance, taking into account occupied survey sites with fewer true zeros in the dataset (Barão-Nóbrega et al., 2022). Given the patchy distribution of dolphin during the low water season, Negative Binomial distributions align well with over-dispersion data (Knape et al., 2018; Kéry and Royle, 2020). The upper bound value for K (abundance estimates) were determined through multiple trials iterations (Fiske and Chandler, 2011; Knape et al., 2018; Kéry and Royle, 2020). Site covariates such as channel width, meander, fishing intensity, water discharge, individual river characteristics, and anthropogenic influences are hypothesized to influence the relative abundance (λ) of dolphin and detection covariates (Table S2) influencing detection probability (p), when dolphins are present at a site. These covariates were chosen based on existing knowledge and relevant literature (Das et al., 2022; Paudel et al., 2015). A comprehensive set of 32 N-mixture models, encompassing various combinations of univariate and multivariate factors, were created to evaluate the abundance and detection probability of dolphins, under the Negative Binomial distribution. MacKenzie and Bailey goodness-of-fit test was performed to evaluate model performance (MacKenzie and Bailey, 2004). Models were ranked based on Akaike Information Criterion (AIC) scores and AICc weights were taken into consideration while determining overall covariate significance (Akaike, 1974; Burnham and Anderson, 2004). A final model set was generated from the top-ranked univariate models that included combinations of site use and detection covariates with ΔAICc ≤ 2, indicating substantial empirical support. Significant covariate influence was determined if the 95% confidence interval of the beta coefficient ($\beta \pm 1.96 \times$ SE) did not overlap zero, with the sign of the coefficient indicating the impact's direction (Searle et al., 2020). The probability of Gangetic dolphin relative abundance (λ) was estimated for each site by averaging the predicted values from the most parameterized top-ranked models within the final model set, using the '*MuMin*' package in R(Bartoń, 2013; R Development Core Team, 2023). We performed a goodness-of-fit test for the highest-ranked model with the maximum parameters (Searle et al., 2020).

2.3.3.2. Gangetic dolphin abundance estimation using correction factor (D_{cf}). Correction Factors (D_{cf}) compensate for missed individuals during visual encounter surveys (Bashir et al., 2010; Richman et al., 2014; Vu et al., 2018). Therefore, we determined the relative abundance of Gangetic dolphin using mean correction factors (D_{cf}) obtained from previously published studies conducted in rivers across the Indian subcontinent (Das et al., 2022). These studies encompassed a range of river types, including narrow and wide channels with varying widths, depths, and lengths. The derived indices were then compared with population estimates derived from *N*-mixture models. The corrected population estimates of Gangetic dolphin were obtained by multiplying the correction factor (D_{cf}) by the total number of sightings recorded in a given river.

2.3.4. Conservation Priority Stretch (CPS)

To predict the potential distribution and delineate priority stretches, we employed maximum entropy (MaxEnt) models. The MaxEnt is one of the effective modelling algorithms, which take environmental variables and species presence-only data to predict and model species distribution. It is also capable of predicting future distributions under the influence of global climate change (Clements et al., 2012; Elith et al., 2006; Phillips et al., 2006).

For MaxEnt modeling, we utilized a total of 176 dolphin presence locations across seven rivers (no Gangetic dolphin presence was recorded in three rivers). To generate the species distribution model, we selected 33 variables comprising bioclimatic (n=19), hydromorphological (n=4), physiochemical parameters (n=5), and human induced stressors (n=5) (Das et al., 2022; Jain and Singh, 2020; Rai et al., 2023). The climatic variables were resampled at 5 km^2 resolution, obtained from WorldClim version 2 with a spatial resolution of 2.5 arc minutes (approximately 4.5 km^2) to ensure uniformity (Fick and Hijmans, 2017). All pairs of variables were assessed for correlation, and variables displaying a Pearson correlation coefficient of $\geq$0.70 were removed if they were found to have minimal ecological significance (Zuur et al., 2010). Finally, a subset of 12 uncorrelated ecologically meaningful variables was used to generate dolphin distribution in the seven rivers using MaxEnt software (version 3.4.4) (Table S2). Model over-complexity and overfitting, were adjusted by optimizing user-modifiable factors, *viz.*, regularization multipliers and the feature classes (Elith et al., 2010). We examined a variety of model combinations, initially individual feature classes (e.g. Linear (L), Quadratic (Q), Product (P), Threshold (T), and Hinge (H) with varying regularization values at 0.5, 1.0, 1.5, and 2.0. For example, within the linear feature class, four different models were assessed L-0.5, L-1.0, L-1.5, and L-2.0 (Table S3). The best fit models were assessed using AIC approaches computed in ENMTools 1.4.4 software (Warren et al., 2010). The prediction probabilities were transformed into a raster layer to generate a probability distribution map using ArcGIS 10.6 (https://www.esri.com/). Subsequently, the probability distribution was categorized in three classes viz. >0.70, 0.61–0.70 and 0.51–0.60. These classes were then translated to priority stretches following Das et al. (2022) as CPS1->0.70, (High Conservation Priority Stretches), CPS2 −0.61–0.70 (Moderate Conservation Priority Stretches), and CPS3 −0.51–0.60 (Low Conservation Priority Stretches).

3. Results

3.1. River habitat assessment

The surveyed rivers exhibited diverse hydro-morphological characteristics and physicochemical properties along their lengths. The average channel depth across studies rivers was 3.03 m ± 2.71 (mean ± SD), with individual rivers varying significantly between a depth of 1.78 m ± 0.91 in Sind River and 5.25 m ± 4.37 in Bagmati River (ANOVA, $F = 15.55$, $p < 0.001$). Notably, the Mahananda, Rapti, and Bagmati rivers exhibited depth variations, primarily due to the presence of deeper pools compared to the other studied rivers (Figure S1). The mean river width was 253.13 m ± 177.27, with widths ranging from 83 m ± 24 in Sind River to 525 m ± 281 in Sharda River. A significant difference in mean channel width was observed across the studied rivers (ANOVA, F = 147.26, p <0.001) (Figure S1). Additionally, the presence of meanders varied significantly among the rivers. Physicochemical properties also displayed substantial variations among the studied rivers (Table S2).

We observed significant variations in various human induced stressors across the studied rivers. The fishing intensity, measured as the average number of active nets per BEU (mean= 8.81, range= 0–131), varied significantly (ANOVA, F = 23.94, p <0.001). The Mahananda River had the highest fishing intensity (38.64 0–131 nets/BEU), while the Sind River had the lowest (0.14, 0–3 nets/BEU). No fishing activity was observed in the Girwa and Kauriyala rivers, as these rivers flow through the Katerniaghat Wildlife Sanctuary a Protected Area declared under the Indian Wild Life (Protection) Act, 1972. The mean number of ferry crossings (1.95, 0–34 ferry/per BEU) also varied significantly (ANOVA, F = 22.04, p <0.001) among the rivers. Sand mining intensity, including activities involving boats, tractors, and earthmovers, differed significantly across the rivers (ANOVA, F = 6.439, p <0.001), with the highest intensity in the Betwa River (5.52, 0–58 activities/BEU) and the lowest in the Babai River (0.13, 0–2 activities/BEU). Notably, there were no signs of mining activities in the Girwa, Kauriyala, and Rapti rivers. Extraction of water through pumps among the rivers also exhibited significant variations (ANOVA, F = 34.675, p <0.001). The Bagmati River had the highest occurrence of water extraction pumps (6.75, 0–10pumps/BEU), while the Rapti River had the lowest (0.11, 0–3) (Table S2).

3.2. Encounter rate (ER) and site occupancy

A total of 359 sightings of Gangetic dolphins were documented within the 1120 km survey stretch across seven rivers, accounting for 41% of the total BEUs covered (Fig. 2 **A**). Maximum sightings were recorded from the Mahananda River (n=169, 47%) followed by sightings in the Rapti (n=89, 25%), Bagmati (n=68, 19%), Kauriyala (n=13, 4%), Girwa (n=9, 3%), Sharda (n=7, 2%), and the Babai River (n=4, 1%) **(**Table S4**)**.

The average encounter rate of dolphin across rivers was 0.49 ± 0.15 (mean ± SE) sightings/linear km and ranged between 0.03 ±0.02 sightings/km in Sharda and 1.13 ± 0.04 sightings/km in Bagmati river. The highest encounter rate was observed in the Bagmati River (1.13 ± 0.04 sightings/km), followed by the Kauriyala (0.87 ± 0.47), Mahananda (0.73 ± 0.1), Girwa (0.45 ± 0.17), Rapti (0.18

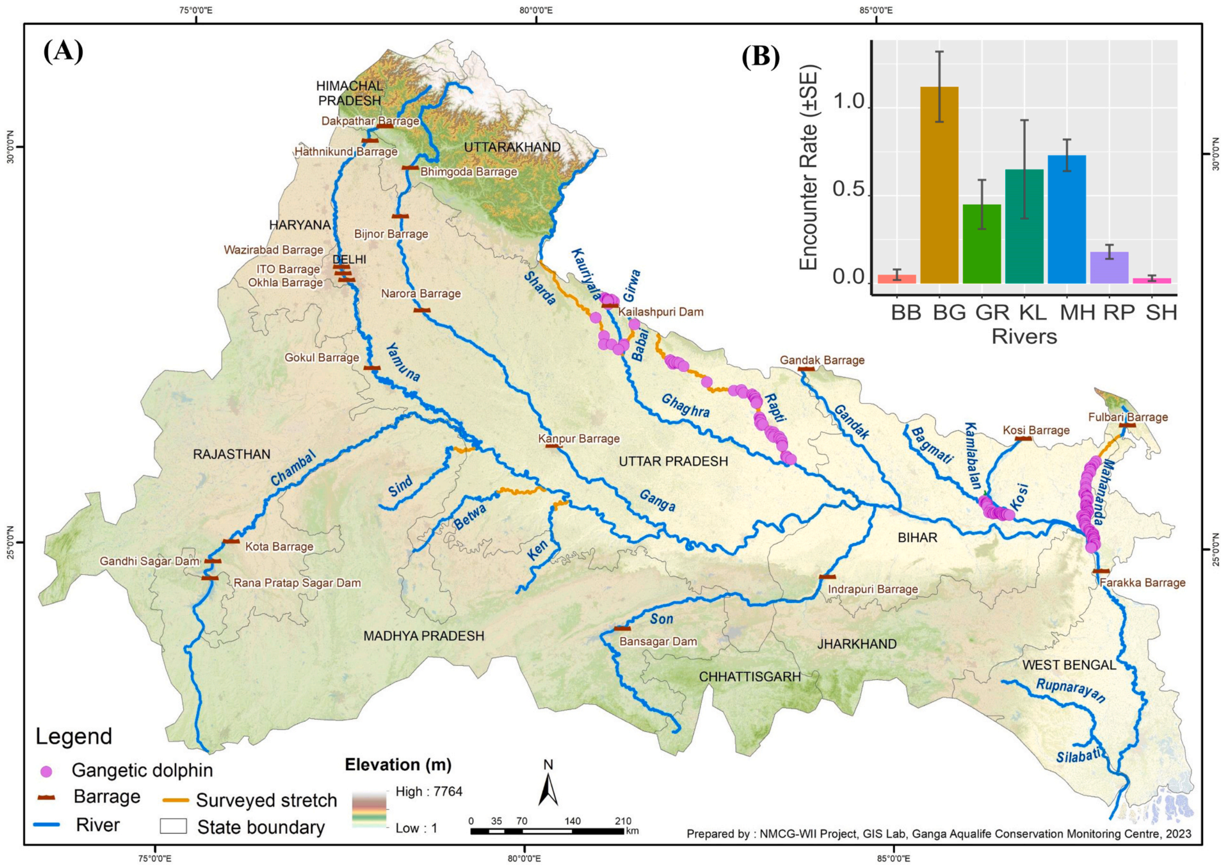

Fig. 2. **(A)** Sighting locations of Gangetic dolphin and **(B)** Gangetic dolphin encounter rate (sightings/linear kilometer) recorded in seven small rivers of the Ganga River Basin, India. (BB=Babai; BG=Bagmati; GR= Girwa; KL=Kauriyala; MH=Mahananda; RP= Rapti; SH= Sharda).

± 0.04), Babai (0.05 ± 0.04), and Sharda (0.03 ± 0.02) rivers (Fig. 2 **B**). A significant variation in encounter rates was observed across the surveyed rivers (ANOVA, $F = 25.20$, $p < 0.001$). Gangetic dolphins were detected in 31 sampling units, resulting in a naïve occupancy of 0.68 ± 0.07 (95% CI = 0.54 − 0.81). The mean probability of detecting Gangetic dolphin was estimated at (P) 0.61 ± 0.04, and the average likelihood of these dolphins occupying a site was $\Psi = 0.68 \pm 0.04$.

3.3. *Abundance estimation*

3.3.1. *Gangetic dolphin abundance estimation using N-mixture model*

The total estimated population of dolphin across the examined rivers was 606 ± 142.77 (mean ± SE) dolphins (CI = 381 – 923) (Table 1). Among the rivers, the Mahananda River encompassed 43.56% of the estimated total population, at 264 ± 47.07 individuals (CI = 180–363) and lowest in the Babai River, at 8 ± 7.08 individuals (CI = 4–18) constituting only 1.32% of the total estimated population. The Rapti, with an estimated abundance of 146 ± 45.79 individuals (CI = 79–256) constitutes the second largest population, contributing to 24.09% of the total estimated population. The Bagmati River had an estimated population of 120 ± 22.13 individuals, accounting for 19.80% of the total estimated population. The Kauriyala River was estimated to have 36 ± 8.48 individuals, Girwa River had 19 ± 5.22 individuals, and Sharda River held 13 ± 7.08 individuals using the *N*-mixture model. The Babai River exhibited the lowest abundance estimate, with 8 ± 7.08 individuals, constituting only 1.32% of the total estimated population across all the rivers analyzed **(**Table 1**)**.

3.3.2. *Gangetic dolphin abundance estimation using correction factor (D_{cf}).*

The mean derived correction factor ($D_{cf} = 1.52$) and the abundance estimated using correction factor was 546 ± 37.05 individuals (CI = 473–619) (Table 1). The abundance estimate was highest in Mahananda River (47.06%) with 257 ± 11.15 individuals (CI = 235–279). Similar to the estimates obtained through the N-mixture model, the Rapti River displayed the second-largest Gangetic dolphin population of 135 ± 11.67 individuals (CI = 112–158). Following this, the Bagmati River had an estimated 103 ± 8.10 individuals (CI = 87–119), while the Kauriyala accounted for 20 ± 2.26 individuals (CI = 16–24). The Girwa River accounted for 14 ± 1.09 individuals (CI = 12–16), followed by Sharda with an estimate of 11 ± 1.69 individuals (CI = 8–14). The lowest abundance estimate was for the Babai River, with 6 ± 1.09 individuals (CI = 4–8) using the correction factor (D_{cf}).

3.3.3. *Factors affecting Gangetic dolphin abundance (λ)*

The optimal model for estimating abundance (λ) included factors such as channel depth, meanders, and individual rivers, while for detection (p) it included river width and effort (Table S6**)**. Based on model-averaged parameter estimates (cumulative weight of $\Sigma w = 1.00$), factors such as channel depth, meanders and individual rivers were identified as the most reliable predictors of dolphin abundance (Table S6). While the parameter 'river' was present in the final model set, their individual impact varied. Among these rivers, Bagmati and Mahananda had a notably positive influence on dolphin abundance, whereas the Sharda exhibited a negative influence (Table S6). Moreover, the width of the river was determined to have a notably adverse impact on the detection probability (cumulative weight of $\Sigma w = 1.00$), while the level of effort displayed a positive correlation with the detection probability of Gangetic dolphins in the Ganga Basin (Figs. S3 and S4).

3.4. *Identification of Conservation Priority Stretches (CPS)*

The Species distribution model (SDM) yielded an impressive Area Under Curve (AUC = 0.97, SD 0.008) **(**Figure S2**)**. The prediction model identified seven bioclimatic variables - Annual Mean Temperature (Bio 1), Isothermality (Bio 3), Temperature Seasonality (Bio 4), Precipitation of the Wettest Month (Bio 13), Precipitation Seasonality (Bio 15), Precipitation of the Driest Quarter (Bio 17), and Precipitation of the Warmest Quarter (Bio 18) as key factors influencing the distribution of Gangetic dolphin. Other hydrological and human induced stressors such as channel depth, channel width, water discharge, fishing, and sand mining contributed significantly in determining the species distribution **(**Figure S2**)**. The predicted potential distribution of dolphin indicated that water discharge contributed the most (30.6%), followed by Temperature Seasonality (16%) and Annual Mean Temperature (12.5%) in the Basin

Table 1
The length of the river surveyed, number of sightings, abundance estimates derived using the N-mixture model and Correction factor (D_{cf}) of Gangetic dolphin across seven small rivers in the Ganga River Basin, India.

River	Surveyed length (km)	Concurrent least sightings	Population estimates (λ), Mean ± SE (CI 95%)	Population estimates (D_{cf}) Mean ± SE (CI 95%)
Babai	75	4	8 ± 3.8 (4–18)	6 ± 1.09 (4–8)
Bagmati	60	68	120 ± 22.13 (81–168)	103 ± 8.10 (87–119)
Girwa	20	9	19 ± 5.22 (10–30)	14 ± 1.09 (12–16)
Kauriyala	15	13	36 ± 8.48 (21–55)	20 ± 2.26 (16–24)
Mahananda	230	169	264 ± 47.07 (180–363)	257 ± 11.15 (235–279)
Rapti	500	89	146 ± 45.79 (79–256)	135 ± 11.67 (112–158)
Sharda	220	7	13 ± 7.08 (7–33)	11 ± 1.69 (8–14)
Grand total	**1120**	**359**	**606 ± 142.77 (381–923)**	**546 ± 37.05 (473–619)**

(Table S5).

The MaxEnt models predicted a probability distribution of Gangetic dolphin that encompassed a total stretch of 1150 km, including both historical and current ranges. Out of the entire projected distribution, approximately 54% (620 km) of river stretches were identified as suitable for dolphins (based on probability distribution score ≥0.50) (Table 2). Priority stretches were delineated and categorized based on the Gangetic dolphin's potential distribution map. About 37.39% (430 km) of the river stretches were designated as High Conservation Priority Stretches, followed by 9.57% (100 km) of river stretches as Moderate Conservation Priority Stretches, and 6.96% (70 km) of river stretches as Low Conservation Priority Stretches. Most of the CPS1 stretches were concentrated in the lower sections of the Rapti, Bagmati, and Mahananda rivers (Figs. 3 and 4), while the remaining CPS1 were located in the confluences of tributaries. Among the rivers with suitable habitat, the Mahananda River had the largest contiguous, suitable river segment spanning 170 km, accounting for 14.78% of the total predicted stretch.

4. Discussion

The dynamic hydrological and morphological characteristics of rivers and their physicochemical attributes contribute to high habitat heterogeneity, which plays a central role in determining the species occurrences (Ward, 1998). Unfortunately, most rivers in the GRB are now highly regulated, thus homogenous and offer limited biodiversity conservation potential (Pradhan et al., 2023). The growing human population in the Basin is predicted to further magnify human-induced stressors, such as agriculture, fishing, and mining during the dry season, making these rivers sub-optimal and less conducive for biodiversity conservation (Haidvogl, 2018; Schmutz and Sendzimir, 2018; Das et al., 2022). Unlike terrestrial ecosystems, the riverine system are more vulnerable and poised with challenges arising from conflicting resource use, direct human dependency and land use conflicts (Ledger et al., 2023). These effects are more conspicuous and cascading in small river systems (Dudgeon, 2000). In such circumstances, delineating areas of conservation significance in these small rivers holds potential for protecting and restoring local ecosystems and maintaining the integrity and health of entire river basins. The umbrella-species concept, advocating that conservation strategies crafted for one species can positively impact co-occurring species, has gained prominence as a framework for conservation planning (Branton and Richardson, 2011). Faced with constraints such as limited funding, knowledge, and time for action, conservation efforts often seek efficient strategies for biodiversity maintenance. The umbrella species concept, recently attracting increased attention, proposes using species requirements as a foundation for conservation planning. This concept serves as a tool for determining the minimum size of conservation areas, selecting sites for inclusion in protected area networks, and establishing minimum standards for the composition, structure, and processes of ecosystems (Roberge and Angelstam, 2004).

The study presents an insight into the distribution and abundance of the Gangetic dolphin and utilizes its presence location to identify conservation priority stretches in the lesser-known tributaries and sub-tributaries of the GRB. In the present study, we found that the Gangetic dolphin distribution, shows a reduction in its range, especially in the peninsular rivers, with the last recorded presence noted in 1998 (Sinha et al., 2000; Sinha and Kannan, 2014). On the basis of the present study and literature, we conclude that the Gangetic dolphin may have locally extirpated from Ken, Betwa and Sind rivers (Behera et al., 2014; Sinha et al., 2000). The encounter rate and distribution of Gangetic dolphins have decreased in the Girwa, and Rapti rivers (Table 3) (Behera et al., 2014; WWF-UPFD, 2015), whereas in Mahananda River encounter rate remains unchanged (Kelkar and Dey, 2021). Gangetic dolphin sightings were more frequent in the lower sections of the rivers, particularly near the confluences (Bashir et al., 2012; Choudhary et al., 2012).

The variations in encounter rates and distribution, especially local extirpation of dolphin from Ken, Betwa and Sind rivers, may be linked to substantial river development projects that resulted in flow alteration (Sinha and Kannan, 2014). Previous surveys were mainly restricted to small stretches where dolphin sightings were common, which could have skewed the results (Das et al., 2022, Paudel et al., 2015). Further, habitat loss related to increasing water demands, creation of physical barriers (Braulik et al., 2014; Aggarwal et al., 2020; Sonkar and Gaurav, 2020; Paudel and Koprowski, 2020), deliberate killing for oil (Kolipakam et al., 2020) and mortality in the fishing gears (Kelkar et al., 2010) may have contributed to these changes. The clustered presence and frequent sightings of dolphins in the downstream sections of rivers could be linked to the presence of optimum habitat such as adequate river depth, discharge, and the presence of meandering habitats which are preferred by dolphins. Variations in the sighting frequency of

Table 2
Delineation of the Conservation Priority Stretches (CPS) in the small rivers of the Ganga River Basin, India.

River	Length (km)	Predicted length (km)	CPS1 (km)	CPS2 (km)	CPS3 (km)
Girwa	20	20	5 (0.43%)	5 (0.43%)	0
Kauriyala	20	15	10 (0.87%)	0	0
Babai	85	75	10 (0.87%)	0	0
Sharda	455	220	30 (2.61%)	25 (2.17%)	0
Rapti	510	510	175 (15.22%)	70 (6.09%)	55 (4.78%)
Bagmati	395	60	50 (4.35%)	0	5 (0.43%)
Mahananda	285	250	150 (13.04%)	10 (0.87%)	20 (1.74%)
Grand total	1685	1150	430 (37.39)	110 (9.57%)	80 (6.96%)

The abbreviations used are as follows: 'CPS1' stands for High Conservation Priority Stretches, 'CPS2' represent Moderate Conservation Priority Stretches and 'CPS3' represents Low Conservation Priority Stretches.

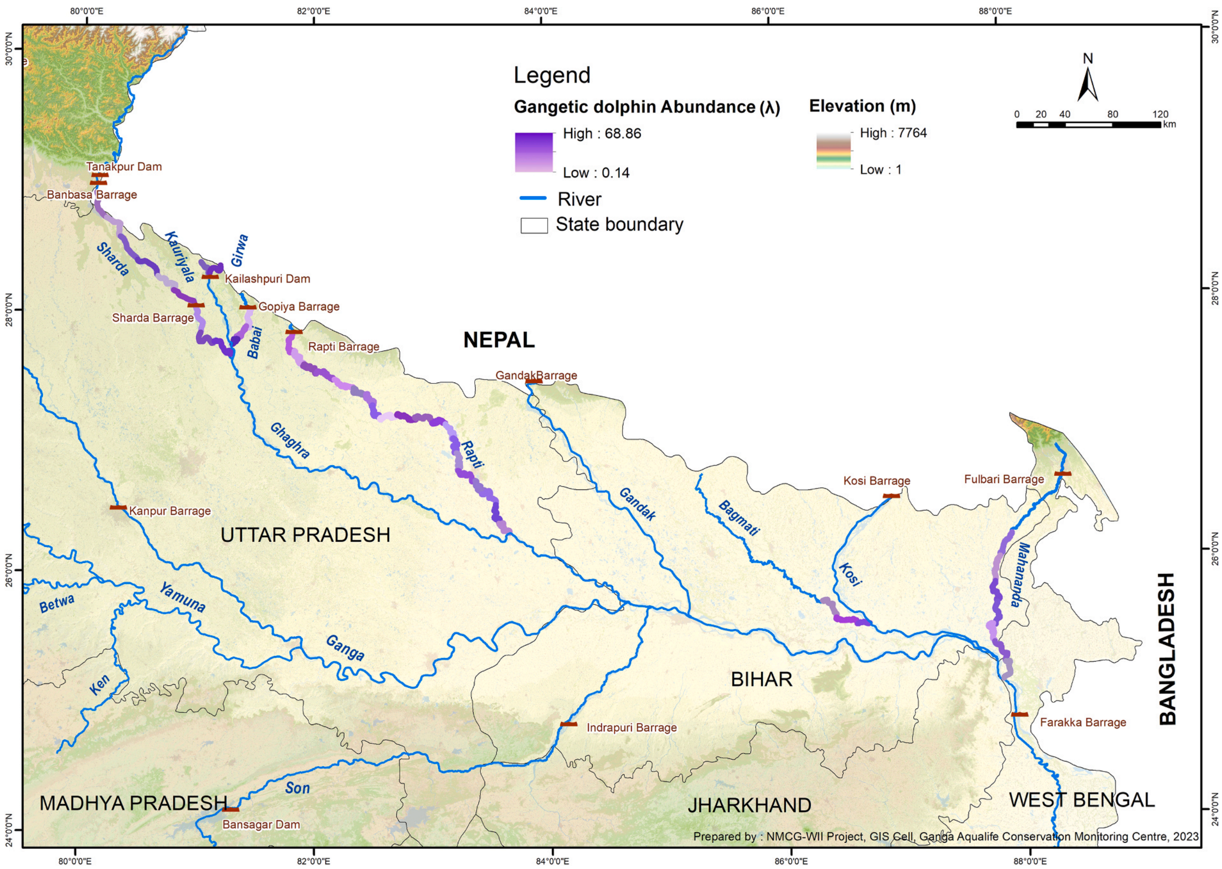

Fig. 3. Model-averaged estimates of Gangetic dolphin relative abundance (λ) (with 95% confidence intervals). Map was generated utilizing the highest-ranked model determined by AICc ranking.

Gangetic dolphin were noted along the studied stretch, with certain sections indicating an upsurge while others exhibited a decline (Behera et al., 2014; Choudhary et al., 2012; Das et al., 2022). In order to comprehend the plausible causes of these apparent increases, changes in barrage operations during the November 2022 survey may be a contributing factor. Sharda and Babai rivers, being alluvial, exhibit inherent dynamism in response to variations in water and sediment inputs during the monsoons (Midha and Mathur, 2014). During November, when there is less demand for irrigation water, the release of water from the lower Sharda Barrage located in Lakhimpur-Kheri to the main channel (Midha and Mathur, 2014) would have deepened the channel profile, potentially influencing dolphin estimates, as observed in our results. Similarly, in the Babai River, the Gopiya barrage's excessive discharge into the downstream river led to increased flows and channel depth during the survey period (Bhattarai, 2009). The river's inherent hydrological dynamics play a pivotal role in shaping the distribution of Gangetic dolphins, and alterations in hydrological processes are likely to impact dolphins spatial and temporal distribution (Braulik et al., 2014; Sonkar and Gaurav, 2020; Rai et al., 2023; Sharma et al., 2022).

The study provides a comprehensive assessment of the Gangetic dolphin populations in surveyed rivers, offering vital insights into the distribution and abundance of this iconic aquatic mammal in the region. The overall abundance estimates of the dolphin across these rivers revealed that small rivers hold 15% of dolphin population of the entire GRB (Table S8). Notably, the Mahananda and Rapti rivers contain 10% of the Gangetic dolphin population of the basin, and thus emerge as a vital dolphin stronghold. The Bagmati River also contributed significantly to dolphin population. Additionally, rivers like Kauriyala, Girwa, and Sharda displayed varying dolphin presence, underlining the need for tailored conservation strategies. Our findings highlight a significant difference in fishing intensity between the Mahananda and Babai rivers. Mahananda exhibited a higher fishing intensity at 38.64 $\pm$ 38.01 (mean $\pm$ SD) compared to Babai at 1.27 $\pm$ 1.79. Besides channel depth and the presence of meanders, fishing intensity emerges as another critical factor indicating the presence of an optimal prey base in the Mahananda River, influencing dolphin persistence.

Based on the results of the N-mixture model, channel depth and meanders emerged as significant variables influencing the relative abundance of dolphins. The average channel depth across the studied rivers was 3.03 m $\pm$ 2.71 (mean $\pm$ SD), while the Rapti and Bagmati rivers measured 3.36 m $\pm$ 2.85 and 5.25 m $\pm$ 4.37, respectively, significantly higher than the mean depth of all studied rivers. Moreover, the mean count of meanders per BEU across rivers was 1.11 $\pm$ 0.93, while the Rapti and Bagmati rivers had counts of 1.53 $\pm$ 0.95 and 0.83 $\pm$ 0.94, respectively. We would assume that this variation in depth and the presence of meanders in the Rapti and Bagmati rivers may have inflated the abundance estimates. However, during the peak dry period (March-May) when water discharge becomes limiting, fishing intensity may substantially affect dolphin persistence (Kelkar et al., 2010; Paudel and Koprowski, 2020;

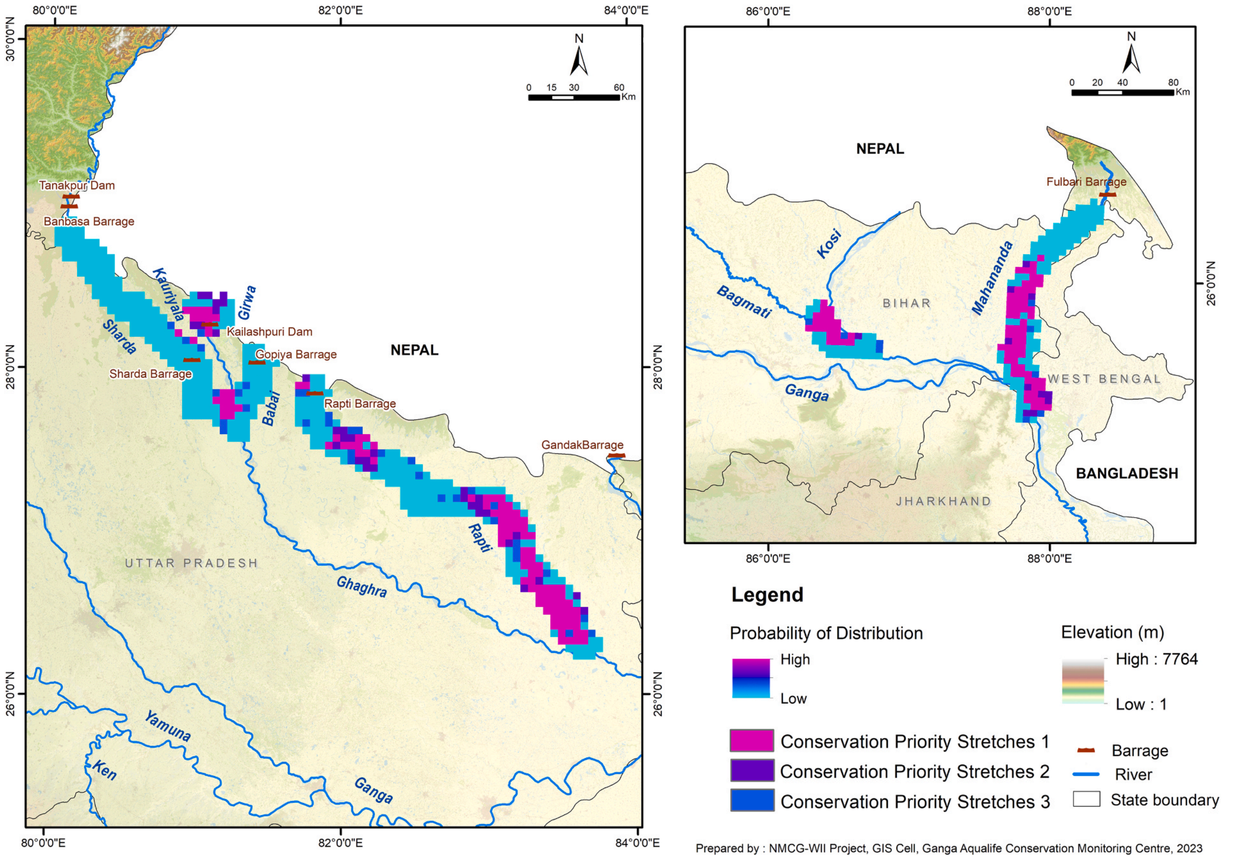

Fig. 4. Map showing Conservation Priority Stretches in the small rivers of the Ganga River Basin, India.

Samad et al., 2022).

Additionally, the lower stretch of the Bagmati River receives adequate discharge from the Kamla River and a distributary of the Kosi River to sustain dolphin population, as evident from the increasing depth as well as the high congregation of dolphins in the lower stretch of the Bagmati River. River systems exhibit inherent dynamism in response to variations in water and sediment inputs, with each element of their hydro-geomorphology playing a vital role in governing species distribution (Nestler et al., 2012). Given that the studied rivers originate from different sources and traverse through varied biogeographic regions and land-use classes are likely to influence species distribution beyond depth and width would contribute to dolphin occurrence. This is well-supported by our findings that the factor 'river' emerged as one of the contributing factors to dolphin abundance in the final model, indicating the complexity of riverine ecosystems and their influence on species distribution patterns. Our results underscore the importance of maintaining adequate dry season discharge and mitigating fishing activity in rivers such as Mahananda, Bagmati, and Rapti to sustain dolphin population and reduce competition from fishing activities. Additionally, the present study was conducted exclusively between November and February months, encompassing only the dry season. The impact of seasonal variations on the abundance of dolphins needs to be studied and considered when formulating conservation strategies. By incorporating data from different seasons, we can gain a more comprehensive understanding of the dynamics of dolphin populations and their habitats. Such consideration would offer valuable insights into formulating effective conservation strategies for Gangetic dolphins and their habitats.

The abundance estimate obtained using the N-mixture model and correction factors (D_{cf}) were comparable and hence provide support for the usability of these for abundance estimate of aquatic species. Nonetheless, the distribution and abundance of Gangetic dolphin were influenced by the availability of fish resources and the presence of deep pools in particular segments, despite the apparent uniformity in hydrological characteristics of these rivers (Bashir et al., 2010; Rai et al., 2023; Samad et al., 2022). Dolphin residing in small river stretches face heightened vulnerability due to their specific requirements within the environment, such as adequate water flow, which enables them to traverse deep pools, and hydraulic shelter to protect them from swift currents (Smith and Reeves, 2000; Smith et al., 2009). Our findings align with the observation that the predominance of Gangetic dolphins in rivers of moderate size within low-lying areas corresponds to their preference for habitats characterized by moderate annual average flow and greater depths. Although, the D_{cf} approach produced better Confidence Intervals (CIs) compared to the N-mixture models. In the absence of river-specific D_{cf} values, we utilized overall D_{cf} values derived from published literature conducted in various rivers with varying channel widths and depths. It is important to note that using an average across rivers may present a limitation, as detection rates may vary among rivers, potentially leading to biases in estimates. Therefore, we opted to apply the N-mixture model in this study,

Table 3
Past and present Encounter Rate of Gangetic dolphin in the Ganga River Basin, India.

River	River Segment	Survey length (Km)	Encounter rate	Year	Reference	Present study
						Encounter rate (SE)
Ganga	Haridwar barrage to Bijnor barrage	100	0	1996	Sinha et al. (2000)	0
	Bijnor Barrage to Narora Barrage	175	0.34	2010	Bashir et al. (2012)	0.33 ± 0.06
	Narora to Kanpur	300	0.01	2010	Behera et al. (2014)	0.05 ± 0.02
	Kanpur to Prayagraj	240	0.39	2012	Behera et al. (2014)	0.43 ± 0.09
	Prayagraj to Buxar	400	0.48	1997	Sinha et al. (2000)	1.7 ± 0.26
	Buxar to Manihari ghat	500	1.62	2006	Sinha et al. (2010a)	1.03 ± 0.14
	Manihari ghat to Farakka	90	1.64	1998	Sinha, (1999)	0.54 ± 0.12
	Farakka Feeder Canal	38.2	0.55	1996	Sinha et al. (2000)	0.06 ± 0.04
	Jangipur to Triveni Ghat	300	0.37	1995	Sinha, (1997)	0.10 ± 0.02
	Triveni ghat to Sagar Island	190	0.51	2008	Sharma, (2010)	0.38 ± 0.09*
Yamuna	Bareh-Prayagraj	400	0.07	2012	Behera et al. (2014)	0.12 ± 0.06
Chambal	Rajghat-Pachhnada	235	0.36	2012	Behera et al. (2014)	0.37 ± 0.12
Ken	Sindhan kalan village - Yamuna confluence	30	0	2012	Behera et al. (2014)	No sightings
Betwa	Orai - Yamuna confluence	84	0	2012	Behera et al. (2014)	No sightings
Sind	Yamuna confluence to 110 km upstream	110	0.04	1998	Sinha et al. (2000)	No sightings
Girwa	Pathrena-Girijapuri barrage	18	2.17	2012	Behera et al. (2014)	0.45 ± 0.17
Kauriyala	India Nepal border- Girijapuri barrage	15			NA	0.87 ± 0.47
Babai	Gopiya barrage-Ghaghra confluence	75			NA	0.05 ± 0.04
Sharda	Sharda barrage-Palia	100	0	2001	Sinha and Sharma, (2003b)	0.03 ± 0.02
Ghaghra	Girijapuri barrage-Chhapra	630	0.52	2012	Behera et al. (2014)	0.54 ± 0.08
Rapti	Ghaghara confluence to 30 km upstream	30	0.26	2012	Behera et al. (2014)	0.18 ± 0.04
Son	Bichhi-Doriganj	130	0.08	1998	Sinha et al. (2000)	No sightings
Gandak	Valmiki Nagar-Ganga confluence	295	0.77	2010	Choudhary et al. (2012)	0.36 ± 0.05
Bagmati	Jagmohra- Badlaghat				NA	1.13 ± 0.24
Kosi	Kosi Barrage-Kursela	235	0.42	2001	Sinha and Sharma, (2003)	0.76 ± 0.13
Mahananda	Balubari ghat- Jankiramtala	250	0.76	2021	Kelkar and Dey, (2021)	0.73 ± 0.1
Rupnarayan	Bander-Gadiara	80	0.42	2006	WWF Nepal, (2006)	0.68 ± 0.17

as it considers imperfect detection and allows for the straightforward identification of explanatory variables affecting abundance (λ) and detection (p). Additionally, it provides independent estimates for each site, which are comparable to the D_{cf} approach derived from capture-mark-recapture methods (Courtois et al., 2016; Ficetola et al., 2018; Royle, 2004). Despite other sampling methods being available, such as capture–recapture and distance sampling, the minimal data collection effort and cost-effectiveness of the N-mixture model make it a preferred choice for the present study (Dennis et al., 2015).

These lesser-known rivers are home to more than 15% of the Gangetic dolphin population, supporting previous findings that these small rivers function as refuges for macrofauna, support habitat diversity and species assemblage (Bouska et al., 2023; Pracheil et al., 2013). This proffers the importance of protecting these rivers for biodiversity conservation and functioning of the ecological processes. Furthermore, the species distribution model provided valuable insights into the distribution of dolphins across the Ganga Basin. Bioclimatic, hydrological and human-induced stressors emerged as significant determinants of Gangetic dolphin distribution. The predicted probability distribution encompassed a substantial stretch of 1150 km, representing both historical and current ranges of the species. Notably, approximately 54% (620 km) of the river stretches, accounting for 22% of the priority stretches in the Ganga Basin, were deemed suitable for dolphins, underscoring the significance of these stretches for dolphin persistence (Table S9). Bioclimatic variables that significantly influence the distribution of Gangetic dolphins, such as Annual Mean Temperature, Isothermality, and Temperature Seasonality, were found to play pivotal roles. This underscores the importance of considering climatic factors in understanding the habitat preferences and distribution patterns of the species, particularly during water-scarce periods. Interestingly, similar to the findings of previous studies (Choudhury et al., 2019; Sinha and Kannan, 2014), we also observed a high suitability near the confluence areas. Tributary confluences are significant, not just due to their ability to modify environmental conditions and trigger a biological response upon merging with the main channel (Benda et al., 2004; Fernandes et al., 2004; Rice et al., 2008), but they also represent areas of inherent ecological importance, concentrating specific biophysical processes and ecosystem services (Kiffney et al., 2006; Rice et al., 2008). The high suitability of the confluence areas underscores the significance of these regions in the conservation of the Gangetic dolphin. (Choudhary et al., 2012; Das et al., 2022; Kelkar, 2008). The suitability, translated into potential conservation priority stretches, represents a valuable resource for managers and policymakers, by allowing for concentrated efforts aimed at preserving the biodiversity and ecological integrity of the riverine ecosystem.

Identification of the priority river stretches is one of the most important tenets of the systematic conservation planning, which is followed by monitoring of spatial and temporal biodiversity changes, implementing stringent measures to reduce pollution, enforcing sustainable fisheries management practices, implementing measures to safeguard and restore riverine habitats, engaging local communities and stakeholders participation, awareness programs to enhance understanding about the importance of biodiversity conservation, consideration of socio-economic aspects and potential conflicts between conservation goals and human activities and ensuring alignment with existing conservation laws and policies, along with implementation of new protective measures (Hermoso et al., 2012; Bond et al., 2014; Linke et al., 2019). Addressing these points makes systematic conservation planning a more effective and inclusive process, contributing significantly to the long-term protection of biodiversity and ecosystems. Conservation prioritization of the rivers in the GRB will aid in allocating resources and efforts where they are most needed and where they will have the greatest impact. Such an approach will ensure that conservation efforts are efficient and targeted, addressing the most critical areas first and gradually extending protection to other priority stretches as resources permit. Overall, our approach focuses on preserving the integrity of the priority stretches, as was also recommended in our prior study (Das et al., 2022), which will contribute to the overarching goal of a basin-wide conservation strategy.

5. Conclusions

In the Indian context, the riverine species particularly crocodylians started getting attention in early-1970s (Sharma et al., 2021). However, the conservation of riverscapes and other aquatic species received little attention. The previous efforts to document the aquatic species were limited to the globally known larger rivers such as Ganga, Brahmaputra, and Indus (Dudgeon, 2000). The flagship initiative, 'National Mission for Clean Ganga' by the Ministry of Jal Shakti, Government of India, represents a pioneering effort to develop an integrated basin-wide river restoration strategy through maintaining river habitat and aquatic biodiversity. Yet, the lesser-known smaller rivers, despite their key role in the ecological process received no or very little attention (Richter et al., 1997). The present study provides evidence of smaller rivers as refuges for Gangetic dolphin, thereby supporting the theory that these smaller rivers contributing to the resilience of larger rivers. This contribution is apparent through the presence of a habitat mosaic, diverse species assemblages, and the provision of freshwater inputs. The findings are crucial as a baseline for India's ongoing range-wide population estimation exercise in India and serve as a precedent for future assessments and studies in the region. The establishment of this baseline for the Kauriyala, Babai, and Bagmati rivers sets a precedent. It encourages further research, monitoring efforts, and proactive conservation initiatives in coordination with the State Department of Environment, Forests, and Climate Change and the National Mission for Clean Ganga (NMCG) to safeguard the river's biodiversity, in line with the systematic conservation planning. Community support needs to be harnessed to ensure successful conservation, especially in areas where dolphins are frequently encountered near villages. Linking local concerns about flood erosion, embankments, and livelihood security to biodiversity conservation programs can be a strategic approach to engage and garner support for river conservation efforts.

CRediT authorship contribution statement

Goura Chandra Das: Writing – review & editing, Writing – original draft, Visualization, Software, Methodology, Formal analysis, Data curation. **Aftab Alam Usmani**: Data Curation. **Surya PrasadSharma**: Writing – review & editing, Writing – original draft, Visualization, Software, Methodology, Formal analysis. **Srijani Guha**: Visualization. **Sk Zeeshan Ali**: Visualization. **Shivani Barthwal**: Supervision, Writing – review & editing. **Arkojyoti Sarkar**: Data Curation. **Neeraj Mahar**: DataCuration. **Ajay Rawat**: Data Curation. **Gokulakrishnan. G**: Data Curation. **Javed Anwar**: Data curation. **Sandeep Kumar Behera**: Writing – review & editing, Supervision. **Ruchi Badola**: Writing – review & editing, Supervision, Project administration, Funding acquisition, Conceptualization. **Syed Ainul Hussain**: Writing – review & editing, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

Data will be made available on request.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.gecco.2024.e02900.

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