Factors influencing the habitat selection of the vulnerable Mugger crocodile (*Crocodylus palustris*) and its conservation threats in the Rapti River of Chitwan National Park, Nepal.

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ABSTRACT

Muggers have a sympatric distribution with gharials in the Rapti and Narayani River of Chitwan National Park, but more research and conservation attention has been focused on gharials in Nepal. The inadequate availability of information on the occupied habitats of muggers restrict their evidence-based conservation and management. Therefore, we investigated the ecological factors affecting the habitat selection of muggers and its conservation threats in the Rapti River. We conducted a preliminary survey, followed by a detailed habitat survey, conducted in February and March 2022. During the detailed habitat survey, the pre-defined habitat characteristics were recorded at each station spaced at 500 m intervals along the river as well as the locations where muggers were sighted. We used a generalized linear model (glm) under the binomial family with a logit link function to analyze the factors influencing the habitat selection of muggers. The dependent variable was the presence or absence of muggers at sampling points and the independent variables included: river bank aspect, river width, mid-river depth, river bank substrate type, river bank slope, water current, invasive alien plant species, and anthropogenic disturbances. In addition, a relative whole-site ranking method was employed to determine the most prevalent threats to the mugger. During the survey period, we recorded a total of 46 mugger individuals, 74% were observed basking and 26% were observed submerged in the river. The highest percentage of muggers (39.1%) was observed on the sandy river bank, followed by the grass and forest bank (19.5%), and clay and sandy bank (15.1%), respectively. Only the river banks with moderate (15–25°) and moderately steep (25–35°) slopes were found to be the significant factors influencing the occurrence of muggers. Fishing and extraction of river materials, and disposal of garbage and solid waste were ranked as the most prevalent conservation threats. For the long-term conservation of muggers in the Rapti River, effective habitat management plans and strategies are required to control illegal anthropogenic activities such as fishing, sand mining, and boulder quarrying.

***Keywords**:* Anthropogenic threats, Generalized linear model, Habitat, Sampling points, Sympatric

1. INTRODUCTION

Two species of crocodylians are native to Nepal, namely: the mugger (*Crocodylus palustris*) and the gharial (*Gavialis gangeticus*), out of 24 extant species in the world (Da Silva and Lenin, 2010; Stevenson and Whitaker, 2010; Lamichhane et al., 2022). In Nepal, studies on muggers are very limited and are focused on only a few aspects of their biology and ecology including: population status and distribution (Goit and Basnet, 2011; Bhatt et al., 2012; Khadka et al., 2014; Rajbhandari and Acharya, 2014; Rajbhandari and Acharya, 2016; Khadka and Acharya, 2019; Khadka and Lamichhane, 2022); predatory behavior (Bhattarai, 2015); and, habitat selection (Lamichhane et al., 2022; Bhattarai et al., 2022). There is still limited information on the various environmental and anthropogenic factors that influence mugger habitat selection in Nepal. Past studies that were undertaken in CNP are primarily focused on the population and distributional status of muggers (Khadka et al., 2014; Rajbhandari and Acharya, 2016; Khadka and Acharya, 2019).

Understanding the influence of environmental and anthropogenic factors on the occurrence of threatened species is critical for the effective implementation of both management and conservation measures (Klaassen and Broekhuis, 2018; Pérez-Jorge et al., 2020). We aim to generate baseline data on the important environmental and anthropogenic factors influencing mugger-habitat selection in the Rapti River of the CNP. Furthermore, we aim to identify and analyze the different threat factors to the mugger population. Our findings will help inform conservation authorities to develop the site-based action plans and management strategies, as well as to minimize the prevalent threats to their habitats in the study area.

2. MATERIALS AND METHODS

2.1 Study Area

The study was undertaken in the Rapti River of the CNP. The CNP, Nepal's first National Park established in 1973- is located in the southern part of central Nepal, currently covering an area of 953 sq.km. The park was declared a UNESCO World Heritage Site in 1984 (UNESCO, 2016). The park encompasses a major vegetation cover of deciduous sal (*Shorea robusta*) forest (70%), followed by grassland (10%), riverine forest (7%), mixed forest (7%), and wetlands (4%) (Paudel et al., 2022). The local inhabitant's livelihood is primarily supported by agriculture, livestock

farming and fishing. The current survey was conducted along the 52 km river stretch from Jindagani Ghat (the eastern side) to Golaghat (Rapti-Narayani confluence, the western side; Fig. 1).

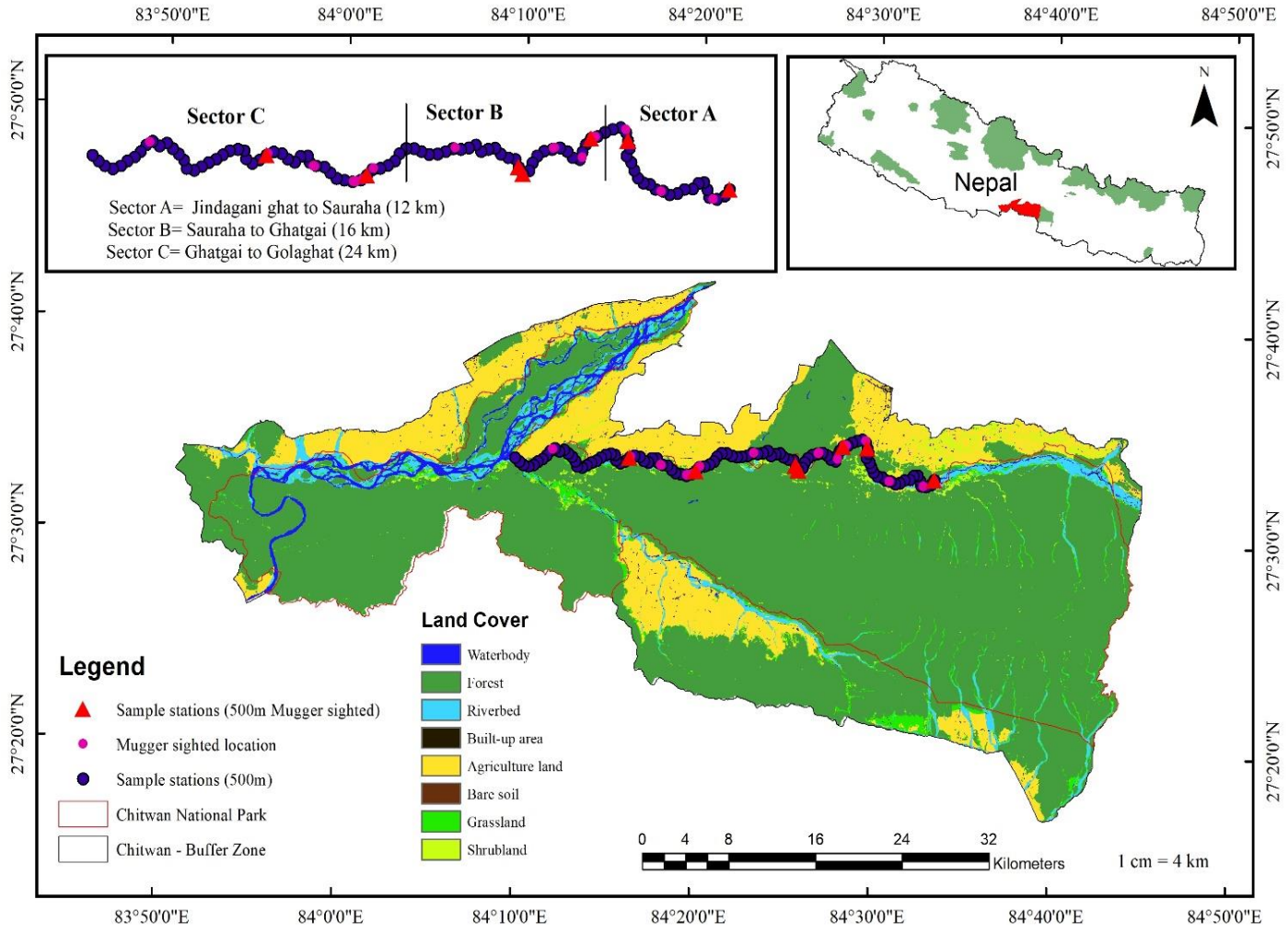


Figure 1: Map of the Chitwan National Park showing the Rapti River along the northern park border, along with sampling stations and sighting locations.

2.2 Sampling design and data collection

The entire survey included a preliminary analysis followed by a detailed habitat survey, conducted during the post-winter months (low water season) between February and March, 2022.

2.2.1 Preliminary survey

Preliminary surveys were conducted for ten days in two phases during February, 2022. In the first phase, we conducted in-depth informal interviews with officials of CNP and National Trust for Nature Conservation (NTNC)- Biodiversity Conservation Center (BCC) personnel who were familiar with the Rapti River. These interviews helped us get an overview of the current distribution of muggers within the different segments of the river and insights into the conservation threats to the mugger. Later, the conservation threats identified through these key informant interviews and direct field observation were used to analyze and rank the threats to muggers. Apart from the key informant interviews, we also conducted a few informal discussions with river-dependent communities along the Rapti River. Similarly, in the second phase, we digitized the mid-channel route of the Rapti river using Google Earth Pro (Version: 7.3.4. 8642). We extracted the downstream mid-channel route, covering a total length of 52 km of the Rapti River (Table 1) where the distribution of muggers has been reported to occur (Khadka et al., 2014; Khadka and Acharya, 2019).

Table 1: Name and length(km) of the three divided sectors of Rapti River of Chitwan National Park

Sector	Sector name	Length (km)
A	Jindagani ghat to Sauraha	12
B	Sauraha to Ghatgai	16
C	Ghatgai to Golaghat (Rapti-Narayani confluence)	24
	Total length of all sectors	52

Using traditional dugout canoes, we surveyed each sector once to understand the river characteristics, to estimate mugger populations, and to collect the essential data such as river bank substrate types, invasive alien plant species, and anthropogenic threat types, which aided us in survey design and planning for the detailed habitat survey.

2.2.2 Major field survey and recording the habitat characteristics

A detailed habitat survey was carried out during March, 2022 for three consecutive days. We generated sampling stations spaced at 500m intervals using ArcGIS 10.8. (ESRI, 2020) by assuming that the habitat characteristics would differ at the intervals of 500 m and there would be a lower probability of basking muggers moving across the subsequent stations during the survey.

We did not focus on repetitive habitat surveys because our aim was not to estimate the population size of muggers but rather the probability of their occurrences with respect to different habitat parameters. Habitat types were assessed on both the left and right banks of the river at each sampling station and at each mugger sighting location. The survey was conducted during the daytime from 9:00 to 16:00 hr. The dugout canoes travelled downstream at a constant speed of 3-4 km per hour. Muggers were observed using binoculars (Vortex optics 8 × 42). The total length of each sighted mugger was estimated visually and categorized into five broad size classes as hatchlings <30 cm, yearlings 30-50 cm, juveniles 50-125 cm, sub-adult 125-180 cm, adult >180 cm (Khadka et al., 2014). Based on preliminary survey and available literature (Neupane et al., 2020; Than et al., 2020; Lamichhane et al., 2022; Bhattarai et al., 2022), eight pre-defined habitat characteristics were identified as potentially influencing mugger occurrences; and those selected variables included: river bank aspect (right or left); mid-river depth; river width; water current; river bank substrate type; river bank slope; invasive alien plant species; and anthropogenic disturbance. Similarly, we recorded the various invasive alien plant species and anthropogenic disturbances that occurred on any river bank within the study site. These noted threats, along with those noted in each sampling station and sighting location, were used in the analysis of conservation threats.

Table 2: Number of sampling stations, sighting location and sighting points during detailed habitat survey.

Description	Number
Stations	104
Sampling points on stations (both river bank)	208
Mugger sighted locations in between the stations	21
Sampling points on mugger sighted locations (both river bank)	42
Total number of sampling points to record the habitat characteristics	250
Number of stations were mugger were sighted	7

2.3 Data Analysis

2.3.1 Factors influencing habitat selection by muggers

A generalized linear model (Hastie and Pregibon, 1992) was used to examine the factors influencing the occurrence of muggers at each selected site. We used the presence/absence (1 =

presence and 0 = absence) of muggers at sampling stations and sighting locations as dependent (response) variables. Similarly, eight habitat characteristics (river bank aspect, mid-river depth, river width, water current, river bank substrate type, river bank slope, invasive alien plant species, and anthropogenic disturbance) were used as independent (predictor) variables.

We ran the full model logistic regression analysis containing all of the independent variables under the binomial family with the logit link function. We developed models with all possible subsets of potential predictors using the R package 'MuMIn' (Barton and Barton, 2015). The models were ranked using the Akaike information criterion (AIC), and adjusted Akaike information criterion for small sample sizes (AICc), as suggested by Burnham and Anderson (2002). We conducted model averaging (models with $\Delta AIC \leq 2$) to generate model-averaged coefficients (Estimate, Std. Error, z value, and (Pr (>|z|)) for each independent variable. The predictive ability of each component model (models with $\Delta AIC \leq 2$) was quantified based on the Area Under Curve (AUC) of the Receiver Operator Characteristics (value range 1 to 0) by using the R package 'ROCR' (Sing et al., 2005). Those AUCs of the Receiver Operator Characteristic values between 0.7– 0.8 are considered acceptable discrimination, 0.8–0.9 are considered excellent, and more than 0.9 are considered superior (Hosmer and Lemeshow, 2000). If the p-value (Pr (>|z|)) is less than 0.05 (at 5% of significance level), then this indicated that the predictors (independent variable) had a statistically significant association with the response variable in the model. All the analyses were completed using R studio 2022.07.1+554 (R Core Team, 2022).

2.3.2 Threat Analysis

The three classification criteria were allocated to each of the top eight threats, and the numeric value was ranked with the highest value equal to the number of total identified threats. From our study site, we identified the eight different major threat types to muggers, with ranking values ranging from 1 to 8. The largest ranking value (8) indicates the highest threat with severe effects to the mugger population for the scope, severity, and urgency criteria, while the smallest ranking value (1) indicates the lowest threat with minimal effects. Later, the ranking values of scope, severity, and urgency criteria were summed up for each threat to classify threats into four-point scale of very high, high, medium, and low. To summarize, the total values of scope, severity, and urgency were used to rank the threats on a four-point scale: very high (20–24); high (15–19); medium (10–14); and low (>10).

Table 3: The Relative Whole-Site Threat Ranking method under scope, severity, and urgency criteria.

Threat classification criteria	Description
Scope	The proportion of the target population that can expected to be affected by the threat within ten years, such that the current circumstances and trends continue
Severity	Within the scope, the damage level to the target population from the threat that can be expected reasonably within ten years, such that the current circumstances and trends continue.
Urgency	The seriousness of taking immediate action to address the threat to sustain the healthy population of target species for a long-term.

3. RESULTS

3.1 Observed number of muggers and its activity

At the study site, a total of forty-six muggers were recorded of different sizes with an encounter rate of 0.88 mugger individuals per km (Table 4).

Table 4: Sighted number of muggers in different sectors of the study area with its size classes and observed activity.

Sector	Total sighted muggers	Size classes and observed activity of mugger
A: (Jindagani ghat to Sauraha)	8	1 adults (basking); 4 sub-adults (all basking); 2 juveniles (1 basking. 1 submerged); and 1 undetermined (submerged).
B: (Sauraha to Ghatgai)	16	8 adults (6 basking, 1 basking with mouth-gaping, 1 submerged); 5 sub-adults (3 basking, 2 submerged); 2 juveniles (all submerged); 1 yearling (swimming).
C: (Ghatgai to Golaghat)	22	10 adults (9 basking, 1 basking with mouth-gaping); 7 sub-adults (5 basking, 2 submerged); 5 juveniles (3 basking, 2 submerged).

3.2 Habitat characteristics associated with observed muggers.

Table 5: Habitat characteristics, number and percentage of observed mugger individuals

Habitat characteristics	Number of observed individuals (N)	Percentage (%)
River bank aspect (RBA)		
South (left)	31	67.3
North (right	15	32.7
River width (RW)		
<50m	8	17.3
50.01m-100m	19	41.3
100.01m-150m	17	37
150.01m-200m	1	2.2
200.01m-250m	1	2.2
Mid-river depth (MRD)		
<0.5m	0	0.0
0.51m-1m	6	13
1.01m-1.5m	21	45.7
1.51m-2m	18	39.1
2.01m-2.5m	1	2.2
River bank substrate type (RBST)		
Sandy bank	18	39.1
Grass and forest bank	9	19.5
Gravel bank	2	4.4
Clay and grassy bank	2	4.4
Gravel and grassy bank	1	2.2
Sand and grassy bank	2	4.4
Sand and gravel bank	1	2.2
Clay and sandy bank	7	15.1
Grassy bank	4	8.7
River bank slope (RBS)		

Gentle	15	32.6
Moderate	20	43.5
Moderately steep	6	13.0
Steep	4	8.7
Very steep	1	2.2
Water current (WC)		
Slow	44	95.6
Fast	2	4.4
Invasive alien plant species (IAPs)		
Present	6	13
Absent	40	87
Anthropogenic disturbances (AD)		
Present	9	19.5
Absent	37	80.5

3.3 Influencing variables and probability of mugger occurrence.

A total of 256 models (smallest AICc: 146.24, largest AICc: 186.40) containing all possible subsets of potential predictors were developed. Among the sixteen different component models developed through model averaging (Table 6) (models with $\Delta AIC \leq 2$), the best fitted model (AICc =146.24, Akaike model weight =0.041, AUC value =0.82) which included river bank slope, mid-river depth, and water current, was followed by the competing model (AICc =146.50, Akaike model weight =0.036, AUC value =0.84) which also included river bank slope, mid-river depth, water current, as well as river bank aspect. The model-averaged coefficients (Table 7) revealed only the river bank slope (with moderate and moderately steep slope) as a significant predictor influencing the occurrence of the muggers out of the eight different predictors examined in this study. The probability of mugger occurrence significantly increased on the river banks with moderate slopes (15–25°), followed by the river banks with moderately steep slopes (25–35°).

Table 6: Component models (models with ΔAIC ≤ 2) describing the different variables influencing the occurrence of mugger crocodiles at the selected site (Jindagani ghat to Golaghat) of Rapti River of Chitwan National Park during March, 2022 and ranked using the Akaike information criterion (AIC), adjusted for small sample sizes (AICs). Model parameters includes river bank slope, mid-river depth, river width, river bank substrate type, water current and anthropogenic disturbance in its abbreviation (as illustrated in Table 5).

S.N.	Models	K[a]	AICc[b]	Δ AICc[c]	logLik[d]	Wi[e]	AUC value[f]
1	RBS+ MRD+ WC	4	146.24	0.00	-65.89	0.041	0.82
2	RBS+ MRD+ RBA+ WC	5	146.50	0.24	-64.94	0.036	0.84
3	RBS + MRD	3	146.60	0.37	-67.13	0.034	0.80
4	RBS + MRD+ RBA	4	146.77	0.54	-66.16	0.031	0.82
5	RBS + RBST	3	146.85	0.61	-59.65	0.030	0.84
6	RBS + MRD + RW	4	147.06	0.83	-66.30	0.027	0.82
7	RBS + MRD+ RBST	4	147.21	0.98	-58.71	0.025	0.86
8	RBS + MRD+ RW+ WC	5	147.25	1.02	-65.33	0.024	0.83
9	RBS + MRD+ RBA+ RW	5	147.30	1.06	-65.35	0.024	0.83
10	RBS + RBST+ WC	4	147.30	1.06	-58.76	0.024	0.86
11	RBS + MRD+ RBA+ RW + WC	6	147.55	1.32	-64.40	0.021	0.84
12	RBS + RBA+ WC	4	147.72	1.48	-66.63	0.019	0.83
13	RBS+ WC	3	147.89	1.65	-67.77	0.017	0.81
14	RBS + MRD+ RBST+ WC	5	147.90	1.66	-57.92	0.017	0.86
15	RBS + RBA+ RBST	4	148.12	1.89	-59.17	0.015	0.85
16	AD+ RBS + MRD + WC	5	148.14	1.91	-65.77	0.015	0.83

[a] Number of parameters including dependent (response) variable.

[b] Akaike's Information criterion for small sample sizes.

[c] Difference between the AICc value of the best-supported model and successive models.

[d] Model fitted by maximum likelihood.

[e] Akaike model weight

[f] The Area Under Curve (AUC) of the Receiver Operator Characteristics (value range 1 to 0). Values between 0.7– 0.8 considered acceptable discrimination, 0.8–0.9 is considered excellent, and more than 0.9 is considered superior (Hosmer and Lemeshow, 2000).

Table 7: Model-averaged coefficients describing the occurrence of mugger at the selected site (Jindagani Ghat to Golaghat) of Rapti River of Chitwan National Park, which was surveyed during March, 2022. The significant variables influencing the mugger occurrence (Pr (>|z|) <0.05) are in bold.

	Estimate	SE[a]	Z value	Pr (>|z|)[b]	Odd ratio
(Intercept)	-4.080	1.308	3.106	0.0019**	0.016
RBS (moderate)	3.057	0.610	4.983	0.000 ***	21.263
RBS (moderately steep)	1.441	0.670	2.137	0.0326*	4.224
RBS (steep)	-0.222	0.852	0.260	0.7950	0.800
RBS (very steep)	-0.605	1.129	0.533	0.5938	0.546
MRD	0.673	0.599	1.121	0.2624	1.960
WC (low)	0.604	0.830	0.726	0.4679	1.829
RBA (right)	-0.237	0.430	0.550	0.5825	0.788
RBST (clay and sandy bank)	0.322	0.922	0.349	0.7274	1.379
RBST (grassy bank)	-0.300	0.995	0.301	0.7636	0.740
RBST (grass and forest bank)	0.314	0.875	0.358	0.7202	1.368
RBST (gravel bank)	-0.181	0.823	0.219	0.8268	0.834
RBST (gravel and grass bank)	0.090	0.936	0.096	0.9234	1.094
RBST (sandy bank)	0.355	0.893	0.396	0.6919	1.426
RBST (sand and grassy bank)	-0.318	0.915	0.347	0.7288	0.727
RBST (sand and gravel bank)	-0.168	0.903	0.186	0.8528	0.845
RW	-0.001	0.004	0.393	0.6943	0.999
AD (present)	-0.010	0.127	0.084	0.9331	0.990

[a] Standard error

[b] Significance codes: 0 '***' 0.001 '**' 0.01 '*'

3.4 Conservation threats

According to the relative whole-site threat ranking method, we classified each of the eight direct threats identified during our survey as very high, high, medium, or low (Table 8).

Table 8: The Relative Whole-Site Threat Ranking results from eight different direct threats identified within the selected site (Jindagani Ghat to Golaghat) of Rapti River of Chitwan National Park, which was surveyed during February (key-informant survey) and March, 2022 (field observation).

S.N.	Direct threats	Description	Scope	Severity	Urgency	Total	Classification
1	Tourism and recreation areas	Hotels, lodge, resorts, and view towers.	6	5	6	17	High
2	Housing and urban areas	Human settlements, bridge, and army posts.	2	3	1	6	Low
3	Fishing and extraction of river materials	Fishing, extraction of boulders, gravel and sand.	7	7	7	21	Very high
4	Recreational activities	Elephant safari, boating, and jeep safari.	3	1	2	6	Low
5	Work and other activities	Grass cutting, livestock grazing, washing, and swimming.	1	2	4	7	Low
6	Gabion wall dyke	Gabion retaining walls for water management	4	6	3	13	Medium
7	Invasive alien plant species	Water lettuce (*Pistia stratiotes*) and water hyacinth (*Eichhornia crassipes*)	8	4	5	17	High
8	Disposal of garbage and solid waste	Plastic pollution.	5	8	8	21	Very high

4. CONCLUSION

The study recorded a total of forty-six mugger individuals in the Rapti River of CNP. Out of eight habitat variables analyzed in our study, the probability of muggers occurring was significant only

with respect to river bank with moderate and moderately steep slopes. Other habitat variables that include mid-river depth, river width, river bank aspect, river bank substrate type, water current, invasive alien species, and anthropogenic disturbances were found to be insignificant for the occurrence of muggers at our study sites. Fishing and extracting river materials, and disposal of garbage and solid waste, were ranked as the most severe conservation threats to the muggers in the Rapti River.

5. RECOMMENDATION

i) A win-win conservation situation between vulnerable muggers and the local community is deemed necessary for the viable and long-term conservation of muggers in the Rapti River. The conservation authorities of Chitwan National Park should prioritize integrating local communities into effective conservation and management programs with economic incentives.

ii) The study recommends the conservation authorities of CNP to effectively control the illegal fishing and sand mining activities and restore the degraded river banks of the Rapti River.

iii) The research on spatio-temporal partitioning between mugger and gharials is recommended to understand how resources are shared by the species and how they select their nesting and basking sites (Choudhary et al., 2018).

PHOTO PLATES





C



D



E



F







***Photo description*:**

A: Basking adult mugger with mouth-gaping behavior.
B: Research team recording the habitat parameters.
C: Mugger basking in the sloppy river bank area with its head submerged inside the water.
D: Researcher scanning the mugger from long distance.
E: Key informant interview with officials.
F: Gill nets left inside the river while illegal fishing and one of our survey members was taking out of it.
G: Loaded tractors- with gravel, boulders and sand.
H: Adult mugger submerged inside the water.

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