HABITAT USE BY GHARIAL AND MUGGER CROCODILE IN RAPTI RIVER, CHITWAN NATIONAL PARK, NEPAL

Srijana Gurung

T.U. Registration no.: - 5-3-28-254-2019

T.U. Examination Roll no. - 853/076

Batch: 2076

A thesis submitted

In the partial fulfilment of the requirements for the award of the degree of Master of Science in Zoology with a special paper Ecology and Environment

Submitted To:

Central Department of Zoology

Institute of Science and Technology

Tribhuvan University, Kirtipur

Kathmandu, Nepal

May 2023

DECLARATION

I hereby declare that the work presented in this thesis has been done by myself and has not been submitted elsewhere for the award of any degree. All sources of information have been specifically acknowledged by reference to the author(s) or institution(s).

Date 14th May 2023

.....

Srijana Gurung

Batch: 2076

Roll no: 853/076

त्रिभुवन विश्वविद्यालय
TRIBHUVAN UNIVERSITY
प्राणी शास्त्र केन्द्रीय विभाग
CENTRAL DEPARTMENT OF ZOOLOGY
कीर्तिपुर, काठमाडौं, नेपाल ।
Kirtipur, Kathmandu, Nepal.
01-4331896
Email: info@cdztu.edu.np
URL: www.cdztu.edu.np

पत्र संख्या :-

Central Department of Zoology, Kirtipur

RECOMMENDATION

This is to recommend that the thesis entitled **"Habitat Use by Gharial and Mugger Crocodile in Rapti River, Chitwan National Park, Nepal"** has been carried out by Miss Srijana Gurung for the partial fulfilment Master's Degree of Science in Zoology with special paper Ecology and Environment. This is her original work and has been carried out under my supervision. To the best of my knowledge, this thesis work has not been submitted for any other degree in any institution.

Date.....14th May 2023

B.P.Bhattarai

Supervisor

Asst. Prof. Bishnu Prasad Bhattarai, PhD

Central Department of Zoology

Tribhuvan University

Kirtipur, Kathmandu, Nepal

त्रिभुवन विश्वविद्यालय
TRIBHUVAN UNIVERSITY
प्राणी शास्त्र केन्द्रीय विभाग
CENTRAL DEPARTMENT OF ZOOLOGY
कीर्तिपुर, काठमाडौं, नेपाल ।
Kirtipur, Kathmandu, Nepal.
☎ ०१-४३३१८९६
01-4331896
Email: info@cdztu.edu.np
URL: www.cdztu.edu.np

पत्र संख्या :-

Central Department of Zoology T.U. Kirtipur

LETTER OF APPROVAL

On the recommendation of supervisor **Assistant Professor** Bishnu Prasad Bhattarai, **Central Department of Zoology, Tribhuvan University,** this thesis submitted by Miss Srijana Gurung entitled **"Habitat Use by Gharial and Mugger Crocodile in Rapti River, Chitwan National Park, Nepal"** is approved for the examination and submitted to the Tribhuvan University in partial fulfilment of the requirements for Master's Degree of Science in Zoology with special paper Ecology and Environment.

Date 14th May 2023

.....

Prof. Kumar Sapkota, PhD
Head of Department
Central Department of Zoology
Tribhuvan University
Kirtipur, Kathmandu, Nepal

TRIBHUVAN UNIVERSITY
प्राणी शास्त्र केन्द्रीय विभाग
CENTRAL DEPARTMENT OF ZOOLOGY
कीर्तिपुर, काठमाडौं, नेपाल ।
Kirtipur, Kathmandu, Nepal.
Email: info@cdztu.edu.np
URL: www.cdztu.edu.np

पत्र संख्या :-

CERTIFICATE OF ACCEPTANCE

This thesis work submitted by Miss Srijana Gurung entitled **"HABITAT USE BY GHARIAL AND MUGGER CROCODILE IN RAPTI RIVER, CHITWAN NATIONAL PARK, NEPAL"** has been accepted as a partial fulfillment for the requirement of Master's Degree of Science in Zoology with special paper Ecology and Environment.

EVALUATION COMMITTEE

.....

Supervisor

Asst. Prof. Bishnu Prasad Bhattarai, PhD

Central Department of Zoology

T.U., Kirtipur, Nepal

.....

Head of Department

Prof. Kumar Sapkota, PhD

Central Department of Zoology

T.U., Kirtipur, Nepal

.....

External Examiner

Asst. Prof. Ramesh Prasad Sapkota, PhD

Central Department of Environment Science

Tribhuvan University

.....

Internal Examiner

Prof. Tej Bahadur Thapa, PhD

Central Department of Zoology

Tribhuvan University

Date of Examination: 28 May 2023

ACKNOWLEDGEMENTS

I would like to express my immense appreciation to Prof. Kumar Sapkota, the Head of the Central Department of Zoology, for offering me invaluable academic assistance in completing this thesis. Additionally, I extend my gratitude to all my esteemed instructors and the administrative staff at the Central Department of Zoology for their unwavering support and assistance in any capacity possible.

Once again, I would like to express my sincere gratitude to my respected supervisor, Dr. Bishnu Prasad Bhattarai, for his unwavering supervision, guidance, and invaluable suggestions. This work would not have been possible without his constant support and assistance. I would also like to thank DNPWC/CNP, and the people of the local community for their kind cooperation during the study. I would like to thank all the officials' personnel from Sauraha and Kasara for their generous help. I would also like to thank Mr. Prem Sharma, keeper of Gharial Breeding Center for his valuable suggestion and knowledgeable information.

I would like to extend my heartfelt gratitude to Mr. Suraj Baral for his continuous help and direction in carrying out field surveys and guidance for field surveys. Once again, I want to express my appreciation to my friend Mamata Thapa for her constant assistance and support. I would also like to give special thanks to Mr. Jaganath Adhikari for supplying the necessary equipment during the field survey.

Last but not least, I am very much grateful to my family who provided encouragement and inspiration during the difficult part of my study. I appreciate everyone whom I have missed to remember and have contributed intentionally and unintentionally towards the completion of the work, and also all those who are my well-wishers.

LIST OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AUC	Area Under Curve
AIC	Akaike Information Criterion
CNP	Chitwan National Park
GPS	Global Positioning Unit
GLM	Generalized Linear Model
IUCN	International Union for Conservation of Nature
LR	Likelihood ratio
ROC	Receiver Operating Curve
UNESCO	United Nations Educational, Scientific and Cultural Organization

ABSTRACT

In Nepal, two crocodilians, Mugger (*Crocodylus palustris*) and Gharial (*Gavialis gangeticus*), share a sympatric range in the Rapti River in Chitwan National Park. To better understand the influence of different habitat characteristics on the distribution of these crocodiles and aid in their conservation, a study was conducted between February and March 2023. The study collected data along the river, focusing on habitat characteristics at 500-meter intervals and areas where both species were observed. Generalized Linear Model with binary logistic regression was used for statistical analysis. This model helped to examine the presence or absence of Mugger and Gharial at different sampling points, using seven habitat characteristics as predictors. These predictors included the slope and aspect of the river bank, distance to the forest and human settlements, level of human disturbances, water current, and river bank substrate type. The statistical significance of these predictors was assessed using the likelihood ratio test, and the probability of crocodile sightings in relation to habitat variables was determined using the Akaike Information Criterion. The results of the analysis showed that human disturbances and water currents were significant factors influencing the presence of Gharials. On the other hand, only the slope of the river bank was found to be a significant factor in the presence of Muggers at specific sampling stations. These findings highlight that Gharials and Muggers have distinct habitat preferences, emphasizing the importance of effective habitat management by the concerned authorities. The study underscores the necessity of considering these influential factors in conservation efforts aimed at protecting the Mugger and Gharial species in the Rapti River. By understanding their specific habitat requirements and promoting suitable coexistence, conservationists can contribute to the effective conservation of these crocodilians.

1. INTRODUCTION

1.1 General Background

There are only two types of crocodilians found in Nepal, the Gharial *(Gavialis gangeticus*) and the Mugger *(Crocodylus palustris*) (Bhattarai et al. 2022) which can often be found living in the same areas (Da Silva and Lenin 2010).

Crocodilians tend to divide up their habitat within bodies of water to avoid competition or predators (Hutton 1989). This can be particularly evident when multiple species live in the same area (B. Cott 1961). The crocodilians' preference for different habitats can also be linked to their behavior during the breeding season and their various methods of finding food (Rootes and Chabreck 1993). Separation based on size occurs both within and between species, as individuals of different sizes have different behaviors when it comes to finding food and avoiding threats (Magnusson et al. 1987).

1.2 Morphology and Ecology

1.2.1 Gharial

The Gharial is a crocodilian species that can be found in large (Maskey 1989) deep, and fast-flowing rivers in the plains (Shah and Tiwari 2004). Adult male Gharials have a large protuberance on the end of their snout that resembles an earthenware pot, which is where the species gets its name (State & Smith, 1931). Gharials exhibit sexual dimorphism, with males looking noticeably different from females. They reach sexual maturity at around 13 years old for males and 16 years old for females, when they are nearly three meters long (Thapaliya et al. 2009). One male Gharial will mate with and protect a group of females during the breeding season, which lasts from November to January. Nesting takes place in March, April, and May, and during the dry season, the nests are dug in sandbanks near the river (Whitaker and Basu 1982). Gharials spend a significant amount of time basking on sandbanks during the winter when water levels and temperatures are low (Whitaker and Basu 1982).

1.2.2 Mugger

The Mugger (*Crocodylus palustris*) is a medium-sized crocodile with the widest snout among all living members of the Crocodylus genus (up to 4-5 meters in length), Muggers are semi-aquatic and play a key role as top predators in slow-flowing freshwater habitats (Da Silva and Lenin 2010). The mugger lays its eggs during the annual dry season and is a hole-nesting species. Females become sexually mature at around 1.8-2 meters in length and

lay about 25-30 eggs (Whitaker and Basu 1982). Nesting occurs in various settings, with some females even nesting at their burrow entrance or inside it (Stevenson and Whitaker 2010). Muggers, like other crocodilians, feed on aquatic insects, small fish, and crustaceans when they are young, and as they grow older, they prey on larger vertebrates such as fish, turtles, birds, and mammals (Wagle 2010). Muggers attain maturity between the ages of 6 and 10 years and are typically between 1.7 and 2.6 meters in length (Whitaker and Whitaker 1989); Nesting takes place during the annual dry season, from late March to early April in the case of CNP. Nests are found in a variety of environments, including at the entrance or inside burrows (Stevenson and Whitaker 2010).

1.3 Population status and distribution in Nepal

The current population of Gharials in Nepal is small, with only 198 individuals remaining. These gharials are found in different rivers of Nepal, including Narayani (84), Rapti (82), Babai (31), and Karnali (1) (DNPWC, 2018). Monitoring of gharial populations takes place annually during the winter months, typically in February and March, with a team of experts overseeing the process (Lamichhane et al. 2019). In the past, mugger crocodiles were found in a wider range of habitats, such as marshy lakes, ponds, and small rivers throughout Nepal's Terai region (Nishan et al. 2023). However, currently, their population is limited to a few isolated areas in Nepal, including Chitwan National Park, Bardiya National Park, Shuklaphanta National Park, Koshi Tappu Wildlife Reserve, and the Ghodaghodi lake complex (Khadka et al. 2020). Recent studies show that the largest number of muggers are concentrated in Chitwan National Park, with 397 individuals observed (Lamichhane et al. 2022); 26 muggers were observed inside and around the Ghodaghodi Lake complex (Lamichhane et al. 2022); and 35 individuals were observed inside and around the Koshi Tappu Wildlife Reserve (Bhattarai et al. 2022). The muggers in Nepal are mostly found along the Rapti, Narayani, and Bishazari rivers, as well as in stagnant ponds within Chitwan National Park (Lamichhane et al. 2022).

1.4 Major threats

The decline in the Gharial population is due to multiple factors such as hunting for skin, eggs, and indigenous medicine, as well as habitat destruction caused by riparian agriculture, grazing, and other human activities (Whitaker et al. 1974). The decrease in the mugger population in Nepal is mainly attributed to anthropogenic activities such as wetland habitat loss, water pollution, and sedimentation (Andrews and McEachern 1994). The Rapti River in CNP is subjected to considerable human pressure, including illegal fishing, sand mining,

and boulder quarrying. The Rapti River population of both species faces threats from water pollution, sedimentation, and seasonal changes in water level (Khadka et al. 2014). Muggers and gharials share the same range in CNP's Rapti and Narayani rivers, and both species are impacted by human activities and other stressors (Da Silva and Lenin 2010).

1.5 Rationale

To date, several studies on the status and distribution of gharial and mugger in Nepali rivers have been undertaken (Poudyal et al. 2018), but there is very little information on their associated habitat characteristics. Thus, the purpose of this study was to address a knowledge gap about the inhabited habitat characteristics of gharial and mugger in the study region in order to provide improved decision-making information to management authorities. The Mugger crocodile has been kept in the shadows in terms of conservation when compared to other terrestrial flagship species, despite being an apex predator species in the wetland ecosystem (Khadka et al. 2014). Mugger and gharial have sympatric relationships in the Rapti River, but there have been limited studies on both species simultaneously. Hence, this study focuses on the factors influencing habitat shared by gharials and muggers in Rapti River.

1.6 Objectives

1.6.1 General objective

The general objective of the study was to determine the habitat use by two sympatric species.

1.6.2 Specific objectives

To determine different classes, sizes, and activities of observed gharial and mugger

- To identify factors influencing habitat use by mugger and gharial crocodiles
- To determine the likelihood of crocodile occurrence in relation to specific habitat variables.

2. LITERATURE REVIEW

2.1 Gharial

A survey by Bashyal et al. (2021) estimated the Gharial population in Bardiya National Park to be around 40. This was an increase from the previous year's estimate of 28 individuals, demonstrating a good trend. For basking and nesting, gharials require deep, fast-flowing rivers with sandy banks. The Karnali and Babai rivers provide good nesting and basking locations for Gharials in the Bardiya National Park. Human activities such as sand mining, water extraction, and fishing, on the other hand, can modify the environment and had a negative impact on Gharial populations. The biggest hazard to Gharials in Bardiya National Park was human activity. Neupane et al. (2020) conducted a survey to examine habitat occupancy and risks to the gharial population in Nepal's Rapti River. The survey discovered 53 gharial individuals, with the majority of them basking on the south riverbank, sandy riverbanks, and flat topography areas with no anthropogenic hazards. The habitat variable "topography" was found to be significant in determining the likelihood of spotting gharial. The most serious concerns were identified as pollution and natural habitat change.

Choudhary et al. (2018) investigated the spatiotemporal distribution and habitat usage of two sympatric crocodilian species, the gharial and the mugger, in the Indian wildlife sanctuary of Katarniaghat. Gharials, on the other hand, preferred deeper waters with faster currents, whilst Mugger crocodiles favored shallower areas with slower currents. The study also discovered that the two species had temporal partitioning, with Gharials being more active during the day and Mugger crocodiles being more active at night. The researchers also noticed that the two species had some spatial partitioning, with the Gharials inhabiting the upstream sections of the river and the Mugger crocodiles inhabiting the downstream areas. This spatial partitioning could be owing to the two species' distinct habitat preferences, as well as competition for resources.

According to the findings of Poudyal et al. (2018), the Rapti River located in Chitwan National Park, Nepal, is considered to be a favorable habitat for Gharials. Several factors contribute to this suitability. Gharials are known for their unique long, narrow snouts, which are specialized for catching fish. These sandy banks offer ideal spots for Gharials to bask under the sun. Moreover, these sandy banks also provide suitable sites for nesting, as Gharials lay their eggs in sandy areas along the riverbanks.

During the winter when water temperatures and levels are low, Gharials are often seen basking on sand banks for extended periods. Whitaker et al. (1974) noted that Gharials have a predictable behavior of returning to the same basking spot daily, which unfortunately makes them more susceptible to poaching. These sand banks serve as crucial habitats for Gharial survival, not only for basking but also for nesting. The Narayani River showed the highest concentrations of Gharials in areas where there was a maximum availability of sand banks and deep channels. This suggests that the presence of ample sand banks and deep channels is vital for supporting higher Gharial populations in the river in a study by Thapaliya et al. (2009) .

2.2 Mugger

Nishan et al. (2023) discovered that Mugger crocodiles were more likely to be located in regions with slower current velocities, deeper water, and more vegetation cover. According to the researchers, these environmental choices are most likely related to the species' eating behavior and thermoregulation requirements. The investigation conducted by Lamichhane et al (2022) in the Ghodaghodi Lake Complex, Nepal reported a total of 26 Mugger crocodiles. The likelihood of seeing Mugger crocodiles in the lake complex was discovered to be affected by distance to communities, distance to rivers, and human disturbance. The most serious risks to the species, according to the report, are habitat modification and illegal fishing, followed by pollution, infrastructure development, invasive species, encroachment on watershed areas, and human-mugger interactions. Bhattarai et al. (Bhattarai et al. 2022) conducted a study to evaluate the present distribution and status of Mugger crocodiles in the Koshi Tappu Wildlife Reserve and nearby areas, as well as to analyze the species' habitat utilization. From April 2011 to March 2012, mugger crocodiles were discovered in both the Koshi River and its adjoining wetlands, with 24 individuals spotted throughout the survey period. The researchers observed that the species' spread was uneven and reliant on the availability of suitable habitats. Mugger crocodiles have been reported to favor slow-moving or stagnant water, dense vegetation, and sandy or muddy banks. The study also discovered that seasonal variations in the environment influenced the species' habitat utilization. Mugger crocodiles were discovered in deeper water with slower currents during the monsoon season when water levels in the Koshi River and associated wetlands were high. The species was found in shallow pools and channels with sandy or muddy banks during the dry season when water levels were low.

The marsh crocodiles observed in Beeshazari Lake and the surrounding Khageri canal tend to favor muddy and grassy banks, as well as areas covered by floating mats of vegetation such as *Leersia hexandra, Cyperus species, Mikania, and Eichornia*. These preferred spots are situated close to open water courses and serve as ideal locations for their basking activities. Unfortunately, the seasonal and permanent wetlands within the Beeshazari Lake Complex are facing significant challenges due to the extensive growth of various weed species, including *Leersia hexandra*, *Cyperus* species, *Ipomoea carnea fistulosa*, and *Eichornia crassipes*. As a result of this growth, the water level is decreasing, leading to the loss of suitable habitats for the marsh crocodiles in a study by Bhandari et al. (2014).

3 MATERIALS AND METHODS

3.1 Study area

The study was carried out in the CNP's Rapti River. The CNP, Nepal's first National Park, was established in 1973 and is located in the southern section of central Nepal, covering an area of 953 square kilometers. The park was declared a UNESCO World Heritage Site in 1984 (United Nations Educational and Organization 2016) and recognized as a global biodiversity hotspot. Agriculture, livestock farming, and fishing are the primary sources of income for the locals. The current survey was carried out along a 39-kilometer stretch (Fig.1) of the river from Bhandara (on the eastern side) to Dhruba Post (on the Western side).

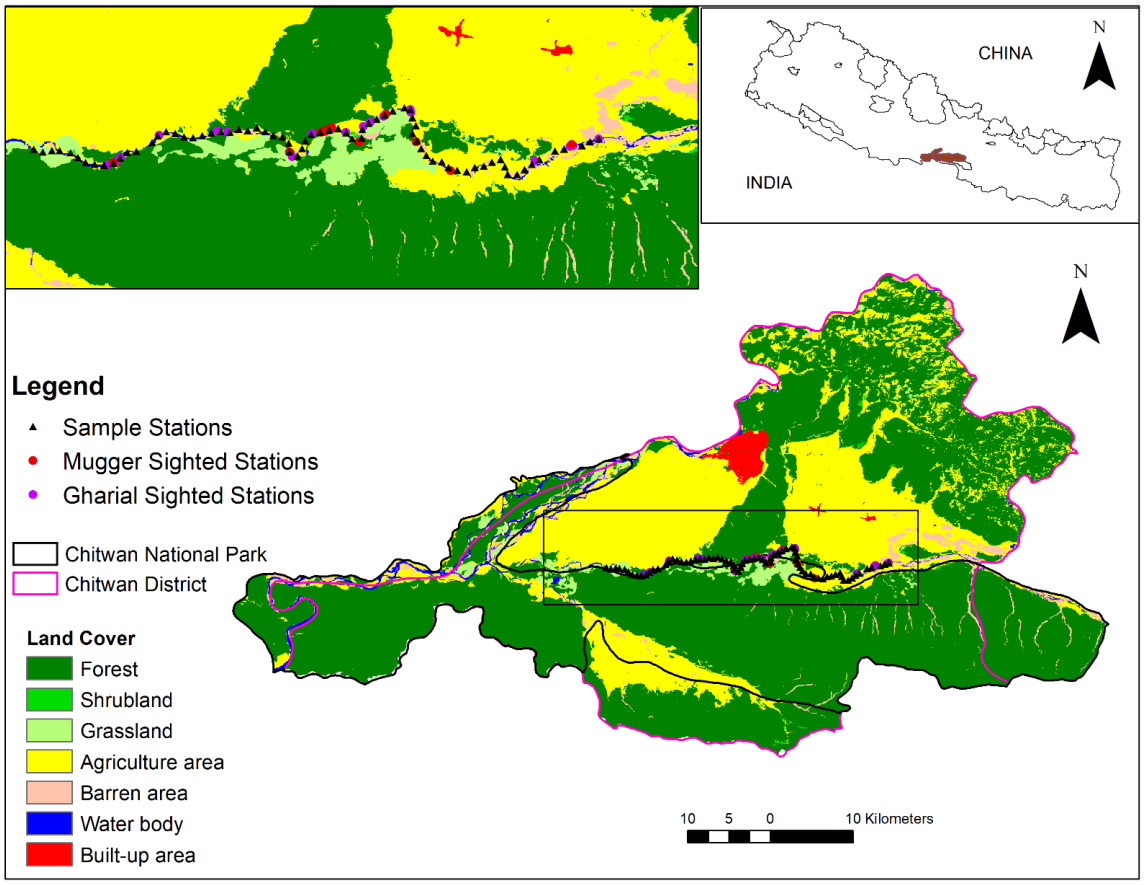


Figure 1. Map of the Chitwan National Park showing the Rapti River, along with sampling stations and sighting locations.

3.2 Research design

A survey method was used, in which particular portions of the river were chosen as research areas (mainly 39 km) and divided into distinct sampling locations (in this study, a 500 m gap between two sampling stations was used). Data was gathered from observations of gharial and mugger presence and absence in relation to habitat characteristics.

3.3 Preliminary survey

In February 2023, preliminary surveys were conducted to gather information on the distribution of muggers and gharials in different segments of the Rapti River. In order to learn more about the current geographic distribution of both muggers and gharials, the keepers and warden of the Kasara Breeding Center as well as representatives of riverbank communities were questioned during the initial stage of the research. The Rapti River's downstream mid-channel course was afterwards was digitized using Google Earth Pro. This involved mapping a 39-kilometer stretch of river where the population has been previously documented (Khadka et al. 2014). The 39-kilometre stretch of the river starts at Bhandara on the eastern and ends at Dhruba Post on the western side.

To prevent bias from repeated surveys of the same mugger or gharials individuals, we divided the extracted 39-kilometer stretch of the Rapti River into three distinct segments (Table 1). This also allowed us to survey each segment in a single day, which was more efficient for our field arrangements.

Table 1. Name and length (km) of the studied segments of Rapti River, CNP

Segment	Segment name	Length of the segment
1	Bhandara to Sauraha	14 km
2	Sauraha to Ghatgai	17 km
3	Ghatgai to Dhruba post	8 km
	Total length	39 km

The three river portions were surveyed using traditional dugout canoes. This method made it easier to gather vital data on the different types of river bank substrates and indications

of human disturbance, which was essential for the preparation and establishment of the habitat study. Every individual's GPS coordinates were captured, keeping a safe distance between us and the species to reduce any possible dangers or inaccuracies. We next used ArcGIS 10.8 to determine the slope of each recorded point in order to confirm and validate the numerical values of the predicted virtual slopes. A similar virtual estimate technique was used by Neupane et al. (2020) to evaluate the habitat occupancy of gharials in the Rapti River of CNP. The total length (TL) of muggers was visually measured and divided into different age groups. According to size, the following age groups were included in this classification: hatchlings (under 30 cm), yearlings (30–50 cm), juveniles (between 50 and 125 cm), sub-adults (between 125 and 180 cm), and adults (above 180 cm). The classification system used here corresponds with the suggestions offered by Khadka et al. (2014). Based on their size, gharials were divided into distinct size groups. Hatchlings (less than 120 cm), juveniles (between 120 and 180 cm), sub-adults (180-270 cm), and adults (above 270 cm). These classifications were suggested by (Rajbhandari and Acharya 2013).

For this survey, we designated sections of the river where paddling was necessary as low-water current River and segments where the boat proceeded without paddling as fast-water current. During our extensive field study, we were able to accurately estimate the water current by using visual estimates.

Within the selected river segment designated for the detailed habitat survey, the required number of points were generated along the river segment using the following formula through the ArcGIS tool (ESRI 2011).

N= length of the river/ Pdistance

Where

N = number of survey points

Lriver =Length of survey segment

Pdistance =Plot to plot distance

N= 39000/500

= 78

= 78 sampling points

Using this formula and assuming that habitat characteristics would differ at intervals of 500 meters, we generated 78 survey points on each bank, spaced 500 meters apart. This spacing was chosen to minimize the possibility of basking individuals moving across consecutive stations during the survey in the downward direction of the river.

3.4 Major field survey

A detailed habitat survey was carried out in March 2023. At designated sampling stations, each species sighting location, and 500 m intervals on both sides of the river, the habitat was examined. Hussain (2009) stated that each sampling site was considered as a separate habitat unit. On successive sunny days between 9:00 and 16:00, the study was conducted because it was anticipated that both species' individuals would be basking at that time (Lamichhane et al. 2022).

Similar methods and presumptions were utilized in numerous research for various crocodile species (Bhattarai et al. 2022). The habitat types on the river's left and right banks were evaluated at each sampling station and site for species observation. The downstream movement of the dugout canoes was constant at 3–4 km/h. Gharial and mugger crocodiles were observed using binoculars (Canon Optics 10X32). The location of each sampling point was noted using handheld GPS devices, and pictures of a portion of the observed individuals and their surrounding habitats were obtained. The ecosystems were documented and photographed.

3.5 Data collection

The boat was stopped for at least four to five minutes at each sampling site and for each species' sighting location to capture the pre-defined habitat parameters. Seven pre-defined habitat characteristics were identified as potentially influencing the presence of muggers and gharials based on the preliminary survey and the literature that was available (Neupane et al. 2020, Bhattarai et al. 2022, Lamichhane et al. 2022); and those selected variables included: river bank aspect (right or left); water current; river bank substrate type; river bank slope; distance to the forest: distance to settlement and human disturbance. Similarly, the observed river bank substrate was classified into categories as factors ; factor 1(Sandy substrate) , factor 2 (Sandy with the presence of small gravels), factor 3 (Sandy with fine gravels and presence of small grasses or shrubs) , factor 4 (Muddy , sandy with small grasses o shrubs) and factor 5 (Muddy surface with fine gravel and small grasses or shrubs).

At each sampling site and sighting location, there were also human disturbances (human walking routes, infrastructure construction, waste disposal, sand and stone mining, fishing, swimming, washing clothes, cattle presence, grass collection, jeep safaris, and elephant rides).

3.6 Data analysis

To determine the factors that affect the presence or absence of muggers and gharials at different locations, a generalized linear model was employed (Hastie and Pregibon 1992). The presence or absence of both species at each site was used as the dependent variable, while seven habitat factors were used as the independent variables. These seven factors were river bank aspect, slope, distance to forest, distance to settlement, water current, bank substrate type, and human disturbances. Human activity was assigned a value of 'present = 1' if it was observed at a sample station or sighting location and 'absent = 0' if not. Bank substrate, water current, and human disturbance were categorical variables, while the other factors were continuous variables measured in meters, including slope, aspect, distance to forest, and distance to settlement.

Binary logistic regression was used in the analysis along with generalized linear modeling (GLM), with both continuous and factor variables serving as predictors. The remaining factors, including slope, aspect, distance to forest, and distance to settlement, were considered as continuous variables. The categorical variables employed in the analysis were bank substrate, human disturbance, and water current. The continuous variables were standardized using z-transformations to verify that they were comparable. A Variance Inflation Factor (VIF) test was run on each variable to look for multicollinearity (Montgomery et al. 2021) using the package ‘faraway’ (Boomsma 2014) in R 4. 0. 4 (Team 2016). Selected study variables with tolerance values more than 0.1 and VIF values less than 10 did not exhibit any multicollinearity (Bowerman and O'connell 1990).

To determine the statistical significance of predictors, we used the likelihood ratio (LR) chi-square test, using package ‘Desctools’ (Signorell et al. 2019) and ‘manipulate’ (Racine 2012) which compares the likelihood of data under a full model to the likelihood of data under a reduced predictor model (Lewis et al. 2011). If the reduced model has a significant decrease in fit compared to the full model, the eliminated predictor is considered a significant contributor to the full model. To conduct likelihood ratio tests of individual predictors, reduced models were created using the ‘ANOVA’ function to test the decrease

in model fit resulting from eliminating a given predictor. The approach was described in studies by Zhang et al., (2016).

To determine the best-fitting model, we used the Akaike information criterion (AIC) and adjusted AIC for small sample sizes (AICc) following Burnham and Anderson's suggestion (Burnham 1998). The lower the AIC value, the better the model fit. We also used Receiver Operating Characteristics (ROC) to evaluate the selected model's predictive performance. ROC is a plot of sensitivity versus 1-specificity, and the area under the ROC function (AUC) summarizes test accuracy. An AUC of 0.5 indicates no discrimination, while 0.7-0.8 is acceptable, 0.8-0.9 is excellent, and above 0.9 is superior. We computed the ROC curve using the Package 'ROCR' and interpreted the AUC values based on established benchmarks (Sing et al. 2005).

Table 2. Variables used and their sources

Abbreviation	Variable type	Variable description	Range of habitat feature	Sources
Slope (River Bank Slope)	Continuous	Measurement of slope (in meters) of sampling station	0 – 65 m	ArcMap
Aspect (River Bank Aspect)	Continuous	Measurement of Aspect (in meter) of sampling station	0- 350 m	ArcMap
DTF (Distance to forest)	Continuous	Measurement of distance to forest from sampling station (in meter)	30 - 700 m	(OCHA Nepal, 2021)
DTS (Distance to settlement)	Continuous	Measurement of distance to settlement from sampling station (in meter)	50- 5000 m	(OCHA Nepal, 2021)
WC (Water current)	Categorical	Speed of water in sampling	Fast - 1 Slow - 0	Field Survey
HD (Human disturbances)	Categorical	Presence of human activities in sampling station	Presence - 1 Absence - 0	Field Survey
RBST (River bank Substrate type)	Categorical	Bank substrate type of sampling stations	Factor 1 – Sandy Factor 2 – Sandy + Gravel Factor 3 – Sandy + Gravel + Grassy Factor 4 – Muddy + Sandy + Grassy Factor 5 – Muddy + Gravel + Grassy	Field Survey

4 RESULT

4.1 Size, Class, and Activities of Crocodilians

4.1.1 Gharial

At our study site, we recorded a total of 41 gharial individuals of different sizes. Among the three sectors, the highest number of gharials was observed in Segment 2 (Sauraha to Ghatgai, N = 27; 67 %), and Segment 1 (Bhandara to Sauraha, N = 8; 19.51%). Regarding the different size classes, the majority (N = 22; 53.6 %) of the observed gharials were classified as adults, followed by sub-adults (N = 14; 34.14%), and juveniles (N = 4; 9.75%). The majority of the observed gharials (N = 32; 78.04%) were basking. The other observed gharials (N = 9; 21.95%) were submerged in the river.

Table 3. Sighted number of gharials in different segments of the study area with their size classes and observed activity

Segment	**Total sighted gharials**	**Size, class, and observed activities**
1: Bhandara to Sauraha	8	4 sub-adults (1 submerged in water and 3 basking), adults (all submerged in water); 1 juvenile (submerged in water)
2: Sauraha to Ghatgai	27	16 adults (15 basking and 1 submerged in water) ; 10 sub-adults(10 basking); 1 juvenile (submerged in water)
3: Ghatgai to Dhruba post	6	3 adults (basking) ; 3 juvenile(2 submerged in water , 1 basking)

4.1.2 Mugger

As for the mugger 10 individuals of different sizes were encountered (Table 4). Among the three sectors, the highest number of muggers was observed in Segment 1 (Bhandara to Sauraha, N = 5; 50%), followed by Sector B (Sauraha to Ghatgai, N = 4; 40 %), and Sector A (Bhandara to Sauraha, N = 1; 10 %). Regarding the different size classes, the majority (N = 7; 70%) of the observed muggers were classified as adults, followed by juveniles (N = 3; 30%). The highest number of the observed muggers (N =7; 70%) were basking. None of the muggers were seen submerged in water.

Table 4. Sighted numbers of muggers in different segments of the study area with their size classes and observed activity.

Segment	Total sighted muggers	Size, class, and observed activities
1: Bhandara to Sauraha	5	4 adults (all basking); 1 juvenile (basking)
2: Sauraha to Ghatgai	4	2 juvenile (basking); 2 adults (basking)
3: Ghatgai to Dhruba post	1	1 adult (basking)

4.2 Influencing habitat variables

This study conducted a statistical analysis using a generalized linear model with binary logit to determine the factors influencing the presence of gharials in the study region. The results indicated that water current (WC) and human disturbance (HD) were found to be statistically significant in their impact on gharial occurrence. According to the data presented in Table 5, the p-values associated with these variables were calculated to be 0.0120 for water current and 0.0272 for human disturbance.

Whereas, the significance of variables impacting the occurrence of muggers (another species) differed from gharials. The results revealed that out of all the variables examined,

only slope was found to have a statistically significant effect on the presence of muggers. The corresponding p-value for this variable was calculated to be 0.0193, as indicated in Table 6.

Table 5. Influencing habitat variable for occurrence of gharial using GLM

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	-2.0313395	1.9164443	-1.060	0.2892
Slope	-0.0031328	0.0227002	-0.138	0.8902
Aspect	0.0013063	0.0032158	-0.406	0.6846
DTF	0.0002501	0.0019601	0.128	0.8985
DTS	-0.0002569	0.0002911	-0.883	0.3775
WC	2.7182521	1.0825644	2.511	0.0120 *
HD	-1.2038289	0.5451276	-2.208	0.0272 *
RBST	0.9502170	0.5127744	1.853	0.0639

Table 6. Influencing habitat variables for occurrence of mugger using GLM

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	1.5238513	2.2324386	0.683	0.4949
Slope	-0.1205418	0.0515066	-2.340	0.0193 *
Aspect	0.0005019	0.0050803	0.099	0.9213
DTF	-0.0003814	0.0032960	-0.116	0.9079
DTS	0.0002207	0.0003975	0.555	0.5787
WC	-1.6179336	1.0257576	-1.577	0.1147
HD	1.3039449	1.0448936	1.248	0.2121
RBST	0.0189346	0.3583800	0.053	0.9579

4.3 Probability of occurrence of crocodiles associated with different habitat variables

4.3.1 Gharial

Out of 78 sampling stations, gharials were recorded from 19 stations. Using likelihood chi-square test predictors for statistical significance showed the deviance for the full model (Full model) to be 59.666 (Table 7). The chi-square test revealed a substantial worsening in fit for HD ($p = 0.00150$) and WC ($p = 0.00197$) when the variables were removed. As a result, these variables are regarded as major contributors to the overall model. Similarly, the chi-square test did not indicate a significant worsening in fit for the variables: Slope, Aspect, Distance to forest (DTF), and Distance to settlement (DTS) as a result of eliminating the variables. As a result, these variables are regarded as non-significant in the overall model. Therefore, among seven pre-set habitat parameters, there was significant variation in the chance of seeing Gharials in Rapti River with respect to HD and WC.

Table 7. Summary of the likelihood ratio chi-square test to test predictors for statistical significance

Model	Resid. Df	Resid.Dev	Df	Deviance	Pr(>Chi)
Full model: Obs ~ Slope + Aspect + DTF + DTS + HD+ WC + RBST	69	59.666			
Model 1: Obs ~ Aspect + DTF + DTS + HD + WC + RBST	70	5.910	1	-53.756	0.2816
Model 2: Obs ~ Slope + DTF + DTS + HD + WC + RBST	70	9.809	1	-49.857	0.32230
Model 3: Obs ~ Slope + Aspect + DTS + HD + WC + RBST	70	9.803	1	-49.863	0.18202
Model 4:Obs ~ Slope + Aspect + DTF + HD + WC + RBST	70	9.961	1	-49.705	0.43471
Model 5: Obs ~ Slope + Aspect + DTF + DTS + WC + RBST	70	11.315	1	-48.35	0.00150
Model 6: Obs ~ Slope + Aspect + DTF + DTS + HD + RBST	70	11.310	1	-48.356	0.00197
Model 7: Obs ~ Slope + Aspect + DTF + DTS + HD + WC	70	10.966	1	-48.7	0.257617

The model with the least AIC value is considered as the best-fitted model among all the set of model. Here for gharial Model with a slope as a reduced predictor was the best-fitted

model for the probability of sighting gharial in the study area with the value of AICc = 51.04 while the model without human disturbance and water current has AICc values of 88.94 and 88.98 which has the highest value among all the model subset hence is regarded as unfit models.

Table 8. Akaike Information Criterion scores (AICc, ΔAIC & AIC weight) of a generalized linear model with binomial structure predicting the factors responsible for the Gharials observation.

Model Component	K	AICc	Delta AICc	AICcWt	Cum.Wt	LL
Aspect + DTF + DTS + HD + WC + RBST	8	51.04	0.00	1	1	-16.46
Slope + Aspect + DTS + HD + WC + RBST	8	77.93	26.89	0	1	-29.91
Slope + DTF+ DTS + HD + WC + RBST	8	77.97	26.93	0	1	-29.93
Slope + Aspect + DTF + HD + WC + RBST	8	79.16	28.12	0	1	-30.52
Slope + Aspect + DTF + DTS + HD + WC	8	86.56	35.52	0	1	-34.22
Slope + Aspect + DTF + DTS + HD + RBST	8	88.94	37.90	0	1	-35.41
Slope + Aspect + DTF + DTS + WC + RBST	8	88.98	37.94	0	1	-35.43

The area under ROC function (AUC) (Fig. 2) values for the full model (GLM with binary logistic regression) were estimated to be 0.9052632 with the accuracy value of 0.8194192 and thus considered to be acceptable.

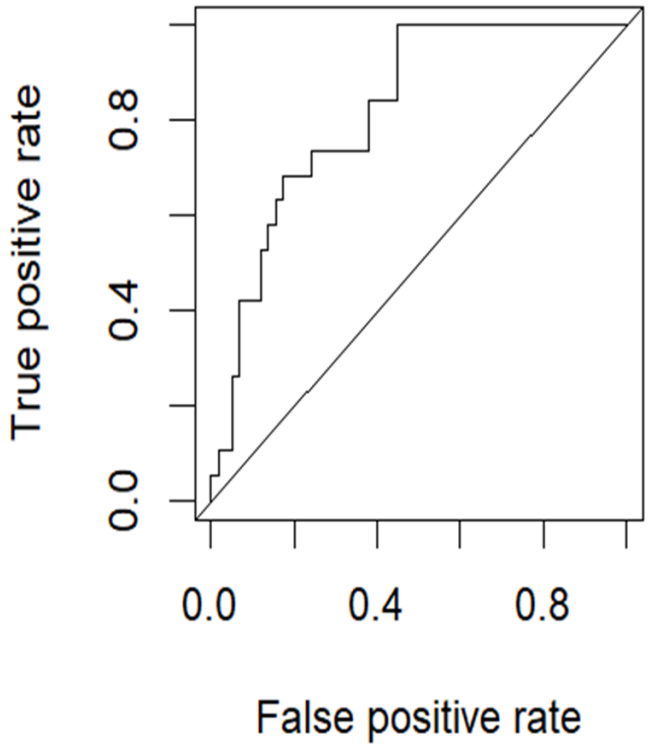


Figure 2. ROC curve for full model for Gharial

4.3.2 Mugger

Out of 78 sampling stations, muggers were recorded from 10 stations. Using likelihood chi-square test predictors for statistical significance showed the deviance for the full model (Fullmodel) to be 32.921(Table 7). The chi-square test revealed a substantial worsening in fit for Slope ($p = 0.0103$) when the variable was removed (Table 9). As a result, these variable is regarded as major contributors to the overall model. Similarly, the chi-square test did not indicate a significant worsening in fit for the variables: Aspect, Distance to settlement (DTS), Water current (WC), Human disturbance (HD), and RBST as a result of eliminating the variables. As a result, these variables are regarded as non-significant in the overall model. Therefore, among seven pre-set habitat parameters, there was significant variation in the chance of seeing Muggers in Rapti River with respect to Slope, DTF, and WC.

Table 9. Summary of the likelihood ratio chi-square test to test predictors for statistical significance

Model	Resid. Df	Resi. Dev.	Df	Deviance	Pr(>Chi)
Full model: Obs ~ Slope + Aspect + DTF + DTS + HD+ WC + RBST	69	32.921			
Model 1: Obs ~ Aspect + DTF + DTS+ HD + WC + RBST	70	5.910	1	-27.012	0.0103
Model2: Obs ~ Slope + DTF + DTS + HD + WC + RBST	70	5.3545	1	-27.567	0.0997
Model3: Obs ~ Slope + Aspect + DTS + HD + WC + RBST	70	5.377	1	-27.545	0.0790
Model4: Obs ~ Slope + Aspect + DTF + HD + WC + RBST	70	5.375	1	-27.546	0.9044
Model5: Obs ~ Slope + Aspect + DTF + DTS + WC + RBST	70	5.580	-1	27.341	0.1157
Model 6: Obs ~ Slope + Aspect + DTF + DTS + HD + RBST	70	5.530	1	-27.391	0.7816
Model 7: Obs ~ Slope + Aspect + DTF + DTS +HD + WC	71	5.401	2	-27.52	0.8401

The model with the least AIC value is considered as the best-fitted model among all the set of model. Here for Mugger Model with RBST as a reduced predictor was the best-fitted model for the probability of sighting a mugger in the study area with the value of AICc = 29.54, while the model without the variable slope is considered to be the most unfit model among other sets with the highest value of AICc of 90.87. Therefore, model predictors including Slope, Aspect, DTF, DTS, HD, and WC are considered the best-fitted model.

Table 10. Akaike Information Criterion scores (AICc, ΔAIC & AIC weight) of a generalized linear model with binomial structure predicting the factors responsible for the Muggers observation

Model component	K	AICc	Delta	AICcWt	Cum.Wt	LL
Slope + Aspect + DTF + DTS + HD +WC	7	29.54	0.00	0.42	0.42	-6.96
Slope + DTF + DTS + HD + WC + RBST	8	31.36	1.82	0.17	0.58	-6.62
Slope + Aspect + DTF + HD + WC + RBST	8	31.66	2.12	0.14	0.73	-6.77
Slope + Aspect + DTS + HD+ WC + RBST	8	31.68	2.14	0.14	0.87	-6.78
Slope + Aspect DTF + DTS + WC + RBST	8	33.84	4.31	0.05	0.92	-7.86
Slope + Aspect + DTF + DTS + HD + RBST	8	34.54	5.00	0.03	1.00	-8.21
Aspect + DTF + DTS + HD + WC + RBST	9	90.87	61.33	0.00	1.00	-35.09

The area under ROC function (AUC) (Fig. 3) values for the full model (GLM with binary logistic regression) were estimated to be 0.9183673 with the accuracy value of 0.9350649 and thus considered to be outstanding.

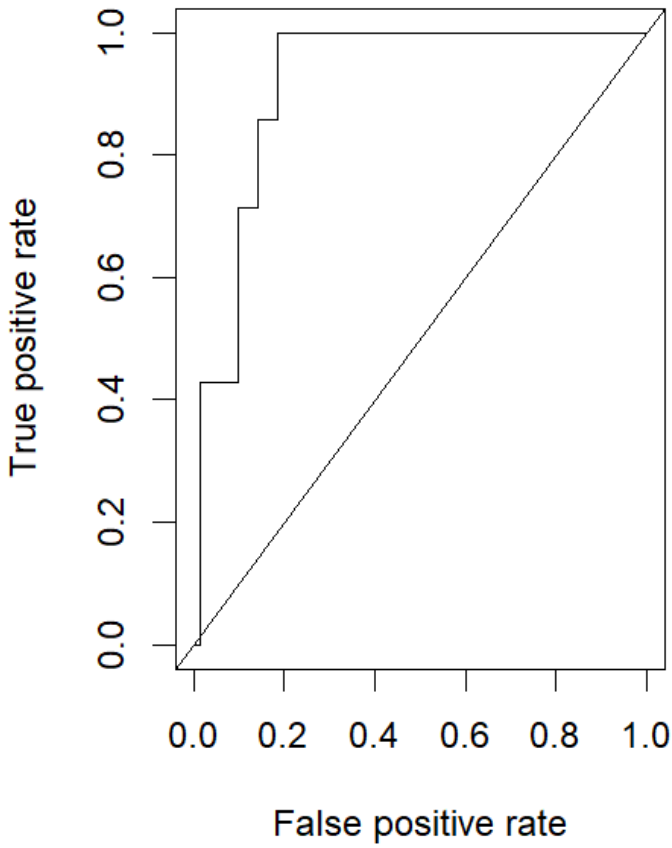


Figure 3. ROC curve for full model for Mugger.

5 DISCUSSION

This study provides factors influencing the habitat use of muggers and gharials, in this study as expected the crocodiles (Both gharial and mugger) were mostly found basking along the river bank while none of the muggers were found submerged underwater. During the survey majority of recorded individuals were classified as adults, followed by sub-adults, juveniles, and yearlings were not observed. The basking sites for thermoregulation are physically contested (Magnusson 1985), and smaller crocodiles are frequently chased out by the dominant larger individuals to occupy optimal basking sites (Venugopal and Deviprasad 2003). This could explain the relatively lower number of observations of juvenile and yearling classes of crocodiles in this survey. The relative ratio of observed adult to sub-adult numbers was consistent with the study of Lamichhane et al. (Lamichhane et al. 2022) which was conducted at the Ghodaghodi lake complex in Nepal.

5.1 Encountered Crocodiles

A study (Poudyal et al. 2018) reported 118 individuals with 36 adults, 12 sub-adults, 66 juveniles, and 4 yearlings in the Rapti River of CNP. These aforementioned studies surveyed the entire length (74 km) of the Rapti River. Since the current investigation was limited to just the major river segment covering 39 km, this may be the reason for the lower population encounter in the field. However, the male and female sex ratio in our study was similar to that of Bhatt et al. (2012). Altogether a total of 41 gharial individuals (only 1 male identified), consisting of 5 juveniles (12%), 14 sub-adults (34%), and 21 adults (51%) were observed in this study which is lesser than the number of individuals recorded in latest study (Neupane et al. 2020) of about 56 gharial individual along the 29.3 km river stretch of Rapti.

During the survey (Bhattarai et al. 2022) in total they recorded 35 individuals of muggers in and around Koshi Tappu Wildlife Reserve. Of the total 35 muggers, 22 individuals were sighted in ponds (private ponds, community ponds, and ponds inside the reserve) while 13 were sighted in the Koshi River, branches of the Koshi River and Moriya River. A previous study conducted by Khatri and Baral (2012) in the Ghodaghodi Lake complex, found only 12 crocodiles in the lake complex that include one mother crocodile and 11 young. Out of 24 lakes in the complex, mugger crocodiles were recorded from four lakes (Ghodaghodi, Nakhrodi, Ojahuwa, and Budhia Nakhrod) only. 46 Mugger individuals were recorded from Rapti River covering the length of 53 km by Nishan et al. (2023)Whereas in this study

along the 39 km river stretch, only 10 individual (7 adults and 3 juveniles basking along the river bank) sightings were recorded indicating a lower population count of muggers.

5.2 Influencing habitat variables and probability of occurrence

A 75 km study conducted in the Chambal River suggested that one-fifth of the study area was preferred by gharial populations (Nair 2010) with the most favored habitat being undisturbed basking locations through sand dunes at junctions of rivers with deep water and availability of fish prey. According to a study by Maskey (1989), small gharials used rocky banks while the larger gharials used sandy banks. Maskey et al. (Maskey 1989) concluded that the tactile qualities of the riverbed substrate, thermoregulatory considerations, and prey availability are all major factors influencing habitat selection in gharial. In our study, about 60% (25 out of 41) of gharials were found basking on undisturbed sandy riverbanks. This is likely due to the fact that it is easier for gharial to crawl on sandy surfaces than on rocky or clay surfaces. The lower moisture content of sand on the riverbank moderates extreme hot or cold environmental conditions, thus reducing the chances of desiccation while basking in the sun. Gharials are usually residents of low current flowing rivers having high concentrations of sandy riverbanks and good fish stocks (Whitaker and Basu 1982) in contrast to this study it was found that fast water current is a major habitat parameter along with least human disturbances for selecting certain habitats, and is a statistically significant factor.

The characteristics of the gharial habitat were recorded at 368 sampling points in 2017 and 374 points in 2019 in Bardia National Park by Bashyal (2021) it was found that Gharials preferred sandy vs. rocky banks for basking, in 2017, all except one were observed basking on sandy banks in 2019, all were observed basking on sandy banks. Meanwhile, none were observed to be basking on sand-grass or clay banks which coincides with this study as most gharials were observed basking along sandy and fine gravel banks (N = 23 individuals). Areas with less human disturbance were preferred by the gharials, in this study which coincides with the study done by Bashyal et al. (2021)which indicated that gharials require fast-flowing rivers, with sandy banks to bask and in the absence of human disturbances which increased the population in Bardiya National Park.

Vashistha (2021) experimented with the addition of sand and vegetation removal for creating noble nesting sites for gharials which resulted in more hatching success rate in

addition to sand than vegetation removal, indicating that sandy surface is more suitable for gharials. In contrast to this study, it was found that river bank substrate type did not contribute to the presence of gharial in the study site.

In this study, we observed mugger individuals on sloping riverbanks while basking on a variety of riverbank substrate types, but the majority of them were on sandy or muddy with few grasses banks. Our results were similar to those of Choudhary et al. (2018) at Katarniaghat Wildlife Sanctuary in India, slope is one major factor contributing to sightings of muggers, which also coincided with the study done by Bhattarai (2022), referring that slope as an important habitat variable for mugger in Koshi Tappu Wildlife Reserve. The study conducted by Lamichhane et al. (Lamichhane et al. 2022) found that the probability of sighting a mugger did not significantly differ with slope.

Mugger crocodiles have the ability to choose from a diverse range of substrate types to bask in, such as sand, grass, gravel, rock, clay, and fallen logs.; (Bhatt et al. 2012, Choudhary et al. 2018, Khadka et al. 2020, Lamichhane et al. 2022) our result supports this statement as the probability of sighting the Muggers in the study area was not significantly different with respect to the bank substrate. They were found mostly in sandy, muddy with the presence of little grasses and favored least with a gravel surface. Some of the observed basking mugger individuals were using mouth-gaping behavior for effective thermoregulation, as crocodiles sweat through their mouth, and lying with an open mouth has been considered a basic way to cool down (Whitaker and Basu 1982).

Unlike gharials, several studies have found that muggers are more tolerant of human disturbances (Venugopal and Deviprasad 2003, Khadka et al. 2014). According to this study's findings, human disturbance was not a significant factor determining the presence of muggers in the study region, which is consistent with earlier findings. In a study conducted by Lamichhane (2022) in the Ghodaghodi Lake complex, distance to settlement was a significant predictor for observing muggers at allocated sightings, which increased with an increase in the distance but in the case of this study distance to the settlement did not play any role in determining the presence of mugger maybe because of different study settings, however, it is considered as an insignificant variable for determining habitat characteristics of a mugger. As our study goal was not to assess nesting sites through a standardized survey, we did not observe and record any nests during our entire field survey. Nevertheless, the information on mugger nesting sites can aid in understanding their

reproductive biology and habitat characteristics (Choudhary et al. 2018). Thus, we recommend future studies on the nesting behavior of gharial and muggers for the long-term viability of the population in our study area.

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The study recorded 41 gharial individuals and 10 muggers in the same river from Bhandara to Dhruba post covering up to 39 km in total of Rapti River. In comparison, the population of gharial in Rapti is extensively higher than that of mugger indicating that Rapti is more suitable for gharial than mugger. The entire section of the river consists of fast as well as slow-moving water and both species seem to occupy accordingly. The probability of observing mugger was found significant with the slope only and other variables including aspect, distance to forest, distance to settlement, human disturbance water current, and bank substrate type were statistically insignificant. Meanwhile, gharial water current and lesser human disturbance were important factors for determining its presence and were unaffected by other variables considered in this study.

6.2 Recommendations

More research into the effects of seasonal changes on habitat suitability is recommended to improve conservation efforts for gharials and muggers since this study only focused on one season. These crocodile species' habitat quality and resource availability can be severely impacted by seasonal variations, such as changes in water levels, temperature, and prey availability. Designing efficient conservation efforts can benefit from an understanding of how these seasonal changes impact their distribution and behavior. Additionally, it is crucial to recognize and address human-induced disturbances that can negatively impact crocodile populations. Activities such as habitat encroachment, pollution, poaching, and disturbance of nesting sites can have detrimental effects on crocodile populations and their habitats. Therefore, implementing measures to mitigate these disturbances, such as creating protected areas, enforcing regulations, and promoting community involvement in conservation efforts, is essential for the long-term survival of gharials and muggers. As well as an entire river should be taken into consideration as only a few sections of the study were performed.

REFERENCES

Andrews, H. V. and McEachern, P. 1994. Crocodile conservation in Nepal.

B. Cott, H. 1961. Scientific results of an inquiry into the ecology and economic status of the Nile crocodile *(Crocodilus niloticus)* in Uganda and Northern Rhodesia. The transactions of the Zoological Society of London **29**(4):211-356.

Bashyal, A., Shrestha, S., Luitel, K. P., Yadav, B. P., Khadka, B., Lang, J. W., et al. 2021. Gharials (*Gavialis gangeticus)* in Bardiya National Park, Nepal: Population, habitat and threats. Aquatic Conservation: Marine and Freshwater Ecosystems **31**(9):2594-2602.

Bhatt, H. P., Saund, T. B. and Thapa, J. B. 2012. Status and threats to Mugger Crocodile *Crocodylus palustris* Lesson, 1831 at Rani Tal, Shuklaphanta Wildlife Reserve, Nepal. Nepal Journal of Science and Technology **13**(1):125-131.

Bhattarai, D., Lamichhane, S., Pandeya, P., Bhattarai, S., Gautam, J., Kandel, R. C., et al. 2022. Status, distribution and habitat use by Mugger crocodile (*Crocodylus palustris)* in and around Koshi Tappu Wildlife Reserve, Nepal. Heliyon **8**(8):e10235.

Boomsma, A. 2014. Regression diagnostics with R. Regrdiag R. tEx. department of statistics & measurement theory. Univ. Gron. Groninga Neth **22**.

Bowerman, B. L. and O'connell, R. T. 1990. Linear statistical models: An applied approach. Brooks/Cole. p.

Burnham, K. P. 1998. Model selection and multimodel inference. A practical information-theoretic approach.

Choudhary, S., Choudhury, B. C. and Gopi, G. V. 2018. Spatio-temporal partitioning between two sympatric crocodilians *(Gavialis gangeticus & Crocodylus palustris)* in Katarniaghat Wildlife Sanctuary, India. Aquatic Conservation: Marine and Freshwater Ecosystems **28**(5):1067-1076.

Da Silva, A. and Lenin, J. 2010. Mugger crocodile *Crocodylus palustris.* Crocodiles. Status survey and conservation action plan:94-98.

Da Silva, A. and Lenin, J. 2010. Mugger crocodile *Crocodylus palustris*. Crocodiles. Status survey and conservation action plan **3**.

ESRI, R. 2011. ArcGIS desktop: release 10. Environmental Systems Research Institute, CA **634**:315-325.

Hastie, T. and Pregibon, D.1992. Generalized linear models In: Chambers JM, Hastie TJ, editors. Statistical Models in S. Pacific Grove. California: Wadsworth & Brooks. Cole Advanced Books & Software.

Hussain, S. A. 2009. Basking site and water depth selection by gharial Gavialis gangeticus Gmelin 1789 (Crocodylia, Reptilia) in National Chambal Sanctuary, India and its implication for river conservation. Aquatic Conservation: Marine and Freshwater Ecosystems **19**(2):127.

Hutton, J. 1989. Movements, home range, dispersal and the separation of size classes in Nile crocodiles. American Zoologist **29**(3):1033-1049.

Khadka, B., Bashyal, A., Luitel, K. P. and Kandel, R. C. 2020. Nesting ecology of gharials *(Gavialis gangeticus)*: Implications from in situ and ex situ conservation programs in Chitwan National Park, Nepal. Herpetologica **76**(3):297-303.

Khadka, B., Maharjan, A., Thapalia, B. and Lamichhane, B. 2014.Population Status of the Mugger in Chitwan National Park, Nepal. Crocodile Specialist Group Newsletter, Karama (Northern Territory, Australia) **33**(3):9-12.

Khatri, T. B. and Baral, H. S. 2012. Survey of Ghodaghodi lake complex for cotton pygmy goose Nettapus coromandelianus and Marsh Mugger Crocodylus palustris. Our Nature **10**(1):137-144.

Lamichhane, B. R., Persoon, G. A., Leirs, H., Poudel, S., Subedi, N., Pokheral, C. P., et al. 2019. Contribution of buffer zone programs to reduce human-wildlife impacts: the case of the Chitwan National Park, Nepal. Human Ecology **47**:95-110.

Lamichhane, S., Bhattarai, D., Karki, J. B., Gautam, A. P., Pandeya, P., Tripathi, S., et al. 2022. Population status, habitat occupancy and conservation threats to Mugger crocodile *(Crocodylus palustris)* in Ghodaghodi lake complex, Nepal. Global Ecology and Conservation **33**:e01977.

Lewis, F., Butler, A. and Gilbert, L. 2011. A unified approach to model selection using the likelihood ratio test. Methods in Ecology and Evolution **2**(2):155-162.

Magnusson, W. E. 1985. Habitat selection, parasites and injuries in Amazonian crocodilians. Amazoniana: Limnologia et Oecologia Regionalis Systematis Fluminis Amazonas **9**(2):193-204.

Magnusson, W. E., da Silva, E. V. and Lima, A. P. 1987. Diets of Amazonian crocodilians. Journal of Herpetology:85-95.

Maskey, T. M. 1989. Movement and survival of captive-reared *Gharial Gavialis* gangeticus in the Narayani River, Nepal.

Montgomery, D. C., Peck, E. A. and Vining, G. G. 2021. Introduction to linear regression analysis. John Wiley & Sons. p.

Nair, T. 2010. Ecological and anthropogenic covariates influencing gharial Gavialis gangeticus distribution and habitat use in Chambal River, India. Unpublished Master's Thesis.

Neupane, B., Singh, B. K., Poudel, P., Panthi, S. and Khatri, N. D. 2020. Habitat occupancy and threat assessment of gharial (*Gavialis gangeticus)* in the Rapti River, Nepal. Global Ecology and Conservation **24**:e01270.

Nishan, K., Neupane, B., Belbase, B., Dhami, B., Bist, B. S., Basyal, C. R., et al. 2023. Factors influencing the habitat selection of Mugger crocodile (*Crocodylus palustris*) and its conservation threats in the Rapti River of Chitwan National Park, Nepal. Global Ecology and Conservation **42**:e02406.

Poudyal, L., Dahal, B., Lamichhane, B. and Shrestha, P. 2018. Population status and distribution of Gharial in Rivers of Chitwan National Park, Government of Nepal. Ministry of Forest and Environment, Kathmandu, Nepal.

Racine, J. S.2012. RStudio: a platform-independent IDE for R and Sweave. JSTOR.

Rajbhandari, S. L. and Acharya, P. M. 2013. Population, basking and hatching success of Gavialis gangeticus in Narayani river, Chitwan national park, Nepal. Journal of Natural History Museum **27**:1-11.

Rootes, W. L. and Chabreck, R. H. 1993. Reproductive status and movement of adult female alligators. Journal of Herpetology:121-126.

Shah, K. B. and Tiwari, S. 2004. Herpetofauna of Nepal: A conservation companion.

Signorell, A., Aho, K., Alfons, A., Anderegg, N., Aragon, T., Arppe, A., et al. 2019. DescTools: Tools for descriptive statistics. R package version 0.99 **28**:17.

Sing, T., Sander, O., Beerenwinkel, N. and Lengauer, T. 2005. ROCR: visualizing classifier performance in R. Bioinformatics **21**(20):3940-3941.

Stevenson, C. and Whitaker, R. 2010. Gharial *Gavialis gangeticus*. Crocodiles. Status survey and conservation action plan **139**:143.

Team, R. C. 2016. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. http://www. R-project. org/.

Thapaliya, B. P., Khadka, M. and Kafley, H. 2009. Population status and distribution of Gharial (*Gavialis gangeticus*) in Nepal. The Initiation **3**:1-11.

United Nations Educational, S. and Organization, C.2016. Global Education Monitoring Report Summary 2016: Education for People and Planet: Creating Sustainable Futures for All. United Nations Educational, Scientific and Cultural Organization Paris, France.

Vashistha, G., Lang, J. W., Dhakate, P. M. and Kothamasi, D. 2021. Sand addition promotes gharial nesting in a regulated river-reservoir habitat. Ecological Solutions and Evidence **2**(2):e12068.

Venugopal, P. D. and Deviprasad, K. 2003. Basking behaviour and survey of marsh crocodiles, *Crocodylus palustris* (Lesson, 1831) in Ranganthittu Bird Sanctuary, Karnataka, India. HAMADRYAD-MADRAS- **27**:241-247.

Wagle, B. H. 2010. Institutional strengthening and awareness raising project for sustainable crocodile Conservation in Nepal. Rufford Small Grants Foundation, UK.

Whitaker, R. and Basu, D. 1982. The gharial *(Gavialis gangeticus*): A review. Journal of the Bombay Natural History Society. Bombay **79**(3):531-548.

Whitaker, R., Rajamani, V., Basu, D. and Balakrishnan, V. 1974. Preliminary survey of the Gharial, *Gavialis gangeticus*. Madras Snake Park Trust Report **16**.

Whitaker, R. and Whitaker, Z. 1989. Ecology of the mugger crocodile. Crocodiles, their ecology, management, and conservation:276-296.

Zhang, Z. 2016. Model building strategy for logistic regression: purposeful selection. Annals of translational medicine **4**(6).

Appendix 1. Datasheet for habitat use survey

Presence/ Absence	Lat	Long	DTF	DTS	Slope	Aspect	WC	HD	RBST

Appendix 2. Photographs showing activities of Gharials and Mugger within their Habitats

Photograph: Gharial basking along riverbank and few submerged in water

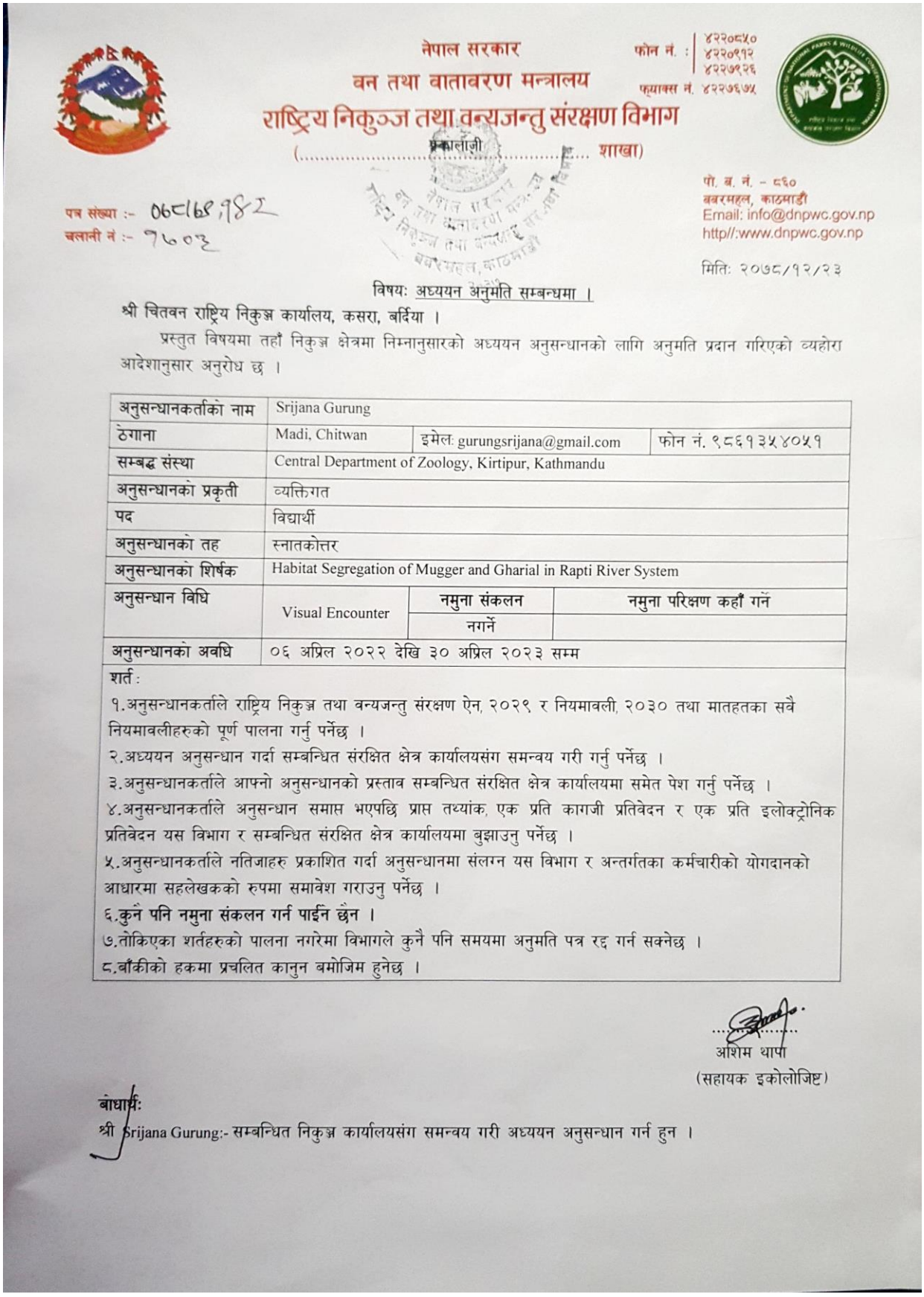
Photograph: Mugger basking along the riverbank

A

B

Photograph A and B: Coexistence of Gharial and Mugger

Appendix 3. Permission letter



नेपाल सरकार
वन तथा वातावरण मन्त्रालय
राष्ट्रिय निकुञ्ज तथा वन्यजन्तु संरक्षण विभाग
(.....प्रकाशी..... शाखा)

फोन नं. : ४२२०८५०, ४२२०९१२, ४२२७९२६
फ्याक्स नं. ४२२७६७५

पो. ब. नं. - ८६०
बबरमहल, काठमाडौं
Email: info@dnpwc.gov.np
http//:www.dnpwc.gov.np

पत्र संख्या :- ०७८।७८।१८२
चलानी नं :- ७६०३

मितिः २०७८/१२/२३

विषयः अध्ययन अनुमति सम्बन्धमा ।

श्री चितवन राष्ट्रिय निकुञ्ज कार्यालय, कसरा, बर्दिया ।

प्रस्तुत विषयमा तहाँ निकुञ्ज क्षेत्रमा निम्नानुसारको अध्ययन अनुसन्धानको लागि अनुमति प्रदान गरिएको व्यहोरा आदेशानुसार अनुरोध छ ।

अनुसन्धानकर्ताको नाम	Srijana Gurung		
ठेगाना	Madi, Chitwan	इमेलः gurungsrijana@gmail.com	फोन नं. ९८६१३५४०५१
सम्बद्ध संस्था	Central Department of Zoology, Kirtipur, Kathmandu		
अनुसन्धानको प्रकृती	व्यक्तिगत		
पद	विद्यार्थी		
अनुसन्धानको तह	स्नातकोत्तर		
अनुसन्धानको शिर्षक	Habitat Segregation of Mugger and Gharial in Rapti River System		
अनुसन्धान विधि	Visual Encounter	नमुना संकलन	नमुना परिक्षण कहाँ गर्ने
		नगर्ने	
अनुसन्धानको अवधि	०६ अप्रिल २०२२ देखि ३० अप्रिल २०२३ सम्म		

शर्तः

१.अनुसन्धानकर्ताले राष्ट्रिय निकुञ्ज तथा वन्यजन्तु संरक्षण ऐन, २०२९ र नियमावली, २०३० तथा मातहतका सबै नियमावलीहरुको पूर्ण पालना गर्नु पर्नेछ ।

२.अध्ययन अनुसन्धान गर्दा सम्बन्धित संरक्षित क्षेत्र कार्यालयसंग समन्वय गरी गर्नु पर्नेछ ।

३.अनुसन्धानकर्ताले आफ्नो अनुसन्धानको प्रस्ताव सम्बन्धित संरक्षित क्षेत्र कार्यालयमा समेत पेश गर्नु पर्नेछ ।

४.अनुसन्धानकर्ताले अनुसन्धान समाप्त भएपछि प्राप्त तथ्यांक, एक प्रति कागजी प्रतिवेदन र एक प्रति इलोक्ट्रोनिक प्रतिवेदन यस विभाग र सम्बन्धित संरक्षित क्षेत्र कार्यालयमा बुझाउनु पर्नेछ ।

५.अनुसन्धानकर्ताले नतिजाहरु प्रकाशित गर्दा अनुसन्धानमा संलग्न यस विभाग र अन्तर्गतका कर्मचारीको योगदानको आधारमा सहलेखकको रुपमा समावेश गराउनु पर्नेछ ।

६.कुनै पनि नमुना संकलन गर्न पाईने छैन ।

७.तोकिएका शर्तहरुको पालना नगरेमा विभागले कुनै पनि समयमा अनुमति पत्र रद्द गर्न सक्नेछ ।

८.बाँकीको हकमा प्रचलित कानुन बमोजिम हुनेछ ।

अशिम थापा
(सहायक इकोलोजिष्ट)

बोधार्थः
श्री Srijana Gurung:- सम्बन्धित निकुञ्ज कार्यालयसंग समन्वय गरी अध्ययन अनुसन्धान गर्न हुन ।