

PhD
Dissertation

Diversity and Conservation of Wild Mammals and Tree Species in a Protected Area of Southeast Bangladesh



A dissertation
submitted to the University of Dhaka for the degree of
DOCTOR OF PHILOSOPHY

By
Bipul Krishna Das
Roll No-01
Registration No. 21
Session: 2022-2023

August, 2026

Department of Zoology
University of Dhaka
Dhaka-1000, Bangladesh

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DEDICATION

Dedicated to my daughter

ANINDITA ANANYA DAS MEGHLIN

and

my elder son

ANINDYA ARANYA DAS

&

lovely younger son

ADITYA ADIDEB DAS ROHAN

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August, 2026

Bipul Krishna Das

CERTIFICATE

This is to certify that the research work presented in the dissertation entitled “**Diversity and Conservation of Wild Mammals and Tree Species in a Protected Area of Southeast Bangladesh**”, submitted by **Bipul Krishna Das** in partial fulfillment of the requirements for the degree of **Doctor of Philosophy (PhD) in Zoology** at the **University of Dhaka, Bangladesh**, is the result of original research carried out by him under our supervision.

To the best of our knowledge, the research work reported in this dissertation has not been submitted, either in whole or in part, for any other degree or diploma at this or any other university or institution.

Supervisor

Dr. Mohammad Firoj Jaman
Professor
Department of Zoology
University of Dhaka

Co-Supervisor

Dr. Mohammed Jashim Uddin
Professor
Institute of Forestry and Environmental
Science
University of Chattogram

DECLARATION

I hereby declare that the dissertation entitled “**Diversity and Conservation of Wild Mammals and Tree Species in a Protected Area of Southeast Bangladesh**” is my original work and has been carried out by me. All sources of information have been properly acknowledged through appropriate citations.

I further declare that this dissertation has not been submitted, in whole or in part, to any other university or institution for the award of any degree or diploma.

August, 2026

Bipul Krishna Das

ABSTRACT

Protected areas in torrid zone are progressively susceptible to habitat fragmentation, anthropogenic pressure, and governance limitations, elevating major issue about their efficacy in conserving biodiversity. This research was conducted between November 2022 and March 2026. This study illustrates and evaluates mammalian persistence, forest structure and regeneration, spatial distribution of biodiversity, threats analysis through community perceptions, and governance challenges to establish an empirical foundation for conservation and management of the Inani National Park, a fragmented critical tropical protected forest of southeastern Bangladesh.

Field investigations were executed between November 2022 and June 2024, applying a multi-pronged approach. Consistent line transects and considerable camera trapping, generating over 4,700 trap-days of data were utilized for the estimation of mammalian diversity and persistence. Imperfect detection was determined through occupancy modeling, while species distribution modeling using the MaxEnt algorithm was applied to map habitat suitability and find out biodiversity hotspots. Stratified random sampling across 131 plots representing four land-cover strata were utilized for analyzing forest vegetation composition, structure, and regeneration dynamics of the park. Socio-ecological parameters were analyzed through structured community surveys (n=271) and semi-structured KII stakeholder interviews (n=43) for evaluation of community perceptions, human-wildlife conflict, and protected area governance potency.

A total of 23 species of wild mammals, inclusive of globally threatened species were recorded during this study. Habitat heterogeneity such as undisturbed hill forests and shrub-dominated mosaics assisting the highest diversity significantly impacted mammalian richness and persistence, especially during the monsoon. It is very enthusiastic that the first confirmed photographic and field evidence of a few survivors population of the threatened species clouded leopard (*Neofelis nebulosa*) in degraded protected forest, Inani National Park (INP) was identified through the study. Occupancy modeling divulged nearly finished sites used by the Asian Elephant, while evasive carnivores such as the clouded leopard exhibits low detection probability and confined occupancy, validating the persistence of a minuscule and vulnerable population. Species distribution models pinpointed profound biodiversity hotspots such as riparian corridors and southern forest patches, accentuated their significance for habitat connectivity within the fragmented forest landforms.

In total 66 tree species across 33 families and 90 regenerating species were recorded through vegetation analyses, which indicating average but spatially uneven diversity. Shrub-dominated strata demonstrated higher species richness and regeneration potential, whereas plantation and heavily modified areas showed simplified structure and limited recruitment of late-successional species. The dominance of invasive and pioneer taxa exhibits ongoing disturbance and ecological imbalance.

Taken as a whole, this dissertation confirmed Inani National Park as a biologically important yet extremely vulnerable refuge and ecological corridor. By incorporating ecological, spatial, and governance analyses, the research offers a comprehensive conservation foundation highlighting habitat restoration, assisted natural regeneration, protection of riparian corridors, conflict mitigation, and strengthened participatory governance. The findings furnish to more extensive insight of protected area effectiveness in the Global South and suggest implementation guidelines for biodiversity conservation and better management in degraded tropical landscapes.

PUBLISHED ARTICLES FROM THE STUDY

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Chapter 1

GENERAL INTRODUCTION

1.1. Biodiversity: The Foundation of Life on Earth

The expression "biodiversity" is derived from the fundamental word "diversity," in combination with the prefix "bio-" (DeLong, 1996). This prefix "bio-" derives from the Greek word "bios," denoting life (Gove et al., 1993). The terms "biological" and "biotic" confines the scientific study of life, encompassing living organisms, their communities, and their variegated functions and interactivities (Allaby, 1994). This abbreviated term came to renown in the mid-1980s, propelled by a 1986 symposium and the seminal publication "Biodiversity" (Wilson, 1988). While these events are constantly cited as the genesis of biodiversity critique, they also admitted prior scholarly contributions while simultaneously catalysing a new era of scientific study and conservation consciousness, the full ramifications of which were not initially predictable. Gradually, the emphasis on variety of life has been displayed in the Convention on Biological Diversity's (CBD) definition of "biodiversity" and the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES). The IPBES conceptual framework, which outlines "nature's contributions to people" (Díaz et al., 2018), includes the issue that biodiversity suggesting solutions for future generations (see Faith forthcoming). This value of living variation complements the recognised value of individual species and line up with the notion that "biodiversity" can mention both to the collection of individual species (or other units) and to this amount of variation within that collection (Faith, 2023).

According to the United Nations (UN), biodiversity refers to all sorts of life on Earth, comprising plants, animals, bacteria, and fungi. It's the diversification within and between species and the different ecosystems they create (UN, 2024). This complicated system of life is indispensable for human survival and economic stability. Over half of the world's economy depends on natural ecosystems, with forests supporting the livelihoods of over a billion people (United Nations, 2023). Biodiversity provides us with food, medicine, and resources treated as the backbone of our economy. It has vital role in combating climate change by absorbing carbon emissions. So, protecting biodiversity is crucial for nature and our economic well-being, making conservation an utmost priority (UN, 2024). Nevertheless, anthropogenic activities are firmly responsible for the decline of biodiversity at worrisome speed due to remarkable drivers include habitat destruction, pollution, overexploitation, and climate change (IPBES, 2019; Díaz et al., 2019). IPBES Global Assessment Report divulged that near about one million species are at risk of extinction, many within the decades ahead, unless paradigm shift is made to reduce the effect of human activities on natural systems (IPBES, 2019). Initiatives to protect biodiversity focus on preserving natural habitats, restoring degraded ecosystems, and encouraging sustainable practices. The prime objectives of the Convention on Biological Diversity (CBD) to resolve these issues through international cooperation and policy implementation and the organization's Conservation strategies also accentuate integrating biodiversity studies into economic planning and development process (CBD, 2020).

1.2. Guardians of Diversity: Protected Areas as Biodiversity Strongholds

The protected areas play as crucial refuges for diverse plant and animal species that are recognized as foundations to biodiversity conservation. Protection of deforestation and habitat fragmentation, these designated zones by mitigating anthropogenic disturbances facilitate the maintenance of ecosystem and the preservation of genetic diversity. A substantial pragmatic interrelation between the extension of forest protection and numerous parameters of biodiversity health—such as species richness, species abundance, and overall ecosystem integrity has been illustrated in multiple ecological studies (Convention on Biological Diversity, 2020). Protected areas preserve existing biodiversity and play a pivotal role in the recovery of threatened species, while maintaining the functioning of vital ecological processes. As such, they are indispensable tools for mitigating the existing global biodiversity adversity (Watson et al., 2014).

A protected area (PA) denotes a distinct geographic place recognized and managed for long-term nature conservation, covers its ecosystem services and cultural values, through legal or other actions (Dudley, 2013). The establishment and maintenance of PAs are prerequisite mechanisms to preserve nature's functions and values (Mace et al., 2008), playing crucial roles in biodiversity conservation while also serving people (Juffe-Bignoli et al., 2014). The Main Ridge Forest Reserve is the world's first protected area, established in 1776 primarily to conserve rainfall for agricultural production, delineating the inception of a global conservation action that has extended to more than 202,000 protected areas worldwide, now cover nearly 15% of the Earth's terrestrial surface with a goal to expand this coverage to 17% (UNEP-WCMC, 2017).

For amplifying effective conservation strategies in PAs, especially in developing tropical countries, it is significant to collect basic biodiversity information, such as species checklists and wildlife distribution, to help decision-makers prioritize areas and implement effective conservation actions (Bernard et al., 2014). Declaring forest lands as PAs is a key step towards sustainable forest and biodiversity conservation in terrestrial ecosystems, coping with Bangladesh's conservation priorities through the designation of various PA categories, including national parks, biodiversity conservation areas, eco-parks, and wildlife sanctuaries (Mukul et al., 2008).

1.3. Ecological and Geographical Setting of Bangladesh

The world consists of five Global Ecological Domains and twenty Global Ecological Zones (GEZ) based on both living and non-living components of ecosystems, incorporating climate, vegetation, and ecological characteristics (Food and Agriculture Organization, 2000). Two zones of the Tropical Domain such as the Tropical Rainforest GEZ (23%) and the Tropical Moist Deciduous Forest GEZ (67%) fall over Bangladesh. The forests prevail in the central, northeastern, and southeastern regions of the country mainly belong to the Tropical Rainforest GEZ. Moreover, 25 bio-ecological zones in Bangladesh, each marked by definite environmental conditions formed by changes in temperature, rainfall, soil composition, and hydrological scheme (FAO, 2012). Bangladesh's unique climatic conditions and geographical position mark it one of the most biodiverse regions in South Asia. The country extends approximately 147,570 km², extending between 20°34' and 26°38' N latitude and 88°01' and 92°41' E longitude, situated in the northeastern part of the Indian subcontinent. Bangladesh

is intersected by the Tropic of Cancer and experiences a subtropical monsoon climate. It is dominated by extensive floodplains landscapes formed by the confluence of major river systems, including the Padma, Meghna, and Jamuna, which cover about 80% of the land area, while the remaining terrain consists of hilly regions (about 12%) and Pleistocene terraces (approximately 8%) (FAO, 2015).

1.4. Protected Areas and Wildlife Conservation Framework in Bangladesh

A protected area network principally created in Bangladesh to conserve its rich wildlife heritage. Although the historical basis of forest management practices started from the Mughal Empire era, some of these reserves find their roots date back to the 1960s. At the beginning, Forests were initially conserved for sport hunting by local rulers during the colonial era and subsequently the British Colonial administration later acquire control of the forests, declaring certain areas as reserves where clear-cutting was forbidden (GOB, 2015). The establishment of the Forest Department in 1865 pronounced a remarkable landmark, succeed by legislative advancements post-independence, especially, the Bangladesh Wildlife (Conservation and Security) Act of 2012 (FAO, 2020).

Wildlife (Conservation and Security) Act, 2012 of Bangladesh accommodated legal definitions for National Parks and Wildlife Sanctuaries and underscores biodiversity conservation, habitat protection, and public awareness. Nevertheless, despite legal protections, challenges prevail in enforcing law and regulations owing to insufficient resources, logistical constraints, and shortages of skilled manpower within the Forest Department (GOB, 2012). Consequently, illegal resource exploitation remains a major issue for conservation.

Bangladesh has attempted a significant number of initiatives to conserve its plant and wildlife diversity, major in the establishment of Protected Areas (PAs) and the preparation of national conservation strategies. At present, 57 PAs have been declared across the country acting as both in-situ and ex-situ conservation sites for biodiversity conservation and ecosystem protection (Bangladesh Forest Department, 2025). These protected areas perform critical tasks toward safeguarding biodiversity. Nonetheless, their effectiveness of such measures remains unattainable and constraints. In spite of these, some progress notable in policy development, the practical implementation of conservation strategies—especially for floral diversity—continues to face challenges pertinent to enforcement, management capacity, and long-term sustainability. Mitigating these limitations is vital to ensure the effective protection and conservation of Bangladesh's unique and diverse plant and wildlife resources (Islam et al., 2018).

Table 1.1: Protected Areas in Bangladesh

Type of PAs	No. of PAs	Areas (Hectares)
National Park	19	53536.60
Wildlife Sanctuary	27	415925.75
Botanical Garden	1	87.13
Marine Protected Area	2	348100.00
Special Biodiversity Area	3	279.88
Eco Park	4	383.16
National Heritage and Kunjubon	1	1.37
Total	57	818313.89

(Bangladesh Forest Department, 2025)

1.5. Biodiversity and Forest Resources of Bangladesh

Bangladesh is home to various flora and fauna in diverse natural ecosystems, including forests, coastal and marine areas, and freshwater wetlands (Hossain et al., 2020). A total of 2,260 plant species in the Chittagong Forest area alone of the country reflecting the rich biodiversity fostered by favorable geographical and climatic conditions (Department of Environment, 2015). Bangladesh covers 1.45 million hectares of forest land, representing 9.8% of its total country's area, which includes 1.21 million hectares (84%) of natural forest and 0.24 million hectares (16%) of plantation (NFA, 2007). The Sundarbans and Tanguar Haor are recognized worldwide for their rich biodiversity. The major wildlife habitats include forests, wetlands, marine areas, bushy and grassy regions, bamboo-dominated areas, and village groves in Bangladesh (Khan, 2018). Despite this diversity, Bangladesh has only 17.47% of forest land (BFD, 2019), which cannot fulfill the demand to maintain ecological balance and meet the demands of the growing population. In recent survey, Forest cover in Bangladesh is calculated to be about 1.78 million hectares, which encircle approximately 12.08% of the country's total landmass (NFI 2023-24, Bangladesh Forest Department); When only terrestrial land area is considered (i.e. excluding Perennial Beels/Haors, Laks, Baor, Ponds, Rivers and Khals), the forest cover is 13.44%. The Hill Forest (29.84%), Shrubs with Scattered Tree (27.48%), and Mangrove Forest (22.09%) contribute to most to the country's total forest area. These small-scale forest areas are also under threats from illegal logging, encroachment, and land-use changes, leading to significant genetic resource erosion and negative impacts on ecosystem functioning (Hossain, 2011).

1.6. Global Status and Conservation Challenges of Mammalian Biodiversity

Wildlife generally is regarded as animals, plants, and other organisms spend lifetime in wild environments without direct human interference. Even though different countries and legal frameworks adopted separate definitions, wildlife commonly encircle wild vertebrates such as mammals, birds, reptiles, and amphibians, while fish are often defined independently within fisheries management systems (IUCN, 2016). Mammals are a group of warm-blooded vertebrates differentiated by the presence of mammary glands, even if which females produce milk to nourish their offspring. They are typically identified by a body covered with hair and skin containing numerous glands. Mammals inhabit a wide range of habitats, including terrestrial, arboreal, aquatic, and subterranean environments (Coleman & Schapiro, 2021). Some species of mammals, for instance bats, possess the power to fly, while others, like flying squirrels have the capable of gliding. Humans are in the class of vertebrates as treated one of the most evolutionarily advanced groups of animals (Khan, 2018). Their impacts on ecosystems are considered as crucial indicators (Ceballos and Ehrlich, 2002) and play critical roles in ecosystem functionality through activities like seed dispersal, pollination, nutrient cycling, and influencing plant succession (Ripple et al., 2015). They are beneficial to humans by providing food, recreation, and income (Naidoo et al., 2016). Thus, understanding the existence and distribution of mammals is paramount for effective conservation planning (Tobler et al., 2008).

The International Union for Conservation of Nature reported that the number of Critically Endangered species and Endangered species surged accordingly from 169 to 203 and from 315 to 506 between 1996 and 2020 indicating escalating threats to mammalian biodiversity worldwide (IUCN, 2020a). In Tropical Asia, which supports a high diversity of threatened mammals, conservation concerns are exceptionally acute. It is projected that 9–36% of lowland forest mammals in Southeast Asia could become extinct by 2100 if present trends of habitat loss and exploitation remain unchanged (Wilcove, D.F. et al., 2013). In spite of their importance, numerous protected areas in Tropical Asia absence of stringent protection measures (Watson et al., 2014). Although tropical regions account for only 7% of the world's land area (Bradshaw et al., 2009), they harbor approximately two-thirds of global biodiversity (Raven, 1988). Anthropogenic activities such as deforestation, habitat fragmentation, and land-use change cause major threats in these biodiverse regions. (Tiller et al., 2019), while Southeast Asia facing severe impacts of these issues (Hughes, 2017). What is more, “Political commitment to biodiversity conservation in many quickly developing regions remains relatively weak, which further enhance current conservation challenges and undermines effective implementation of environmental policies (IPBES, 2019).

1.7. Conservation Policies and Wildlife Management in Bangladesh

Bangladesh, located within the subtropical belt at the confluence of the Indo-Himalayan and Indo-Chinese biotic sub-regions, acts as a critical land bridge and ecological corridor. The country's rich ecological significance and high biological diversity are reinforced due to its unique geographical position. Bangladesh anchorages numerous wildlife species representative of both biotic sub-regions, including the Northern Plains Langur from the Indo-Himalayan region and Phayre's Langur (*Trachypitecus phayrei*) from the Indo-Chinese region (Khan, 2018; IUCN, 2023).

Bangladesh exhibits a strong commitment to biodiversity conservation, especially in the conservation of wildlife, as enlisted in Clause 18A of its Constitution. This provision mandates the state to enhance environmental protection and safeguard natural resources, including wetlands, forests, and wildlife, for the welfare of both existing and future generations. Furthermore, Bangladesh maintains robust co-operation with the international community to encourage the sustainable use and conservation of biodiversity incorporating wildlife as a signatory country to the Convention on Biological Diversity (CBD), (Khan, 2018). Bangladesh's legal framework delivers immense protection for wildlife and their habitats through prevailing statutes such as the Wildlife (Conservation and Security) Act of 2012, the Forest Act of 1927, and the Bangladesh Environment Conservation Act of 1995 (FAO, 2020). In addition, Bangladesh is a contracting party to several international conventions concentrated on conservation, encompassing CITES, the Ramsar Convention, the World Heritage Convention, and the CMS, signifying its dedication to global biodiversity strategies. The government has prepared core strategies and policies, for instance the Bangladesh Wildlife Conservation Master Plan 2015-2035, the National Biodiversity Strategy and Action Plan (2016), and the Bangladesh National Conservation Strategy (2017), to secure potential wildlife conservation and management (Khan, 2018).

Even so, in spite these efforts, a significant number of threats, such as habitat loss and degradation driven mainly by anthropogenic activities impacted massively the wildlife of Bangladesh. Other notable difficulties illustrate illegal hunting, poor law enforcement, corruption, invasive species proliferation, pollution, unsustainable tourism, and the effects of climate change. An extensive strategy encompassing policy reforms, strengthened enforcement, public engagement, and ecosystem-based conservation mechanisms are utmost needed to address these issues properly (Khan, 2018).

1.8. Mammalian Diversity and Conservation Status in Bangladesh

Bangladesh is supposed to provide refuge 138 mammal species, inclusive of nine marine mammals. Among these, 40 species are threatened, encompassing 19 critically endangered, 12 endangered, and 9 vulnerable species, demanding the country's profound conservation importance. Regardless this richness, mammalian diversity encountering severe threats, with at least 11 species by this time documented as nationally extinct (IUCN Bangladesh, 2015). These trends accentuate both the ecological value of mammals in Bangladesh and the utmost need for complete assessments to support fruitful conservation strategies.

The Government of Bangladesh has already recognized 57 forest protected areas, incorporating two marine protected areas, managed by the Forest Department to protect mammalian diversity (Bangladesh Forest Department, 2025). Bangladesh Forest Department sincerely involves in habitat enhancement through afforestation, reforestation, and ecosystem restoration projects and programs. Moreover, the government assists research initiatives under multiple projects to strengthen wildlife management and conservation. Conservation efforts also prioritize keystone species, for instance tigers, elephants, dolphins, and Western Hoolock Gibbons, as a strategy to protect smaller mammals and maintain ecological balance (Bangladesh Forest Department, 2025; Khan, 2018; GOB, 2012). In 2010, Bangladesh initiated and implemented a compensation policy to mitigate human-wildlife conflicts, particularly those engaging tigers, elephants, and crocodiles. Elephant Response Teams and Village Tiger Response Teams were established with active community participation nationwide to assist the implementation of this initiative. Complementary year-round efforts, including awareness campaigns, celebrations, training programs, seminars, and workshops, are conducted to tackle existing conservation challenges and foster coexistence between humans and wildlife (Khan, 2018)

1.9. Background of the Research

Mammals are endangered globally, including in Bangladesh especially Cox'sBazar Region, primarily due to habitat loss, modification, and other anthropogenic disturbances. Inani National Park is a designated protected area in southeast Bangladesh. Government officially declared it a national park on April 15, 2019, with the announcement published in the Bangladesh Gazette on July 9, 2019. This declaration was made under Section 17 of the Bangladesh Wildlife (Conservation and Security) Act, 2012, to protect the natural forest resources and wildlife (GOB, 2019). The Park (INP) is Classified as a Tropical Evergreen Forest, characterized by its dense evergreen trees, with a canopy dominated by vast and tall specimens. The forest possesses a rich diversity of flora, inclusive of valuable species such as Chapalish, Chundul, Pitraj, Uriam, Toon, and Jam. The primary timber species, Garjon, Jarul,

Toon, Chapalish, Telsur, Boilam, Gamar, Kamdeb, Kom, Tali, and Gab were found in the 1920s, (Ahmed, 1992). Apart from its botanical significance, INP plays as a critical habitat for numerous threatened wildlife species, accentuating its importance for biodiversity conservation and overall ecosystem process (Khan, 2018).

Inani National Park (INP) harbors flagship species like the Asian Elephant, Western Hoolock Gibbon, and other wild mammals. These mammals reside in different forest strata, exploiting diverse canopy levels within the park, generating the structural web of the forest and its function in assisting different mammalian communities (Khan, 2018; IUCN Bangladesh, 2015). Mammalian species in Bangladesh, especially in the Cox's Bazar region, encountering substantial anthropogenic threats from habitat loss, poaching, and other human-induced pressures. The only minuscule level biodiversity monitoring attempt in the Inani Forest was conducted by the Department of Zoology at Jahangirnagar University in 2014. No further systematic study has been conducted after the official declaration of Inani National Park, demanding a critical gap resolution from realistic baseline data necessary for effective conservation planning and management (Khan, 2018). Furthermore, the inexistence of devoted botanical and zoological survey organizations has led to in a lack of complete inventories of Bangladesh's flora and fauna, restraining impactful conservation planning and biodiversity management (Hossain et al., 2017). INP lies within the Indo-Burma Biodiversity Hotspot and demonstrates as a critical ecological zone in Bangladesh. This forest PA acts as a profound Asian Elephant corridor between Myanmar and Bangladesh (Kabir et al., 2021; IUCN Bangladesh, 2018). Taking into account, the ecological gravity of this crucial protected area, the study was carried out to identify major threats and explore potential management strategies. Effective management of ecosystems for Inani National Park (INP) claims thorough research, systematic monitoring, and the evaluation of site-specific conservation strategies. This study also aims to address present knowledge gaps and deliver evidence-based insights that can notify policy recommendations, thus, supporting the long-term conservation and sustainable management of the protected area (Watson et al., 2014; GOB, 2012; Khan, 2018).

AIM AND OBJECTIVES

The aim of this study is to explore biodiversity conservation potential at Inani National Park (INP), Cox's Bazar

Objectives:

- 1. Assess the Diversity of Wild Mammals in INP**
- 2. Assess the Tree Species Diversity in INP**
- 3. Identify the Threats and Conservation Needs of the Wild Mammals and Tree Species in INP**
- 4. Recommend Proper Management Practices for the Conservation of Wild Mammals and Tree Species in INP**

Chapter 2

LITERATURE REVIEW

Introduction

Biodiversity assessments play a key role in the preservation and administration of natural habitats (Pielou 1995). It encircles three interrelated dimensions: genetic diversity, species diversity, and ecosystem diversity. Genetic diversity refers to the variety of genes exist within a certain species, whereas species diversity demonstrates the richness and abundance of different species within a particular area. The resilience, functionality, and adaptability of ecosystems totally depend on these dimensions (Gaston & Spicer, 2004). Ecosystem diversity occupies a immense challenge for assessment, as it includes a wide array of sub-ecosystems within a larger ecosystem, each assisting specialized vegetation and distinctive ecological processes (Gaston & Spicer, 2004). To achieve a comprehensive understanding of ecosystem diversity, it is crucial to investigate the communities inhabiting diverse ecological niches. Each niche supports specific species complexes that simultaneously influence the overall composition, structure, and functioning of biodiversity within an ecosystem (Gaston & Spicer, 2004). Sustaining ecosystem functionality through biodiversity conservation is paramount, although identifying the species critical for this purpose can prove daunting (Burton et al., 1992). Proficient forest management necessitates precise data regarding forest composition, which is presently constrained (Wyatt-Smith, 1987). Understanding the distribution, abundance, and dynamics of tree species within a forest is important, and systematic documentation of flora and regeneration is crucial for preparing effective conservation strategies (Whitmore, 1998). It is essential to thoroughly understand the status and composition of biological resources, particularly tree species for the effective conservation and management of natural resources (Hossain et al., 2017).

2.2. Forest Dynamics and Ecosystem Services: The Critical Role of Trees

The occurrence of trees within a forest ecosystem employs an intense influence on the microclimate, regulating components such as light availability, soil moisture, and ambient temperature, which in turn modify ecosystem processes and biodiversity patterns (Berman et al., 2012). Trees provide habitats for wildlife and contribute significantly to the ecosystem by producing oxygen, sequestering carbon dioxide, stabilizing soil (Bratman et al., 2015). Moreover, trees supply materials for shelter and tools, reduce wind speeds, and cool the surrounding air (Jeje et al., 2021). In urban settings, trees can diminish temperatures by as much as 7 degrees (Omoro *et al.* 2010). In addition, trees play a pivotal function in mitigating flooding and soil erosion and act as the foundation of the ecosystem by facilitating carbon sequestration, forming watersheds, providing shade, harboring diverse life forms, and serving as natural purifiers in tropical rainforests (Fuwape and Onyekelu, 2011). However, the quick depletion of forest resources has expressed concerns about their ability to support economic improvement and deliver ecosystem services, as like carbon storage and biodiversity conservation (Piotto et al., 2009). Solving the issue requires a science-based approach to forest management, conservation, and improvement, with forest monitoring playing a vital role in this endeavor. Monitoring supports to install a baseline of forest dynamics over time, assisting early detection of

fluctuations and the necessity for management interventions. According to Jenkins et al. (2002), monitoring is paramount for pinpointing the "normal" range of forest dynamics and identifying the need for timely management interventions.

Complete knowledge of plant types and their diversity, as highlighted by Gentry (1988), is important for understanding the structural and functional dynamics of forest ecosystems (Tang et al., 2016). Recent studies further underscore that analyzing vegetation composition, species diversity, and forest structure is critical for evaluating forest sustainability, conserving species, assessing ecological significance, and designing effective forest management strategies (Kacholi, 2014)

2.3. Estimation of Floral Diversity from the Global Perspective

The demographic structure of tree species within a forest is illustrated by the distribution of individuals across specific girth classes. Population structure reveals the regeneration behavior of tree species (Saxena & Singh, 1984). The occurrence of an ample number of seedlings, saplings, and young trees within a population indicates successful regeneration (Pokhriyal et al., 2010). The quantity of seedlings of a specific species serves as an indicator of its potential regeneration (Negi & Nautiyal, 2005). Regeneration stands as a crucial feature of tropical forest ecosystem dynamics (Getachew et al. 2010), playing a vital role in conserving and conserving biodiversity (Rahman et al., 2011). However, Various disturbances such as logging, landslides, canopy gap formation, litterfall, and herbivory can significantly influence the regeneration potential of forest stand species across spatial and temporal scales (Guarino & Scariot, 2012). Researchers have employed various diversity indices to quantify species diversity in ecological studies, including species richness, the Shannon index, the Simpson index, and the complement of the Simpson index (DeFries et al., 2010). While numerous studies have explored plant diversity across different regions worldwide, studying plant diversity over specific locations with time remains crucial.

Table 2.1: List of different studies used for estimation of floral diversity on global scale

Study Details	Major Findings
Name of the study: "Assessment of tree species diversity and its distribution pattern in Pachamalai Reserve Forest, Tamil Nadu" Author(s): Suganthi et al., 2016 Vegetation sampling was conducted using the quadrat method, where 10×10 m plots were established at different altitudes ranging from 230 to 930 m with regular 50 m intervals.	• A total of 73 tree species belonging to 35 families, comprising 1,372 individuals, were recorded. • The family Fabaceae was the most dominant, represented by 21 species. • <i>Pongamia pinnata</i> exhibited the highest density among tree species, while <i>Tamarindus indica</i> showed the greatest dominance in terms of basal area. • Species diversity was assessed using the Shannon–Wiener index (3.916), Simpson index (0.0206), and Margalef richness index (9.9667). • Species richness was highest in the mid-elevation zone between 580 and 780 m. • These findings contribute to the monitoring and sustainable management of forest resources, helping to

Study Details	Major Findings
	prevent biodiversity loss and support climate change mitigation.
Name of the Study: “Assessment of diversity, population structure and regeneration status of tree species in Hollongapar Gibbon Wildlife Sanctuary, Assam, Northeast India” Author(s): Sarkar & Devi, 2014 Sampling method(s): random plot sampling method consisting of 100 quadrats measuring 10x10 meters	• A total of 75 species of trees belonging to 60 genera and 40 families; • The highest density (7756 individuals. ha⁻¹) and species richness (73) were recorded in the 0-30 cm girth class, while the highest basal area (9.62 m². ha⁻¹) was observed in the 120-150 cm girth class. • The majority of the tree species (36%) exhibited a 'fair regeneration' condition, followed by a 'good regeneration' status (24%).
Name of the Study: “Diversity assessment of tree species in Sitio Dicalarin, Barangay Zabali, Baler, Aurora Philippines” Author(s): Coracero & Malabrigo, 2020 Sampling method(s): 20 · 20 m quadrat was established at every 250 m interval along each transect at the left and right of the existing trail;	• The investigation revealed 2,239 individuals belong to 139 morphospecies, 87 genera, and 46 families in the study area. • 48 Philippine endemic species and two species endemic to Aurora Province were identified. • Minimum 29 threatened species were documented, listed in the <i>IUCN Red List of Threatened Species</i> or the Philippine List of Threatened Species. • The findings signified that high biological diversity in the study area which remained relatively well protected, suggesting effective management of the ecosystem.
Name of the Study: “Assessment of the diversity and abundance of tree species in Afe Babalola University, Ado-Ekiti, Ekiti State, Nigeria” Author(s): Jeje et al., 2021 Sampling method(s): stratified sampling method.	• The study revealed a total of 816 individual trees belonging to 21 tree species from 16 families. • The Aracaceae family had the highest number of species (3 or 14% of the total species), while the Caesalpiniaceae, Combretaceae, and Verbenaceae families had 2 species each. • The remaining families (Anacardiaceae, Annonaceae, Apocynaceae, Araucariaceae, Caricaceae, Euphorbiaceae, Malvaceae, Meliaceae, Moraceae, Myrtaceae, Papilionaceae, Pinaceae) had only one species each.
Name of the Study: “Tree species diversity assessment and spatial analysis in a permanent monitoring plot of natural forest in Musuan, Bukidnon” Author(s): Alex et al., 2013 Sampling method(s): quadrant method, where plots of 10×10m were created in the one-hectare plot;	• The initial findings indicated relatively low species diversity in the selected natural forest, with a Shannon diversity index (H) of 1.21, Simpson’s index (D) of 0.875, and an evenness index (E) of 1.063. • The presence of some threatened and near-threatened species (15%), such as <i>Shorea almon</i> and <i>Azelia rhomboidea</i>, suggests the area's potential as a conservation site. • Despite the high endemism (over 90%) recorded in the sampled area, some dominant species such as <i>Senna</i>

Study Details	Major Findings
	spectabilis, an exotic species, may pose a possible threat to forest regeneration by influencing low diversity. • Spatial analysis revealed that <i>S. spectabilis</i> is clustering, with a Nearest Neighbor Ratio of 0.94. Future studies on the ecology and control of these species are necessary.
Name of the Study: “Assessment of plant species diversity, relative abundances and distribution in Haramaya University, Ethiopia” Author(s): Sorecha & Deriba, 2017 Sampling method(s): Systematic sampling using quadrant method, where plots of 10×10m were created	• The study recorded 34 plant species in Site 1 and 40 species in Site 2, of which 22 species were common to both sites. • Species richness accounted for approximately 76% in Site 1 and 69% in Site 2. • The Shannon diversity index indicated that Site 2 was more diverse ($H = 3.26$) than Site 1 ($H = 2.97$). • The study concluded that the university area supports a variety of plant species across different habitats, including trees and shrubs.

2.4. Geographical Dimensions and Types of Forest Ecosystems in Bangladesh

As located in the northeastern part of South Asia, Bangladesh is considered as the largest deltaic region globally (Hossain 2001). Its landscape is composed of mainly floodplains that is estimated approximately 80% of nation's land area. The deposition of alluvial sediments moved by the Ganges, Brahmaputra, and Meghna rivers and associates established these plains over time (Faisal & Hayakawa, 2022). Furthermore, Bangladesh is characterized by a portion of hilly areas, covering approximately 12% of country's territory (Islam 2003). Its climate is primarily sub-tropical influenced by noticeable monsoon pattern, and its natural forests are widely categorized into hill forests, plain-land Sal forests, and mangrove forests, each associated with definite geomorphic and ecological regions (FAO/Forest Inventory, 2019;). The authentic forest coverage range in Bangladesh is still under discussion. According to the Bangladesh Forest Department and other sources (Khan et al., 2007), forest cover in Bangladesh is calculated to be about 2.53 million hectares, which encircle approximately 17.5% of the country's total landmass. Nevertheless, the FAO-FRA-2005 claims the forested area to be about 0.87 million hectares (FAO, 2006) though 1.53 million hectares of forest land are under management of the Forest Department (Roy, 2004).

Tropical evergreen and semi-evergreen forests occupy the hill forests in Bangladesh that are crucial for watershed preservation and host (APFSOS, 1998). In spite of raising questions among organizations concerning forest area and deforestation rates, one evaluation illustrates that the total natural forest cover extend across 769,000 hectares, comparable to 5.9% of the total country's land area. Additionally, plantations cover another 335,000 hectares, which constitutes 2.5% of the total land area (FAO, 1993). It is important to note that while forest land makes up 18-19% of the total land area, only 10-12% is officially recognized as forest, and the actual tree cover is only 5-7%. Specifically, the hill forests cover an area of 0.67 million hectares, with an estimated growing stock

of approximately 28 million cubic meters or 100 cubic meters per hectare (Anon, 1992). The growing stock is depleted at an annual rate of 1.65%, with the estimated average annual forest growth being 2.5 cubic meters per hectare (FAO, 2003). Furthermore, unclassified state forests in the southeastern region of the country encompass 0.73 million hectares of hilly terrain, while the village forest area spans 0.27 million hectares. Woodlots and bamboo resources contain a growing stock of 54.7 million cubic meters and 7,480 million culms, respectively. Milde et al., (1985) classified the forests in Bangladesh into seven main sub-categories: Tropical wet evergreen, Tropical mixed evergreen, Tropical moist deciduous, Tropical open deciduous, Bamboo, Lowland freshwater swamp, and Savanna. These forests account for approximately 45% of the total forest area in the country and are mainly located in Chittagong, Chittagong Hill Tract, Cox's Bazar, and Sylhet. The primary species in these forests are natural Dipterocarps and their associated species, which also include a portion of plantation species (FAO, 1999).

Bangladesh, located within the Indo-Myanmar zone, bridging the Indo-Himalayas and Indo-China sub-regions, is a tropical country celebrated for its rich diversity of flora and fauna (Mittermeier et al. 1998). Country's biological richness shows intensified due to its geographical position. (Nishat et al., 2002). Trees play a significant role not only in sustaining tropical forest biodiversity but also provide habitats for a wide ranging of forest species (Huston, 1994). Regrettably, estimating the calculation of biodiversity loss in Bangladesh prevails arduous due absence of complete database and minimal information available (Hossain et al., 2004). However, research by Rahman et al. (2000) and Hossain (2001) demonstrates a terrible trend of native species extinction enhanced to the quick loss and degradation of forests in the country. Bangladesh hosts a diverse biological legacy, displaying 3611 flowering plant species (Ahmed *et al.* 2008). The Chittagong region alone accommodates 2260 flowering plant species (Nishat & Haque, 2008). Given this rich heritage, conducting tree assessments is imperative. The main goal of tree assessment is to create a thorough inventory of identified tree species and evaluate their conservation status (Rivers, 2017). Assessing tree diversity provides vital information necessary for effective forest management, including evaluating tree species diversity and determining their conservation status. Through tree diversity assessment, forest managers can make well-informed decisions to enhance conservation and protection efforts in the area (FAO, 2020).

Table 2.2: Several studies have been conducted to assess the floral diversity of various protected areas (PAs) in Bangladesh

Study Details	Major Findings
Name of the study: "Assessment of tree species diversity, composition and structure of Medha Kachhania National Park, Cox's Bazar, Bangladesh" Author(s): Uddin et al., 2020 Sampling method(s): systematic sampling	- Only 10 tree species representing 6 families were identified; - the park was dominated by various species of Dipterocarpus, especially <i>Dipterocarpus costatus</i>; - The high Important Value Index (133.94) and dominance in height and diameter classes of <i>D. costatus</i> indicated its suitability as a habitat for maintaining optimal dispersal, development, and growth.

Study Details	Major Findings
Name of the Study: “Diversity and conservation status of tree species in Hazarikhil Wildlife Sanctuary (HWS) of Chittagong, Bangladesh” Author(s): Hossain et al., 2020 Sampling method(s): systematic quadrat sampling	• A total of 162 tree species belonging to 50 families were recorded in the study area. • The most represented families were Euphorbiaceae (18 species) and Moraceae (12 species). • Conservation status analysis revealed that 85 species (52%) were classified as Least Concern (LC), representing the largest category. Vulnerable, Endangered, Near Threatened, and Critically Endangered species accounted for 20% (32 species), 6% (9 species), 1% (1 species), and 2% (3 species), respectively.
Name of the Study: “Conservation status of tree species in Himchari National Park of Cox’s bazar, Bangladesh” Author(s): Hossen & Hossain, 2018 Sampling method(s): extensive wholes area survey and quadrat survey methods	• A total of 117 tree species with a diameter at breast height (DBH) ≥ 5 cm were recorded, representing 37 families. • The most species-rich family was Moraceae (14 species), followed by Mimosaceae (8), Euphorbiaceae (7), Myrtaceae (6), and Anacardiaceae, Caesalpiniaceae, Meliaceae, and Verbenaceae, each with 5 species. • Conservation status assessment showed that 69 species (59%) were classified as Least Concern (LC). Vulnerable, Endangered, Near Threatened, and Critically Endangered species accounted for 16 (14%), 4 (3%), 2 (2%), and 2 (2%) species, respectively.
Name of the Study: “Assessment of natural regeneration status and diversity of tree species in the biodiversity conservation areas of Northeastern Bangladesh” Author(s): Rahman et al., 2011 Sampling method(s): stratified random quadrat sampling	• A total of 55 regenerating species belonging to 28 families were recorded. • The Meliaceae family was the most dominant, with the highest Family Importance Value (FIV = 26.3) and six species, followed by Moraceae (FIV = 24.24). • Among the five habitat types studied, forests supported the greatest number of regenerating species (43 species). • The study recorded a total of 15 exotic species from 9 families and 40 indigenous species from 24 families.
Name of the Study: “Biodiversity of Inani Protected Forest” Author(s): Feeroz M. M., 2016. Biodiversity of Inani Protected Forest Study area: Inani National Park, Cox’s Bazar, Bangladesh Sampling method(s): Strip-transect sampling, point/central quarter methods	• The park is a habitat for 443 species under 93 families, with 32% being herbs, 19% shrubs, 34% trees, 13% climbers, and 2% epiphytes; • Among them, 41% of species are represented by 10 families whereas 59% of species are represented by 83 families; • The presence of a high number of tree species (151) suggests that the area is rich in tropical forest cover.

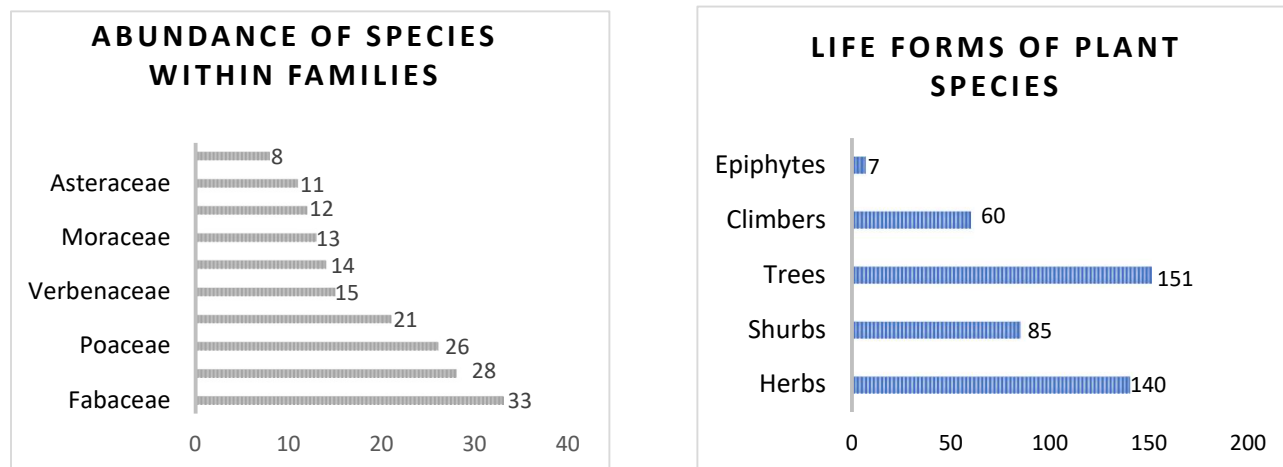


Figure 2.1. Floral Diversity of Inani National Park

2.5. Protected Area: Protected Areas and Biodiversity Conservation Efforts in Bangladesh

Declaring forest land as a Protected Area (PA) is a crucial step toward promoting sustainable forest ecosystems and conserving terrestrial biodiversity, thereby helping to counter forest degradation (Rahman & Islam, 2021). In Bangladesh, various types of forest areas have been allocated as different kinds of protected areas, including national parks, areas for conserving biodiversity, eco-parks, and wildlife sanctuaries, based on the conservation needs of the country (Hassan, 2000). The estimation and conservation of tree biodiversity within forests constitute a crucial and detailed endeavor, facilitate an insight comprehension of forest dynamics, plant-animal relationship, and nutrient cycling (Hossain et al., 2013). The floral makeup of forests serves as a fundamental tool for informed decision-making regarding forest management practices, aimed at ensuring the sustainability and resilience of the ecosystem (Nath et al., 2000). Bangladesh boasts numerous PAs, with several studies conducted over the years to evaluate plant species diversity within these areas (Hossain and Hossain, 2014).

2.6. Mammalian Diversity, Threats, and Survey Methodologies: From Global Studies to Inani National Park

Anthropogenic disturbances are exerting significant pressure on tropical ecosystems (Tilker et al., 2019), with Southeast Asia recognized as one of the most vulnerable regions (Hughes, 2017). The increasing demand for wildlife and wildlife products has emerged as a major threat to tropical wildlife populations, particularly mammals (Symes et al., 2018). Mammals are especially vulnerable to environmental disturbances, particularly large-bodied species that require extensive home ranges to obtain adequate resources and are therefore more likely to encounter human–wildlife conflicts (Ripple et al., 2014). According to the International Union for Conservation of Nature (IUCN), threats to global mammal biodiversity have intensified, with the number of species classified as Critically Endangered increasing from 169 to 203 and Endangered species rising from 315 to 506 between 1996 and 2020 (IUCN, 2020a). Tropical Asia harbors a disproportionately high number of threatened

mammal species (Jenkins et al., 2013), and projections indicate that between 9% and 36% of lowland forest mammals in tropical Southeast Asia may face extinction by 2100 under a business-as-usual scenario (Wilcove et al., 2013). Moreover, many protected areas in Tropical Asia lack strict protection, and political commitment to addressing conservation gaps remains relatively limited in this biodiversity-rich yet rapidly developing region (Watson et al., 2014).

Habitat fragmentation lessens the survival of the threatened species in tropical forests (Primack & Corlett, 2005). Human actions modify the different dimensions and the structural complexity of habitats which affects wildlife populations significantly. Multiple interacting factors, including direct threats such as hunting and illegal wildlife trade, as well as indirect impacts from deforestation and habitat fragmentation simultaneously influence species decline in tropical forests (Dirzo et al., 2007). Especially a high percentage of threatened and endangered wildlife species inhabit in Southeast Asian tropical forests, those are broadly identified as global conservation priorities (Laurance, 2007).

Malaysia and Myanmar, the countries of tropical Asia, where exceptionally high mammal diversity prevailing. Malaysia alone hosts 344 mammal species, approximately 6.2% of global mammalian diversity, showing its vulnerability to extinction despite its tiny isolated land area (IUCN, 2012). A field studies demonstrated 41 species, including five Endangered and ten Vulnerable species were documented in northern Myanmar by employing 174 camera stations across protected and non-protected areas, highlighting the efficacy of camera traps for capturing mammalian diversity even across human-affected landscapes (Lwin et al., 2021). By utilizing line-transect surveys across four habitat types in southern Ethiopia's Loka Abaya National Park, identified 28 species, along with three globally threatened species (*Lycaon pictus*, *Panthera pardus*, *Hippopotamus amphibius*), with minimal seasonal changes in richness, diversity, or composition (Diriba et al., 2020).

Mammal surveys by broadly using camera traps in tropical forests with infrared motion sensors and digital data storage, have revolutionized and cost effective now a days due to contemporary technological advancements (Swann et al., 2004). Camera traps deliver a realistic, non-invasive, and most effective method for sampling medium-to-large mammals (Srbek-Araujo & Chiarello, 2005). Camera traps support long-term monitoring with nominal ecological disturbance and are crucial for estimating species richness, diversity, and distribution across habitats (Caravaggi et al., 2017). Quantitative analyses such as the minimum trapping effort (MTE) and relative abundance index (RAI) enhance survey proficiency. For instance, an MTE investigation in Jangsudae portrayed that 664–1010 camera days were necessary to identify 90–95% of ten target-oriented species (Xu et al., 2014). The RAI, showed as captures per 100 camera-trap days, is broadly used for species in absence of detectable morphological markers and notify regional wildlife management (Palmer et al., 2018). Camera traps are considerably used in national parks worldwide, also in Korea, to assist species monitoring and conservation strategy (Choi et al., 2020). Alternatively, conventional methods such as line transects, direct observation, track and scat identification, trapping, and interviews with local communities, camera traps demand less field effort, operate continuously, and generate reliable data for population estimation, behavioral ecology, species inventories, and wildlife management and conservation. Line-transect methods, meanwhile, remain applicable for assessing species abundance

and community composition across habitat types, especially when integrated with indirect evidence such as tracks, feces, feeding signs, and vocalizations (Girma et al., 2012).

Combining on these methodological advances, the current study employs an integrated camera-trap and transect-based techniques to assess mammalian diversity and habitat use in Inani National Park, Bangladesh. To attain species composition, relative abundance, and spatial patterns of activity, camera traps were positioned systematically across different habitat types, while line-transect surveys were completed to complement detection in dense vegetation area or less accessibility. This integrated methodology enables a robust assessment of mammalian communities in a tropical forest landscape, providing essential baseline data to inform evidence-based conservation and management strategies in one of Bangladesh's key protected areas.

Table 2.3: Camera traps have been employed in numerous studies across Southeast Asia, serving diverse research objectives

Research Purposes	Author(s)
Mammal inventories of specific areas	Dinata et al., 2008
Monitoring animals visiting natural salt licks	Matsubayashi et al. 2007b
Monitoring animals visiting natal dens	Lim & Ng, 2008
Monitoring animals visiting fruiting trees	Yasuda et al., 2007; Van der Meer et al., 2008; Kitamura et al., 2009
Recording animal activity periods	Mohd- Azlan & Sharma, 2006; Suzuki et al., 2006; Kawanishi & Sunquist, 2008
Identifying seed dispersers/predators	Kitamura et al., 2006; Kitamura et al., 2008
Estimating the relative and absolute abundance of tigers	Linkie et al. 2006; Mohd- Azlan & Sharma, 2006; Simcharoen et al., 2007
Estimating the relative and absolute abundance of leopards	Ngoprasert et al., 2007
Estimating the relative and absolute abundance of Malayan sun bears	Wong et al. 2004; Linkie et al., 2007
Estimating the relative and absolute abundance Malayan tapirs	Holden et al., 2003

2.7. Mammal studies in Bangladesh

Several studies have been conducted in the different protected areas and different locations in Bangladesh. Considering the potential of the critical PA, the studies were carried out to divulge the threats and probable management strategies. These researches have also filled critical knowledge gaps and support conservation efforts that would lead to developing policy recommendations to support effective conservation of the Protected Area.

Table 2.4: List of studies have been conducted to assess the mammalian diversity of various PAs and other locations in Bangladesh

Study Details	Major Findings
Name of the study: “Mammalian Fauna and Conservation issues of the Baraiydhala National Park, Bangladesh” Author(s): Rezaul Karim & Farid Ahsan, 2016 Method(s): Transect line methods	• 27 Mammals species under 17 families and 9 orders were identified; • Rodentia appeared as the largest family of 10 species • The overall mammalian density was 239.12/ km² relative abundance of recorded species 15 (51.72%)
Name of the Study: “An Assessment of the Diversity and Seasonal Dynamics of Small-and Medium-Size Mammals in Pittachchara Forest, Bangladesh Using a Camera Trap Survey” Author(s): Shawon et al., 2024 Method(s): Camera Trap Survey	• 8 Small -and medium sized mammals including the Bengal slow loris including northern pig-tailed macaque and leopard cat were recorded; • Significantly higher activity during summer and lower showed in winter
Name of the Study: “Assessment of status and threats of wild mammals in some selected locations of Dinajpur district, Bangladesh” Author(s): Hoque. M. A et al., 2020 Method(s): Belt-transect sampling, Box-trap survey, Mist netting and night survey	• 22 Species of mammals under 11 families and 5 orders were identified; • Rodentia appeared as the largest family of 8 species • 9 species (41%) were recorded as "very common", 6 species (27%) "common", 4 species (18%) "uncommon", and 3 species (14%) "rare". • Among all the mammalian species, 41% (9 species) were nocturnal, 14% (3 species) crepuscular, 37% (8 species) metaturnal and 9% (2 species) diurnal. Of the total species, 19% (4 species) of the known species are nationally threatened comprising of Endangered (5%), Vulnerable (5%) and Near Threatened (9%) and Least Concern (81%).
Name of the study: “Mammalian diversity and conservation in the mixed-evergreen forest of Baraiyadhala National Park, Chattogram, Bangladesh” Author(s): Hasan. M.K et al., 2024 Method(s): Transect survey and camera trapping	• A total of 25 mammal species were recorded in Inani National Park. Among these, 41.82% were classified as rare, followed by 29.09% common, 16.36% uncommon, and 12.73% very common. • The mammalian community was predominantly nocturnal (32.73%), with smaller proportions of metaturnal (23.64%), crepuscular (21.82%), and diurnal species (21.82%). Overall, the park exhibited high mammalian diversity, with a diversity index of $D = 0.06$ and a Shannon-Wiener index of $H' = 3.35$. Importantly, 17 species were recorded under various threatened categories, underscoring the conservation significance of the area.
Name of the Study: “The status of mammalian fauna of the Lawachara National Park, Bangladesh”	• A total of 39 mammal species were recorded, representing 7 orders and 21 families. The dominant orders were Carnivora (38%), Rodentia (24%), Primates (15%), Chiroptera (13%),

Study Details	Major Findings
Author(s): Aziz M.A, 2011 Method(s): Transect survey, Mist netting and photocard interview	and Artiodactyla (5%). Species abundance was highest for common species (36%), followed by uncommon (26%), rare (23%), and very common (15%). The study revealed that 51% of species were threatened, 28% were not threatened, and 21% were data deficient nationally and 23% of species were threatened, while 73% fell into lower-risk categories globally. These findings highlight the mammalian richness of the area and emphasize the need for targeted conservation strategies for species under threat.
Name of the Study: “Application of Multi-Species Occupancy Modeling to assess mammal diversity in northeast Bangladesh” Author(s): Hasan. A. et al., 2021 Method(s): Camera trapping	27 species of mammals, 23 of which were non-domesticated mammals, comprising six orders and 15 taxonomic families. Approximately 37 species of mammals found in this area through regional surveys. Occupancy modeling applying the MSOM method showed that species-specific occupancy followed variation broadly, ranging from 69% for wild boar (<i>Sus scrofa</i>) to 0.1% for small Indian civet (<i>Viverricula indica</i>), expressing changes in habitat use and distribution across the region.
Name of the Study: “Unveiling the diverse mammalian species of a tropical rainforest in northeast Bangladesh” Author(s): Hamza. A. et al., 2023 Method(s): Camera trapping Study area: Latitila reserve forest, Moulvibazar	- The study divulged that A total number of 36 mammal species were documented under 9 orders and 22 families. The order Carnivora clarified the highest percentage (34%), followed by Rodentia (21%), Primates (18%), Chiroptera (10%), and Artiodactyla (5%). - Species abundance of the region showed 37% were categorized as rare, 26% as very common, 24% as occasional, and 13% as common. It is mentionable that 45% of the recorded species are listed as threatened in the updated national Red List of IUCN Bangladesh, accentuating the conservation priorities of the area.

A significant number of factors such as habitat size, ecological requirements, and threats from natural and anthropogenic activities affect the distribution and status of mammals. (Khan et al., 2016). Habitat characteristics, such as plain terrain, low floral diversity, and canopy gaps, can make areas unsuitable for arboreal mammals (Haque et al., 2020). Mammalian diversity is generally higher in natural forests compared to other habitats. In the Dinajpur District, anthropogenic pressures, particularly hunting by the ethnic Santal people, pose significant threats to wildlife. Recommended conservation measures include raising public awareness and implementing conflict management strategies. More broadly, widespread deforestation across Bangladesh and other countries in South and Southeast Asia has negatively impacted mammalian populations over recent decades (Feeroz et al., 2013). Additionally, over the past twenty years, 89 species of wild animals have been involved in conflict activities, including 31 mammal species (Rawshan et al., 2012).

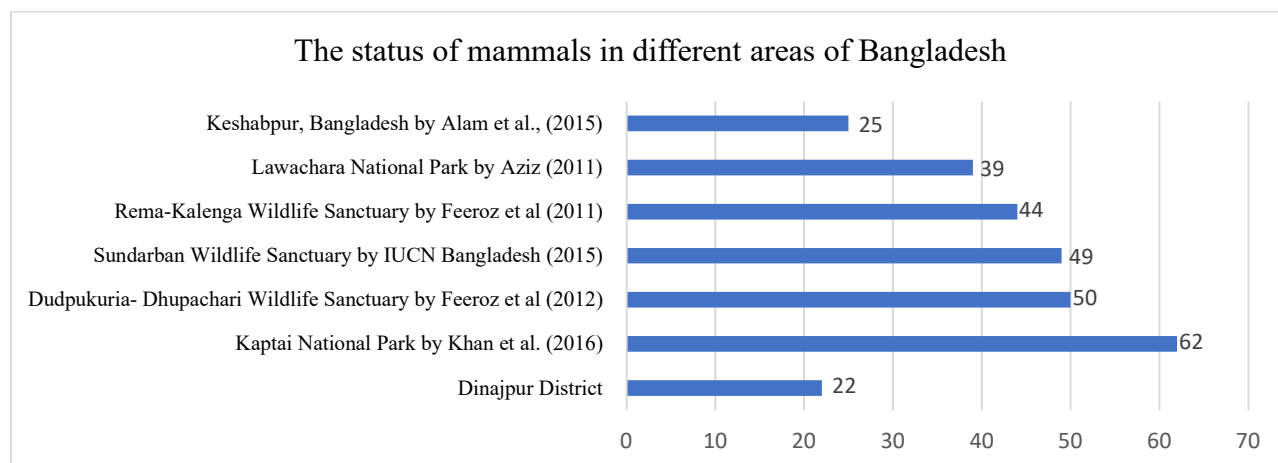


Figure 2.2. The status of mammals in different areas of Bangladesh.

2.8. Survey of Mammals in Inani National Park, Cox's Bazar

The mammalian survey was conducted in Inani National Park, Cox's Bazar, between 2011 and 2014, comprising a total of eight field visits to the protected forest. A variety of methods were employed to monitor and inventory both flora and fauna, including strip-transect sampling, point/central quarter methods, camera-trap surveys, box-trap surveys, pitfall surveys, mist-netting, night surveys, and interview-based surveys with local communities (Khan, 2018; Sugai et al., 2019). These methods allowed a comprehensive assessment of mammalian persistence, habitat use, and diversity within the park.

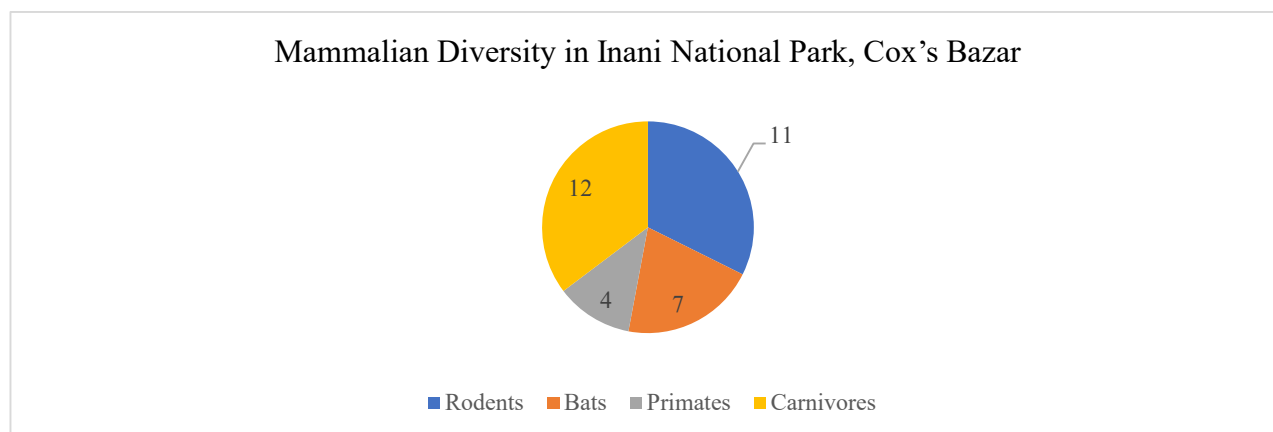


Figure 2.3. Mammalian Diversity in Inani National Park

In a previous survey, a total number of 39 mammalian species were identified in Inani National Park, Cox's Bazar. Among these recorded species, only 5% are commonly observed, while 61% are classified as rare or very rare (Feeroz, 2016).

Chapter 3

Study 1.

MAMMALIAN PERSISTENCE AND CONSERVATION PRIORITIES IN A FRAGMENTED TROPICAL REFUGE OF BANGLADESH

Abstract

Global mammalian diversity is declining rapidly due to habitat loss, fragmentation, and weak enforcement of conservation measures, raising fundamental questions about species persistence in human-modified landscapes. Protected areas serve as critical refuges, yet many in South Asia are small, degraded, and embedded within heavily human-dominated settings. In Bangladesh, Inani National Park supports iconic mammals, including the Endangered Asian Elephant and the Western Hoolock Gibbon. Despite serving as a corridor, the refuge's conservation efficacy under increasing pressure remains poorly understood. To assess drivers of persistence and inform spatial management, we conducted a year-long survey (November 2022–November 2023) combining systematic line transects and extensive camera trapping (4,771 trap-days). We documented 23 wild mammal species, including three globally Endangered and four Vulnerable taxa. Habitat gradients strongly shaped persistence: shrublands supported the highest richness, peaking in the monsoon, whereas plantations and modified habitats were least rich and diverse. Occupancy modelling revealed sharp contrasts in site use: the Asian Elephant showed near-complete occupancy ($\psi = 1.00$), whereas elusive carnivores such as the clouded leopard were rarely detected ($\psi = 0.24$; $p = 0.04$). Our findings highlight INP's role as a key refuge and corridor, but also threats from deforestation, encroachment, and livestock grazing. Conservation priorities include restoring degraded habitats with native vegetation, strengthening boundary protection in high-diversity zones, and implementing community-based measures to mitigate human-elephant conflict. Targeted, evidence-based interventions are essential to secure the long-term persistence of Bangladesh's priority mammal community.

Keywords: Camera trapping; Occupancy modeling; Protected area; Species diversity; Threatened species

Introduction

Mammals play essential roles in sustaining ecosystem structure and function, acting as apex predators, seed dispersers, and ecosystem engineers. Beyond their ecological contributions, they also hold cultural significance and economic value (Lacher et al., 2019). Many mammals are widely recognized as flagship and umbrella taxa, attracting public attention and conservation investment that in turn benefit broader biodiversity (Kalinkat et al., 2017). According to the IUCN Red List, approximately 6,025 mammal species have been assessed worldwide (IUCN, 2025). Alarming, nearly one-quarter of these species are threatened with extinction, primarily due to habitat loss, overexploitation, and climate change (IUCN, 2025). These declines are particularly severe in tropical Asia, including Bangladesh, where high human population density, rapid land-use change, and weak enforcement combine to place intense pressure on mammalian communities (Tilman et al., 2017;

IUCN Bangladesh, 2015). Bangladesh, situated at the ecological confluence of the Indo-Himalayan and Indo-Chinese subregions, supports a remarkable diversity of mammalian fauna across habitats ranging from floodplains to evergreen forests (IUCN Bangladesh, 2015). The country is estimated to harbor 138 mammal species, including nine marine mammals, highlighting its conservation importance. Yet this diversity is under severe threat, with at least 11 species already recorded as nationally extinct, and many others persists only in small, isolated populations (IUCN Bangladesh, 2015). Together, these patterns underscore both the ecological significance of mammals in Bangladesh and the urgent need for comprehensive assessments to inform effective conservation strategies.

Protected areas (PAs) are widely recognized as essential instruments for conserving biodiversity and maintaining ecological balance (Mace et al., 2008). They safeguard species and ecosystems, sustain ecological processes, and simultaneously provide important benefits to human societies (Juffe-Bignoli et al., 2014). Although debates continue over conservation priorities (Soulé, 2013), PAs remain the cornerstone of global conservation strategies, providing critical refuges for mammals and other wildlife (Mace, 2014). When effectively managed, national parks can safeguard viable populations, maintain ecosystem processes, and act as reservoirs of genetic diversity. However, their long-term effectiveness often depends on factors such as size, connectivity, and management capacity, which vary considerably across regions (Geldmann et al., 2019). In South Asia, and particularly in Bangladesh, many PAs are small and fragmented and receive limited conservation attention, making them vulnerable to isolation, edge effects, and intense anthropogenic pressures including resource extraction, livestock grazing, and encroachment. As of 2025, Bangladesh has designated 57 forest protected areas, including two marine sites, under the Forest Department (Bangladesh Forest Department, 2025). Several studies have documented substantial mammalian diversity within these sites, for example, 55 species in Baraiyadhala National Park (Hasan et al. 2024), 46 in Kaptai National Park (Rakib et al., 2025), and between 39 to 50 species across Inani, Chunati, Teknaf, Rema-Kalenga, and Dudpukuria-Dhopachari Wildlife Sanctuaries (Feeroz, 2014). Yet despite these findings, the effectiveness of PAs in Bangladesh remains constrained by small size, isolation, weak management capacity, intense human pressures, and lack of need-based conservation strategy. These challenges underscore the need for site-specific assessments of mammalian diversity to evaluate conservation value of overall biodiversity and inform management priorities.

Inani National Park is situated in Cox's Bazar District, southeastern Bangladesh, within the Indo-Burma Biodiversity Hotspot. Formerly designated as Inani Reserved Forest, it was upgraded to National Park status in 2019 and now represents the southernmost natural forest tract of the country, though much of its habitat has been degraded by illegal activities and weak conservation efforts. Covering the last remnants of natural forest in the Cox's Bazar South Forest Division, Inani harbors ecologically significant species such as the Asian Elephant (*Elephas maximus*) and the Western Hoolock Gibbon (*Hoolock hoolock*), while also serving as a critical transboundary elephant corridor between Bangladesh and Myanmar (Kabir et al., 2021; IUCN Bangladesh, 2015). The park lies at the interface of terrestrial and coastal ecosystems, making it a key land-sea transition zone. At the same time, it is heavily impacted by logging, fuelwood collection, hill cutting, agricultural expansion, and

encroachment, which have converted much of the primary forest into secondary shrubland, grassland and plantations. The Rohingya refugee influx into nearby Ukhia and Teknaf has further intensified pressure on forest resources and increased human–elephant conflict (UNDP Bangladesh & UN Women Bangladesh, 2018). These trends raise urgent questions about how well INP continues to conserve mammalian diversity and what specific actions are required to safeguard threatened species. Despite its ecological importance, systematic knowledge of mammalian diversity and conservation strategies in Inani remains sparse. Several studies over the last decade have documented aspects of wildlife diversity and forest condition (Haidar et al., 2017), and broad reviews have emphasized the park’s role as an elephant corridor (IUCN Bangladesh, 2015; Kabir et al., 2021). However, these works have largely focused on habitat degradation, human–wildlife conflict, or qualitative species checklists, with limited emphasis on comprehensive inventories of mammals. Compared to other protected areas in Bangladesh, where studies have documented 39–55 mammalian species (Feeroz et al., 2014; Rakib et al., 2025), INP lacks robust, up-to-date data on species richness, abundance, or distribution. Small mammals and bats remain particularly under-documented, and no systematic camera-trap surveys or quantitative diversity assessments have previously been conducted. More broadly, data on habitat-specific species richness and abundance, community structure, and the occupancy patterns of flagship and threatened mammals are largely absent, limiting evidence-based planning for zoning, patrolling, restoration, and conflict-mitigation in INP. These gaps underscore the need for targeted assessments to establish a baseline for mammalian diversity in Inani and to inform appropriate conservation and management in the face of ongoing anthropogenic pressures.

To ensure immediate conservation relevance, this study investigates how mammalian communities vary across habitats and season in Inani National Park, addressing long-standing knowledge gaps and the park’s significance for mammal diversity conservation. By combining systematic camera trapping with direct observations (sightings and vocalizations) and indirect evidence (scats and footprints) along transects, we aim to generate a reliable baseline inventory and quantitative measures of mammalian diversity, as well as suggesting effective conservation measures. We expect that the mammal community in Inani to be strongly structured by habitat characteristics, with species richness lower in disturbed or modified habitats and higher in relatively undisturbed, structurally intact areas. Species-wise occupancy patterns are likewise anticipated to vary, with individual species responding differently to habitat quality, fragmentation, and gradients of human disturbance. Building on these ecological patterns, this study identifies priority conservation actions, including habitat restoration, connectivity enhancement, and community-based conflict mitigation, thereby providing actionable guidance for the effective management of mammalian biodiversity in Inani National Park. The findings are intended to guide conservation planning and policy by identifying priority species and habitats, and by providing evidence-based recommendations to support the effective management and long-term persistence of mammalian biodiversity in this threatened forest landscape.

3.2. Materials and Methods

3.2.1. Study Area

Inani National Park (INP) was gazetted as a Protected Area on 15 April 2019 under the Bangladesh Wildlife (Conservation and Security) Act, 2012. The park spans 7,085 ha in the Cox's Bazar South Forest Division, situated ~26 km south of Cox's Bazar town (21°06'–21°17' N, 92°03'–92°07' E; **Figure 3.1**). It is bounded by the Teknaf–Cox's Bazar highway to the east, the Bay of Bengal to the west, Himchari National Park to the north, and Teknaf Wildlife Sanctuary to the south. Thirteen villages are located around its periphery, making the park highly accessible to local communities. Once dominated by tropical evergreen and semi-evergreen forest, INP has undergone severe degradation from commercial logging, agricultural expansion, fuelwood extraction, and settlement encroachment. The present vegetation is a mosaic of fragmented secondary forest, shrubland, grassland, and degraded tree cover. Understory layers are frequently dominated by *Imperata cylindrica* and dense vines, a disturbance-driven vegetation state common across Bangladesh's hill forests (Islam et al. 2001). Despite this degradation, the park retains diverse floral assemblages, including native canopy species with gentle sloping hills and valleys underlain by Mio-Pliocene to Pleistocene sediments, with soils ranging from clay and loam to sandy substrates (Miah and Hossain, 2022). The high rainfall regime and numerous hill streams sustain wetlands and riparian habitats that support both floral and faunal diversity (Das et al., 2018). Importantly, INP provides habitat for several threatened and endangered species, but is also exposed to acute anthropogenic pressures, exacerbated in recent years by regional demographic shifts such as the Rohingya refugee influx into Cox's Bazar (Feeroz, 2016). For habitat-wise sampling and analysis, the park was stratified into four habitat classes derived from land-cover mapping: hill forest (semi-evergreen natural forest on undulating terrain), forest plantation (man-made plantations), shrub with scattered trees (secondary vegetation with grass and vine undergrowth), and mixed (human settlements, cropland, and small waterbodies). These four classes (total mapped area = 6,858 ha) differ in canopy cover, structure, and degree of human disturbance, and thus have different conservation potential (**Table 3.1; Figure 3.1**).

Table 3.1. Habitat classification of Inani National Park showing area, camera deployment, and transect coverage.

Sl No.	Habitat class	Area (ha)	Area (%)	Transects Covered	No. of Camera	Camera Trap Days
1	Hill-forest	1014.29	14.8	T-1, T-2, T-3, T-4, T-5, T-7, T-8	3	382
2	Forest Plantation	245.45	3.6	T-5	2	227
3	Shrub with Scattered Trees	3758.83	54.8	T-1, T-2, T-3, T-4, T-5, T-7, T-8	26	4086
4	Mixed	799.84	26.2	T-1, T-2, T-3, T-5, T-7	1	76
	Total	858.44	100		32	4771

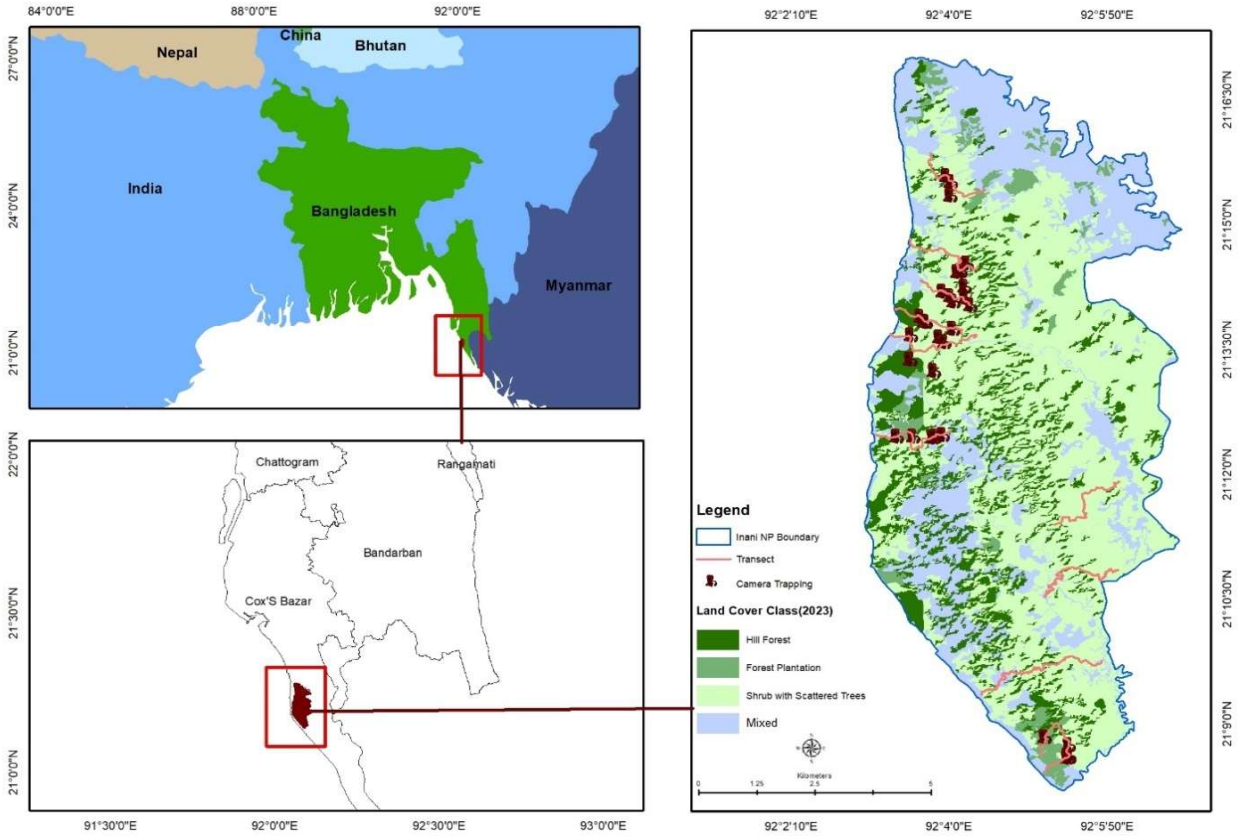


Figure 3.1. Study area and Location of the study sites

3.2.2. Study period and overall design

Field surveys were conducted in Inani National Park between November 2022 and November 2023. We employed two complementary survey methods to characterize mammalian assemblages: (1) systematic transect surveys for direct observations and indirect signs, and (2) camera trapping to target primarily medium- and large-bodied, and crepuscular/nocturnal species. This integrated approach provided both presence/absence and detection-corrected information on species occurrence throughout Inani National Park (O'Connell et al., 2011). Field methods avoided invasive handling: no live-trapping, mist-netting, or baiting was conducted, consistent with national regulations and park management directives as stated in Wildlife (Conservation and Security) Act 2012.

3.2.3. Transect surveys and sign sampling

Transect surveys began with a reconnaissance phase to assess accessibility and species detectability. Eleven transects were initially surveyed (T-1 to T-11); following reconnaissance, seven standardized transects (T-1–T-5, T-7, T-8) were selected and surveyed throughout the study. Transects followed existing trails and streambeds and ranged from 2.1 to 3.5 km in length (mean = 2.8 km) with a fixed survey width of 50 m (25 m on each side). Transects were surveyed in seven-day cycles each month and were walked twice daily during peak mammal activity periods (06:00–10:00 and 15:00–18:00). Transect placement was stratified across the park's major habitat types to maximize coverage of ecological variability. For each direct sighting we recorded date, time, transect ID, GPS coordinates,

species identity, number of individuals (and age/sex class where possible), observed behavior, perpendicular distance to transect (estimated), substrate/vegetation type, and a photographic record when feasible. For indirect signs (scats, footprints, feeding marks, dens, scratch marks, vocalizations), we recorded sign type and number, measurements, GPS location, substrate, and photographs. Sign identification and field procedures followed established protocols (Peralta et al., 2023). Species identifications relied on local photographic guides and regional field guides (Khan, 2018; Menon, 2023) and were verified by senior field biologists. Finally, each sighting/sign GPS point was overlaid on the land-cover map to assign and extract habitat class.

3.2.4. Camera trapping

Prior to camera deployment, reconnaissance surveys and local interviews were used to identify animal trails, stream junctions and other features with high mammal activity (Chakma, 017). Cameras were placed primarily at trail–waterway junctions or along established animal trails and located to maximize detection probability while avoiding obvious human disturbance. Trail-based placements were prioritized because they have been proven to enhance detection of elusive carnivores and increase overall photographic and occupancy rates, and capture greater site-level species richness compared to random placements (Greco et al., 2025). Spacing between camera stations was about 500 m–1 km, consistent with standard protocols for sampling ground-dwelling mammals (Hossain et al., 2016). A total of 15 automatic cameras (CEFC G-Series) were deployed on a rotating basis to cover 32 camera stations across the park’s four major habitat strata: Hill-forest, Forest plantation, Shrub with scattered trees, and Mixed (**Table 3.1**) (**Appendix 1**). Camera placement was guided by both habitat extent and field-level logistical feasibility and security considerations. As the Shrub with Scattered Trees stratum constitutes the largest proportion of the park (54.8%), a greater number of stations and trap days were allocated to this habitat to ensure adequate coverage of this large habitat. In contrast, although the Mixed stratum represents a substantial portion of the park (26.2%), it includes areas subject to high levels of anthropogenic disturbance and encroachment associated with the Rohingya influx. These conditions limited systematic camera deployment and increased the risk of equipment loss or damage, resulting in fewer cameras and reduced sampling effort in this habitat. For the other habitat classes, cameras were deployed in approximate proportion to their mapped extent where logistically feasible. This stratified placement allowed sampling to reflect habitat heterogeneity, although sampling intensity varied among strata due to logistical constraints. Cameras were programmed to record three consecutive images with a 5-second interval when triggered by motion/PIR sensors. The camera-trap survey accumulated 4,771 trap-days (November 2022–December 2023). Cameras were checked regularly to replace batteries and cards; non-triggered cameras (no images within ~2 weeks) were relocated to alternative suitable sites to increase detections (**Appendix 2**). No baits, lures, or traps were used at any time. Photographic records were processed following standard workflows: images were tagged for species, date/time and location. Independent capture events were defined using species-appropriate time thresholds to reduce pseudo-replication; and multiple images of the same individual within a single event were treated as a single detection for occupancy and relative abundance analyses (O’Connell et al., 2011; Rovero and Zimmermann, 2016).

3.2.5. Data Analysis

To compile a comprehensive species inventory for Inani National Park, records from camera traps and transect surveys were aggregated at the species level as presence/absence data, without combining abundance or detection probabilities across methods. Metrics of richness and diversity were calculated separately for each method to account for differences in detectability. Camera-trap data were analyzed using occupancy models and incidence-based estimators, whereas transect survey data were analyzed using abundance-based metrics, relative abundance, and diversity indices. By reporting both method-specific results alongside a combined species inventory, we provide a thorough characterization of the mammalian community while acknowledging method-specific biases in detectability.

Camera-trap data were processed using the Camera Trap Management and Analysis Package (CTAP) developed by the Zoological Society of London (Amin et al., 2016). Image metadata (file name, date, time) were extracted from JPG files with Picture Information Extractor (PIE) software and cross-checked against field records of camera setup, servicing, and recovery. Species identity and image type were subsequently annotated following standard protocols (Amin et al., 2016). From these data, we derived several indices of occurrence and abundance. Global trap rate (Relative Abundance Index, RAI) was calculated as the number of independent detection events per 100 trap-days per species. Naïve occupancy was defined as the proportion of camera stations at which a species was recorded, while modeled occupancy estimates were obtained using single-season occupancy models in CTAP to account for imperfect detection through repeated sampling occasions. For occupancy modeling, detection histories were constructed by dividing the camera-trap survey period into fixed sampling occasions of 7-day intervals (O’Connell et al. 2011; Rovero and Zimmermann, 2016). Independent detection events were used to generate site-by-occasion detection histories. Single-season occupancy models were applied to the full annual dataset, treating the November 2022–December 2023 survey as one biological season. Multi-season (dynamic) occupancy models were not implemented because camera stations were rotated and sampling effort varied across habitats, and precluding consistent repeated sampling at the same sites across seasons. To evaluate the adequacy of sampling effort, a species accumulation curve (rarefaction analysis) was generated from camera-trap detections (Lim et al., 2023). For richness estimation using camera-trap data, we applied the first-order Jackknife estimator, as detections were structured as incidence data.

Data from transect surveys were used to examine community-level patterns. We calculated Shannon diversity index (H'), Pielou’s evenness index (J'), and Simpson’s diversity index (D) to capture complementary aspects of mammalian diversity and evenness across habitats. Relative abundance (RA) was calculated as the percentage of individuals of a specific species (n) divided by the total number of individuals (N) of all species observed ($RA = \frac{n}{N} \times 100$). Population density (D) was estimated using the fixed-width strip transect method, calculated as the number of individuals observed (n) divided by the total area sampled ($D = \frac{n}{L \times W}$), where L is the total length of the transect, and W is the fixed strip width, following established protocols (Jaman et al., 2023). Confidence intervals for diversity metrics were estimated using 9,999 bootstrap iterations to provide robust

measures of variability. In addition, transect survey data were analyzed across habitat strata (Hill-forest, Forest plantation, Shrub with scattered trees, and Mixed habitat) to assess variation in species richness, abundance, and diversity indices among habitats. Seasonal patterns were also evaluated across three major seasons: summer, monsoon, and winter to examine temporal shifts in species detectability and community composition. For these comparisons, diversity indices and relative abundance were calculated separately for each habitat type and season. To estimate species richness using transect survey data, we applied the Chao1 estimator, as observations were recorded as abundance data. Species accumulation curve was generated using “iNEXT” package in R 4.5.1 (Hsieh et al., 2016; R Core Team, 2025).

3.3. Results

3.3.1. Mammalian Richness, Composition, and Occupancy Patterns

Across all survey methods, we recorded 23 mammal species representing 15 families and 7 orders in INP between November 2022–December 2023 (**Table 3.2; Figures 2–3**). This corresponds to roughly 17% of the 138 mammalian species documented in Bangladesh (IUCN Bangladesh 2015), indicating that a substantial portion of the country’s mammalian diversity persists within this relatively small and degraded forest remnant. Of these, three species are globally endangered: the Bengal slow loris (*Nycticebus bengalensis*), western hoolock gibbon (*Hoolock hoolock*), and Asian elephant (*Elephas maximus*). Four species are listed as vulnerable: the clouded leopard (*Neofelis nebulosa*), northern pig-tailed macaque (*Macaca leonina*), capped langur (*Trachypithecus pileatus*), and greater hog badger (*Arctonyx collaris*) (IUCN, 2025). We also recorded the large-toothed ferret badger (*Melogale personata*), which has not previously been evaluated in Bangladesh (IUCN Bangladesh, 2015). Our survey also provided the first photographic confirmation record of clouded leopard (*Neofelis nebulosa*) in INP, adding to previous anecdotal and interview-based reports from the region. Carnivora was the most species-rich order, comprising 10 species (43.47% of recorded species), whereas Chiroptera, Proboscidea, and Scandentia were each represented by a single species. Detection methods were complementary: 19 species were recorded by camera traps, 18 by direct observations (visual sightings or vocalizations along transects), and 18 by indirect signs (scats, tracks, feeding traces). Several taxa were detected by multiple methods, while a small number were unique to a single approach (**Table 3. 2**). An additional incidental record of the red giant flying squirrel (*Petaurista petaurista*) was made outside the predefined transects and is treated here as an indirect observation.

Table 3.2: Mammalian species community in Inani National Park

Sl. No.	Order	Family	Species	Common Name	IUCN Bangladesh Status	IUCN Global Status	Method of observation		
							Direct	Indirect	Camera Trap
1	Carnivora	Canidae	<i>Canis aureus</i>	Golden Jackal	LC	LC	No	Yes	Yes
2	Carnivora	Felidae	<i>Felis chaus</i>	Jungle Cat	NT	LC	Yes	Yes	Yes
3	Carnivora	Felidae	<i>Neofelis nebulosa</i>	Clouded Leopard	CR	VU	Yes	Yes	Yes

Sl. No.	Order	Family	Species	Common Name	IUCN Bangladesh Status	IUCN Global Status	Method of observation		
							Direct	Indirect	Camera Trap
4	Carnivora	Felidae	<i>Prionailurus bengalensis</i>	Leopard Cat	NT	LC	Yes	Yes	Yes
5	Carnivora	Herpestidae	<i>Urva urva</i>	Crab-eating Mongoose	NT	LC	Yes	Yes	Yes
6	Carnivora	Mustelidae	<i>Arctonyx collaris</i>	Greater Hog Badger	VU	VU	Yes	Yes	Yes
7	Carnivora	Mustelidae	<i>Melogale personata</i>	Large-toothed Ferret Badger	NE	LC	No	No	Yes
8	Carnivora	Viverridae	<i>Paradoxurus hermaphroditus</i>	Common Palm Civet	LC	LC	Yes	Yes	Yes
9	Carnivora	Viverridae	<i>Viverra zibetha</i>	Large Indian Civet	NT	LC	No	No	Yes
10	Carnivora	Viverridae	<i>Viverricula indica</i>	Small Indian Civet	NT	LC	No	No	Yes
11	Cetartiodactyla	Cervidae	<i>Muntiacus vaginalis</i>	Northern Red Muntjac	EN	LC	Yes	Yes	Yes
12	Cetartiodactyla	Suidae	<i>Sus scrofa</i>	Wild Boar	LC	LC	Yes	Yes	Yes
13	Chiroptera	Megadermatidae	<i>Megaderma lyra</i>	Greater False Vampire Bat	LC	LC	Yes	No	No
14	Primates	Cercopithecidae	<i>Macaca leonina</i>	Northern Pig-tailed Macaque	EN	VU	Yes	Yes	Yes
15	Primates	Cercopithecidae	<i>Macaca mulatta</i>	Rhesus Monkey	VU	LC	Yes	Yes	Yes
16	Primates	Cercopithecidae	<i>Trachypithecus pileatus</i>	Capped Langur	EN	VU	Yes	Yes	Yes
17	Primates	Hylobatidae	<i>Hoolock hoolock</i>	Western Hoolock Gibbon	CR	EN	Yes	Yes	No
18	Primates	Lorisidae	<i>Nycticebus bengalensis</i>	Bengal Slow Loris	EN	EN	Yes	No	No
19	Proboscidea	Elephantidae	<i>Elephas maximus</i>	Asian Elephant	CR	EN	Yes	Yes	Yes
20	Rodentia	Hystricidae	<i>Hystrix brachyura</i>	Malayan Porcupine	LC	LC	Yes	Yes	Yes
21	Rodentia	Sciuridae	<i>Callosciurus pygerythrus</i>	Irrawaddy Squirrel	LC	LC	Yes	Yes	Yes
22	Rodentia	Sciuridae	<i>Petaurista petaurista</i>	Red Giant Flying Squirrel	DD	LC	No	Yes	No

Sl. No.	Order	Family	Species	Common Name	IUCN Bangladesh Status	IUCN Global Status	Method of observation		
							Direct	Indirect	Camera Trap
23	Scandenti a	Tupaiid ae	<i>Tupaia belangeri</i>	Northern Treeshrew	NT	LC	Yes	Yes	Yes

CR= Critically Endangered, EN= Endangered, VU= Vulnerable, NT= Near Threatened, LC= Least Concern, DD= Data Deficient, NE=Not Evaluated

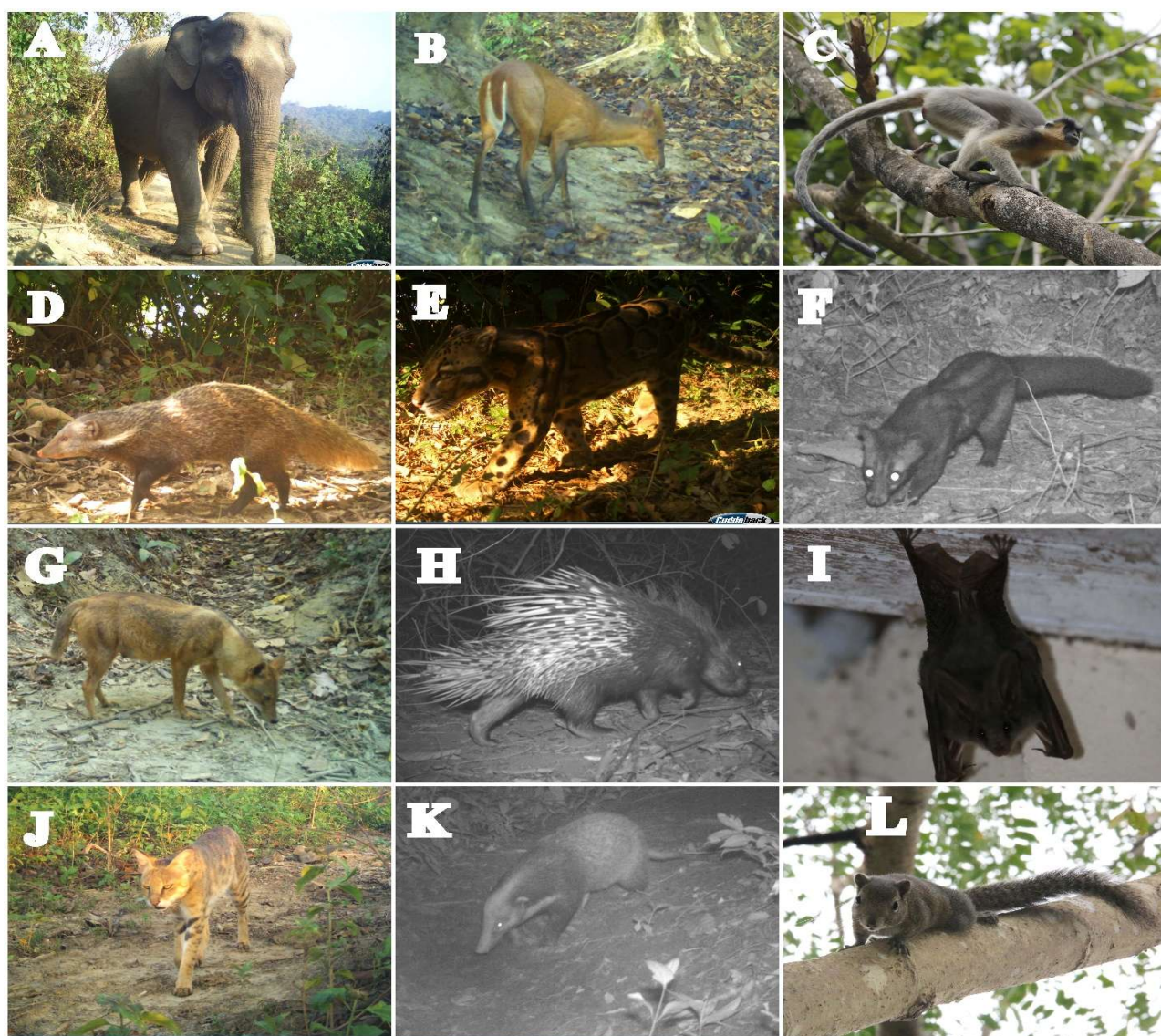


Figure 3.2. Recorded mammalian diversity at Inani National Park, Cox's Bazar; (A) Asian Elephant; (B) Northern Red Muntjac; (C) Capped Langur; (D) Crab-eating Mongoose; (E) Clouded Leopard; (F) Common Palm Civet; (G) Golden Jackal; (H) Malayan Porcupine; (I) Greater False Vampire Bat; (J) Jungle Cat; (K) Hog Badger; (L) Irrawaddy Squirrel.



Figure 3.3. Recorded mammalian diversity at Inani National Park, Cox's Bazar; (M) Wild Boar; (N) Large Indian Civet; (O) Large-toothed Ferret Badger; (P) Rhesus Monkey; (Q & X) Leopard Cat; (R) Northern Pig-tailed Macaque; (S) Northern Treeshrew; (T) Small Indian Civet; (U) Western Hoolock Gibbon; (V) Red Giant Flying Squirrel; (W) Bengal Slow Loris.

Camera traps recorded 19 mammal species across six orders (**Table 3.3**). The overall species-accumulation curve approached an asymptote (Jackknife1 estimate = 20; **Figure 3.4**). Although the curves for mixed habitat and forest plantation continued to increase, their projected richness remained lower than that of shrub with scattered trees, suggesting that additional sampling is unlikely to substantially increase the total number of species recorded. We fitted single-season occupancy models for 11 species that met minimum detection thresholds (independent detections > 5; naïve occupancy > 0.1), which revealed a heterogeneous pattern of persistence across INP. The Asian Elephant (*Elephas maximus*) showed the highest occupancy ($\psi = 1.00$, $p = 1.00$), reflecting its broad spatial presence and consistent detectability across the landscape. In contrast, the Clouded Leopard (*Neofelis nebulosa*) had low estimated occupancy ($\psi = 0.24$; 95% CI: 0.04–0.49) and very low detection probability ($p = 0.04$; 95% CI: 0.01–0.08), consistent with the rarity and cryptic behavior of this nocturnal felid. Intermediate patterns were observed among primates: the Pig-tailed Macaque (*Macaca leonina*) and Rhesus Macaque (*M. mulatta*) exhibited moderate occupancy ($\psi = 0.79$ [95% CI: 0.62–0.95] and $\psi = 0.66$ [95% CI: 0.46–0.86], respectively) but low detection probabilities ($p = 0.12$ and $p = 0.09$), suggesting patchy spatial use or behaviors that reduce detectability.

Table 3.3: Mammal species recorded via camera trapping in Inani National Park, Cox’s Bazar (2022–2023), showing trap rates, naïve and modelled occupancy estimates, and detection probabilities.

Family	Scientific Name	Macro habitat	Trophic Level	No. of Stations Detected in	No. of Images	No. of Events	Global Trap Rate (RAI)	Native Occupancy	Modelled Occupancy ψ (95% CI)	Detection Probability (95% CI)
Canidae	<i>Canis aureus</i>	Terrestrial	Carnivore	11	158	73	1.53	0.44	0.48 (0.27–0.69)	0.09 (0.07–0.12)
Felidae	<i>Felis chaus</i>	Terrestrial	Carnivore	10	33	30	0.63	0.39	0.49 (0.26–0.74)	0.06 (0.03–0.08)
Felidae	<i>Neofelis nebulosa</i>	Terrestrial	Carnivore	3	13	9	0.19	0.13	0.24 (0.04–0.49)	0.04 (0.01–0.08)
Felidae	<i>Prionailurus bengalensis</i>	Terrestrial	Carnivore	15	71	50	1.05	0.61	0.8 (0.58–1)	0.05 (0.03–0.06)
Herpestidae	<i>Urva urva</i>	Terrestrial	Carnivore	11	19	15	0.31	0.39	0.69 (0.41–1)	0.02 (0.01–0.04)

Family	Scientific Name	Macro habitat	Trophic Level	No. of Stations Detected in	No. of Images	No. of Events	Global Trap Rate (RAI)	Native Occupancy	Modelled Occupancy ψ (95% CI)	Detection Probability (95% CI)
Mustelidae	<i>Arctonyx collaris</i>	Terrestrial	Omnivore	7	56	48	1.01	0.26	0.3 (0.12-0.48)	0.1 (0.07-0.13)
Mustelidae	<i>Melogale personata</i>	Terrestrial	Omnivore	2	3	2	0.04	0.04	-	-
Viverridae	<i>Paradoxurus hermaphroditus</i>	Terrestrial	Omnivore	3	11	10	0.21	0.09	-	-
Viverridae	<i>Viverra zibetha</i>	Terrestrial	Carnivore	3	26	6	0.13	0.09	-	-
Viverridae	<i>Viverricula indica</i>	Terrestrial	Omnivore	14	52	43	0.9	0.44	0.52 (0.29-0.75)	0.06 (0.04-0.09)
Cervidae	<i>Muntiacus vaginalis</i>	Terrestrial	Herbivore	3	9	3	0.06	0.13	-	-
Suidae	<i>Sus scrofa</i>	Terrestrial	Omnivore	23	530	150	3.14	0.78	0.77 (0.6-0.93)	0.14 (0.11-0.16)
Cercopithecidae	<i>Macaca leonina</i>	Arboreal	Omnivore	21	532	135	2.83	0.78	0.79 (0.62-0.95)	0.12 (0.09-0.14)
Cercopithecidae	<i>Macaca mulatta</i>	Arboreal	Omnivore	16	533	90	1.89	0.61	0.66 (0.46-0.86)	0.09 (0.06-0.11)
Cercopithecidae	<i>Trachypithecus pileatus</i>	Arboreal	Herbivore	2	6	4	0.08	0.09	-	-
Elephantidae	<i>Elephas maximus</i>	Terrestrial	Herbivore	30	2283	445	9.33	1.00	1 (1-1)	1 (1-1)
Hystriidae	<i>Hystrix brachyura</i>	Terrestrial	Omnivore	19	269	145	3.04	0.65	0.66 (0.48-0.85)	0.15 (0.12-0.18)
Sciuridae	<i>Callosciurus pygerythrus</i>	Arboreal	Herbivore	1	1	1	0.02	0.04	-	-
Tupaiaidae	<i>Tupaia belangeri</i>	Terrestrial	Omnivore	3	3	3	0.06	0.13	-	-

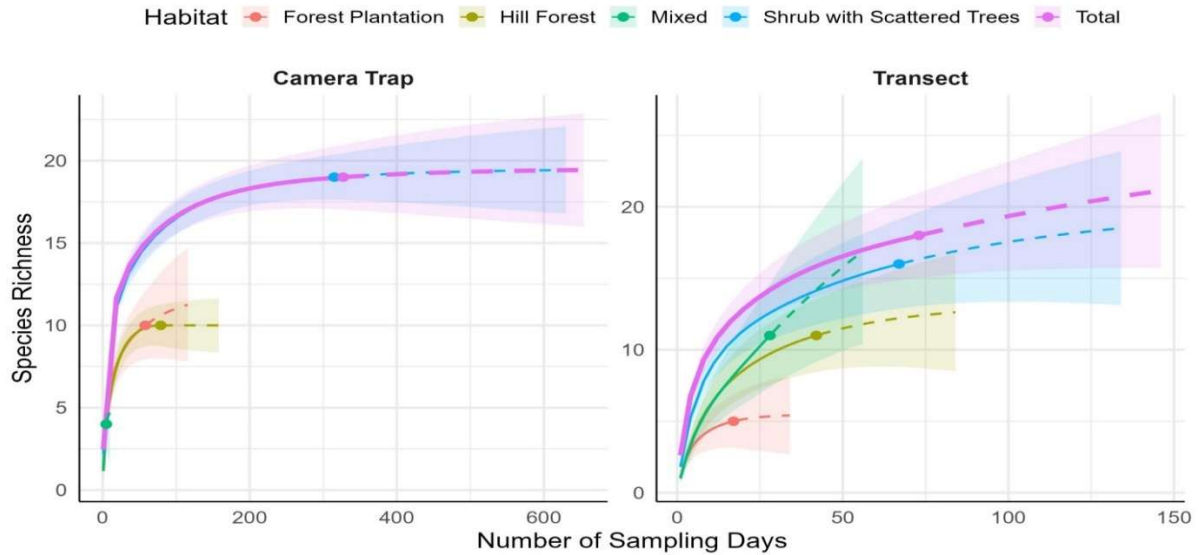


Figure 3.4. Species-accumulation curves for terrestrial mammals in Inani National Park camera-trap (left) and transect (right) surveys. Solid orange lines show the day-wise rarefaction of species richness; dashed portions denote the extrapolated section beyond observed sampling effort. Shaded ribbons indicate 95% confidence intervals.

3.3.2. Diversity, Relative Abundance, and Seasonal Dynamics

Transect surveys recorded 521 individuals representing 18 mammalian species (**Table 3.4**). Relative abundance was the highest for the Rhesus macaque (*Macaca mulatta*, $n = 110$, 21.1%), followed by the Capped langur (*Trachypithecus pileatus*, $n = 107$, 20.5%), the Asian elephant (*Elephas maximus*, $n = 91$, 17.5%), and the Irrawaddy squirrel (*Callosciurus pygerythrus*, $n = 76$, 14.6%). The Hog badger (*Arctonyx collaris*, $n = 1$, 0.2%) and the Bengal slow loris (*Nycticebus bengalensis*, $n = 1$, 0.2%) were the least frequently recorded species. Overall diversity was moderate, with an uneven community structure dominated by a few common species (Chao1 = 19, 95% CI 16–22.5; Shannon $H' = 2.18$, 95% CI 2.09–2.25; Pielou $J = 0.76$, 95% CI 0.73–0.80; (**Figure 3.5**). Habitat-stratified analyses revealed variation in species richness and diversity among habitat classes (Table 5). Shrub with Scattered Trees exhibited the highest species richness ($S = 16$), while Forest Plantation harbored the lowest ($S = 5$). Both Hill-forest and Mixed habitats showed intermediate richness, each harboring 11 species. In terms of Shannon diversity (H'), Shrub with Scattered Trees showed the highest diversity ($H' = 2.05$, 95% CI 1.91–2.13; $J = 0.74$), though its 95% confidence interval slightly overlaps with Hill-forest ($H' = 1.97$, 95% CI 1.70–2.10; $J = 0.82$). Mixed habitat ($H' = 1.84$, 95% CI 1.56–1.96; $J = 0.77$) also showed intermediate diversity similar to Hill-forest, while Forest Plantation has the lowest diversity and evenness ($H' = 0.83$, 95% CI 0.51–1.04; $J = 0.52$). Transect-level variation was also pronounced. Transect T-8 recorded the highest richness and diversity ($n = 102$; $S = 13$; $H' = 2.10$, 95% CI 1.85–2.20; $J = 0.82$, 95% CI 0.75–0.87). Seasonal patterns revealed peak richness during the monsoon ($S = 15$; $H' = 2.24$, 95% CI 2.00–2.34; $J = 0.83$, 95% CI 0.78–0.89), intermediate richness in summer $S = 13$; $H' = 2.02$, 95% CI 1.82–2.11; $J = 0.79$, 95% CI 0.73–0.83), and the lowest richness in winter ($S = 9$; $H' = 1.62$, 95% CI 1.51–1.70; $J = 0.74$, 95% CI 0.71–0.82) (**Table 3.5**; **Appendix 3**).

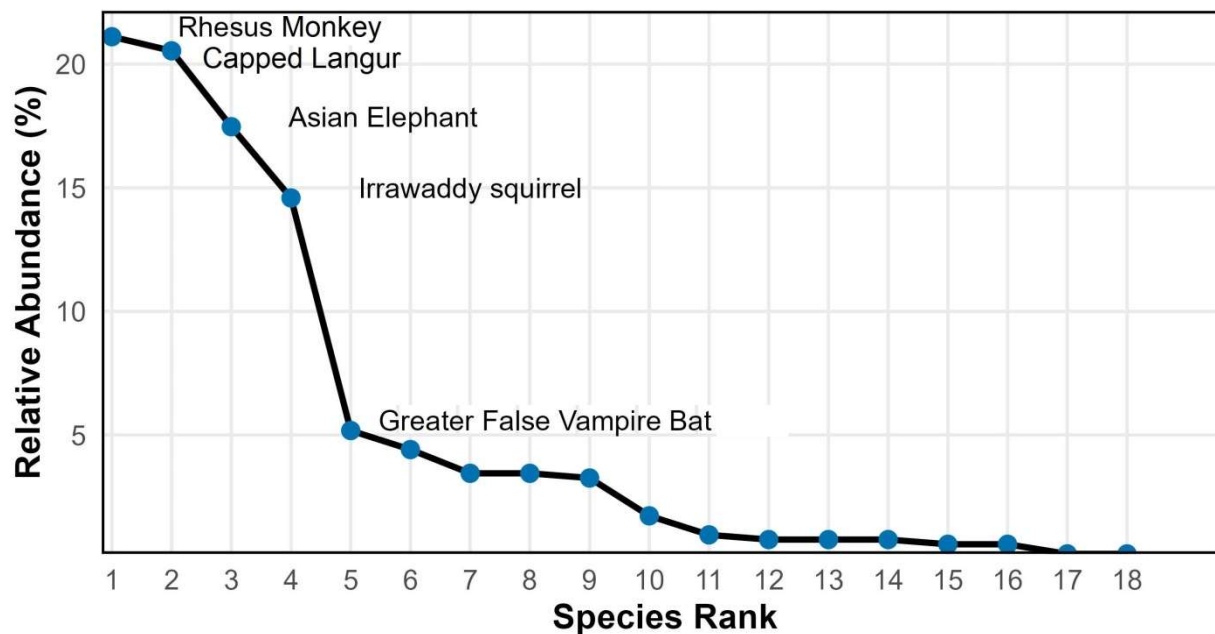


Figure 3.5. Whittaker plot of mammalian community in Inani National Park.

Table 3.4: Population structure of mammals recorded through direct observation at Inani National Park

SL No	Species	Total Individual	Relative Abundance (%)	Density (Individual /square kilometer)	Adult Individual	Young Individual	Young (%)	Ratio (Y/A)
1	<i>Felis chaus</i>	4	0.77	1.15	4	0	-	-
2	<i>Neofelis nebulosa</i>	4	0.77	1.15	4	0	-	-
3	<i>Prionailurus bengalensis</i>	18	3.45	5.19	17	1	5.56	1: 0.06
4	<i>Urva urva</i>	18	3.45	5.19	17	1	5.56	1: 0.06
5	<i>Arctonyx collaris</i>	1	0.19	0.29	1	0	-	-
6	<i>Paradoxurus hermaphroditus</i>	3	0.58	0.86	3	0	-	-
7	<i>Muntiacus vaginalis</i>	5	0.96	1.44	5	0	-	-
8	<i>Sus scrofa</i>	17	3.26	4.90	16	1	5.88	1: 0.06
9	<i>Megaderma lyra</i>	27	5.18	7.78	27	0	-	-

SL No	Species	Total Individual	Relative Abundance (%)	Density (Individual /square kilometer)	Adult Individual	Young Individual	Young (%)	Ratio (Y/A)
10	<i>Macaca leonina</i>	23	4.41	6.63	18	5	21.74	1: 0.28
11	<i>Macaca mulatta</i>	110	21.11	31.71	97	13	11.82	1: 0.13
12	<i>Trachypithecus pileatus</i>	107	20.54	30.84	86	21	19.63	1: 0.24
13	<i>Hoolock hoolock</i>	4	0.77	1.15	4	0	-	-
14	<i>Nycticebus bengalensis</i>	1	0.19	0.29	1	0	-	-
15	<i>Elephas maximus</i>	91	17.47	26.23	79	12	13.19	1: 0.15
16	<i>Hystrix brachyura</i>	9	1.73	2.59	9	0	-	-
17	<i>Callosciurus pygerythrus</i>	76	14.59	21.91	71	5	6.58	1: 0.07
18	<i>Tupaia belangeri</i>	3	0.58	0.86	3	0	-	-

Table 3. 5: Diversity indices of mammalian community across transects and seasons in Inani National Park.

Analysis	Transects /Strata/Season	Total individual	Number of recorded species	Estimate species (Chao1, 95% CI)	Shannon Diversity Index (H') (95% CI)	Simpsons Index (1-D) (95% CI)	Pielou's Evenness (J) (95% CI)
	Total	521	18	19 (16-22.5)	2.18 (2.09-2.25)	0.15 (0.14-0.16)	0.76 (0.73-0.8)
Habitat class	Forest Plantation	60	5	5.5 (3-7)	0.83 (0.51-1.04)	0.59 (0.46-0.74)	0.52 (0.38-0.68)
	Hill-forest	85	11	11.25 (9-15.5)	1.97 (1.7-2.1)	0.19 (0.15-0.26)	0.82 (0.74-0.89)
	Shrub with Scattered Trees	296	16	18.25 (13-23)	2.05 (1.91-2.13)	0.18 (0.16-0.21)	0.74 (0.71-0.8)
	Mixed	80	11	19 (7-19)	1.84 (1.56-1.96)	0.21 (0.17-0.27)	0.77 (0.72-0.87)
Transect	T_1	118	10	10.25 (8-14.5)	1.52 (1.27-1.68)	0.35 (0.28-0.44)	0.66 (0.58-0.75)

Analysis	Transects /Strata/Season	Total individual	Number of recorded species	Estimate species (Chao1, 95% CI)	Shannon Diversity Index (H') (95% CI)	Simpsons Index (1-D) (95% CI)	Pielou's Evenness (J) (95% CI)
	T_2	31	7	10 (4-11.5)	1.57 (1.16-1.73)	0.25 (0.2-0.39)	0.81 (0.72-0.94)
	T_3	29	6	6.5 (4-9)	1.41 (0.95-1.6)	0.32 (0.23-0.51)	0.79 (0.62-0.92)
	T_4	68	11	17 (7.5-19)	1.87 (1.57-1.99)	0.2 (0.17-0.28)	0.78 (0.72-0.88)
	T_5	126	8	8.5 (6-10)	1.57 (1.39-1.67)	0.25 (0.22-0.31)	0.75 (0.7-0.84)
	T_7	47	10	14 (6-19)	1.78 (1.38-1.93)	0.23 (0.18-0.34)	0.77 (0.7-0.88)
	T_8	102	13	13.17 (10.5-19)	2.1 (1.85-2.2)	0.16 (0.14-0.21)	0.82 (0.75-0.87)
Season	Summer	156	13	13 (11-17.5)	2.02 (1.82-2.11)	0.17 (0.15-0.21)	0.79 (0.73-0.83)
	Monsoon	111	15	23 (11.25-23)	2.24 (2-2.34)	0.14 (0.12-0.2)	0.83 (0.78-0.89)
	Winter	254	9	9.25 (7-12)	1.62 (1.51-1.7)	0.24 (0.22-0.28)	0.74 (0.71-0.82)

3.4. Discussion

Our results demonstrate that Inani National Park (INP) retains high conservation value for mammals at both national and regional scales, despite its small size and degraded condition. Using complementary transect surveys, sign-based detections, and camera traps, we documented 23 species spanning 15 families and 7 orders, including multiple globally threatened taxa such as the Asian elephant (*Elephas maximus*), western hoolock gibbon (*Hoolock hoolock*) and Bengal slow loris (*Nycticebus bengalensis*). These 23 species represent approximately 17% of Bangladesh's recorded mammalian fauna (IUCN Bangladesh, 2015), highlighting remarkable species persistence within a small and heavily human-modified coastal landscape. Notably, our study also provides the first photographic confirmation of the clouded leopard (*Neofelis nebulosa*) in this southeastern coastal forest, underscoring INP's importance for regional carnivore conservation. Beyond serving as a local refuge, INP functions as a critical connectivity node between Himchari National Park and Teknaf Wildlife Sanctuary, supporting wide-ranging species such as elephants and large carnivores. Maintaining its ecological integrity is therefore essential not only for resident fauna but also for sustaining metapopulation dynamics and gene flow across the broader Cox's Bazar Forest matrix. These findings provide crucial evidence to guide habitat restoration, strengthen protection, and inform cross-boundary landscape-level conservation planning, establishing INP as a priority site for both national and regional mammal conservation strategies.

Camera-trap surveys recorded 19 species, with a species-accumulation curve estimating 20 species, suggesting that our sampling effort captured most of the medium- and large-bodied terrestrial mammal assemblage in the study area. Although species-accumulation curves for mixed habitat and forest plantation did not fully level off, no additional species were detected in these habitats during transect surveys, indicating that further sampling would likely result in only minor increases in total species richness. However, this estimate is lower than the total mammal richness previously reported for the area. These results suggest that, although increased sampling effort in mixed and forest plantation habitats could potentially detect additional species, transect surveys indicate that any such increase in species richness would likely be minimal. Earlier studies documented higher species richness ($N = 39$), likely because those surveys incorporated methods targeting small mammals and bats or included anecdotal local knowledge (Feeroz, 2013). Our non-invasive camera- and line-transect design efficiently samples larger, ground-active, and diurnal species but likely under-represents small mammals, trail-avoiding species, bats, and strictly arboreal or fossorial taxa, which require mist-netting, live-trapping, or targeted acoustic sampling (Feeroz, 2013; Karim & Ahsan, 2016). Habitat condition and fragmentation strongly shaped species richness and diversity, with Shrub with Scattered Trees supporting the highest number of species. Hill-forest and Mixed strata exhibited comparable and intermediate richness levels, whereas Forest Plantation supported the lowest number of species. The Forest Plantation habitat also had the most uneven community structures ($J = 0.52$), indicating dominance by a few adaptable generalist taxa, compared to other habitats ($J > 0.7$). These patterns likely reflect variation in structural complexity, resource availability, and levels of disturbance. However, the relatively low number of species detected in Forest Plantation may also partly reflect lower survey effort in this habitat. Long term monitoring is needed to understand the mechanistic process of these patterns or if these patterns are influenced by uneven sampling effort and detection heterogeneity across strata. Species richness was the highest during the monsoon, probably driven by seasonal peaks in fruiting and vegetation growth, which increase local food availability and attract frugivores and herbivores, followed by their predators. However, these seasonal differences may partially reflect temporal variation in detectability rather than true changes in population size. Collectively, these habitat-specific and seasonal patterns indicate that spatial habitat quality and temporal resource pulses are key drivers of mammal occurrence and activity in INP (Shawon et al., 2024). Conserving or restoring structural heterogeneity, including canopy continuity, understory complexity, and riparian resources, would disproportionately benefit less adaptable, specialist species and enhance overall community evenness across the park (Watson et al., 2015).

Occupancy analyses revealed species-specific patterns reflecting ecological traits and habitat use. Asian elephants exhibited near-ubiquitous occupancy ($\psi = 1.00$, $p = 1.00$), consistent with their wide-ranging behavior and use of multiple habitat types, whereas clouded leopards showed low occupancy ($\psi = 0.24$) and very low detectability ($p = 0.04$), indicative of their cryptic, low-density, and nocturnal habits. Primates such as rhesus macaques and capped langurs had moderate occupancy but low detectability, likely reflecting patchy spatial use and behavioral avoidance of humans. These patterns align with global findings, where large, mobile herbivores are more readily detected by ground-based

cameras and transects, whereas cryptic, low-density, arboreal, or nocturnal species remain under-sampled (O'Connell et al., 2011; Rovero & Zimmermann, 2016). It should also be noted that, occupancy estimates and detection probabilities are influenced by camera placement, rotation, and species-specific detectability, and these may underestimate occurrence of cryptic or low-density taxa. To reduce bias and improve inference, future surveys should expand spatial coverage and camera density, deploy canopy or arboreal cameras and bat acoustic detectors, and integrate non-invasive genetic sampling (scat/eDNA) or ethically approved live-capture methods. Incorporating habitat and anthropogenic covariates, such as canopy cover, distance to edge, and human activity, into occupancy models would further refine estimates, distinguishing true absences from detectability limitations (Amin et al., 2016; Peralta et al., 2023; Lim et al., 2023). Such approaches are essential for monitoring rare, cryptic, or low-density species (e.g., clouded leopard, hog badger, slow loris) and to guide evidence-based management and conservation interventions in INP. Additionally, the photographic confirmation of clouded leopard underscores the conservation and policy significance of INP, supporting its inclusion in national carnivore monitoring frameworks and justifying targeted investment in anti-poaching patrols and habitat protection across the southeastern forest belt.

INP functions as both a local stronghold for wide-ranging taxa and a key component of a transboundary corridor connecting Teknaf Wildlife Sanctuary and adjacent forest blocks. Frequent detections and consistent occupancy of Asian elephants underscore the park's role as a critical connectivity node for wide-ranging species (Kabir et al., 2021). Despite its ecological importance, INP faces intense anthropogenic pressures that compromise its ability to sustain sensitive mammal communities. Anthropogenic degradation (illegal logging, hill cutting, betel-leaf cultivation, fuelwood extraction, and encroachment) has fragmented once continuous canopy forests into shrub-dominated mosaics (Uddin et al., 2013). Landscape-scale land-use changes, including agricultural expansion, road development, and urbanization, further erode habitat integrity (Watson et al., 2015). The recent Rohingya refugee influx into nearby upazilas has dramatically increased extraction of forest resources and intensified human–elephant conflict (UNDP & UN Women Bangladesh, 2018). Limited conservation capacity and insufficient management response exacerbate these pressures. These landscape-scale pressures underscore how anthropogenic disturbance acts as an ecological filter, mediating species access to resources and structural refuge, thereby directly impacting persistence in this human-dominated matrix. Consequently, less adaptable, specialist, and low-density species including clouded leopards, slow lorises, and hog badgers are disproportionately affected through reduced canopy cover, diminished prey availability, and declining habitat suitability and occupancy (Mattos et al., 2021). These converging pressures highlight the urgent need for coordinated, landscape-scale conservation interventions to safeguard both resident and wide-ranging mammals in INP. Given INP's position within a functional movement corridor, unmanaged anthropogenic pressures in this landscape not only erode local habitat quality but also disrupt regional connectivity essential for elephants, large carnivores, and other wide-ranging taxa.

Based on observed patterns of occupancy, diversity, and species-specific threats, we propose a prioritized, evidence-driven management agenda for INP. First, immediate interventions should focus on halting the ongoing conversion of diverse native habitats, particularly hill-forests, shrub zones,

and riparian habitats into forest plantations, through strengthened law enforcement and targeted patrolling (Uddin et al. 2013). This prioritization is supported by our results, which show that the Forest Plantation stratum has the lowest species richness and evenness compared to all other habitats, demonstrating the severe biodiversity cost of such conversion and underscoring the urgency of preventing further habitat loss to plantation expansion. Second, active habitat restoration in degraded forest plantation areas and hill-forest zones including native canopy reforestation, invasive-species control, and bamboo stand recovery, should be implemented to restore structural complexity and resource availability essential for forest specialists (Primack, 2006). This approach is justified by our observation that intact Shrub with Scattered Trees supported highest richness and diversity among all surveyed habitats and hosted the majority of threatened primates and carnivores. Third, maintaining and improving landscape connectivity with Teknaf Wildlife Sanctuary and Himchari National Park is crucial for elephant movement pathways and gene flow (IUCN Bangladesh, 2015). In addition, implementing spatial zoning would substantially enhance management effectiveness. Using kernel density or intensity mapping of priority species detections (e.g., elephant movement paths, gibbon groups, carnivore records) and human–wildlife conflict incidents can identify high-use ecological zones and high-risk conflict sectors. Such spatial prioritization would allow targeted restoration, strategic patrol deployment, conflict mitigation, and focused enforcement where conservation return is maximized. Fourth, community-based interventions are recommended to reduce dependency on park resources, especially around the Mixed habitats, which experience elevated human activity. Providing alternative livelihoods, managed fuelwood programs, and participatory benefit-sharing can reconcile local welfare with conservation objectives, reflecting the anthropogenic pressures documented during field surveys (UNDP Bangladesh & UN Women Bangladesh, 2018). Finally, we recommend institutionalizing a long-term monitoring program that combines stratified camera-trapping, community reporting, and non-invasive genetic sampling to track trends in occupancy and abundance of focal threatened species and to evaluate management effectiveness (Peralta et al., 2023). This is particularly pertinent for cryptic or low-density species such as clouded leopards, Bengal slow lorises, and hog badgers, whose limited detections during this study underscore the need for continuous, systematic observation.

We acknowledge several limitations that qualify the interpretation of our results. The one-year sampling window, combined with the decision to exclude live-trapping and mist-netting, driven by ethical and permitting constraints, likely contributed to under-detection of small mammals, bats, and some strictly arboreal taxa (Karim & Ahsan, 2016). Camera-trap coverage, while substantial, was spatially constrained by accessibility and the need to rotate a limited number of units; consequently, some low-density and wide-ranging carnivores may remain under-represented even after accounting for imperfect detection through occupancy modelling (O’Connell et al., 2011;). Environmental stochasticity and seasonal behavioral shifts also affect detectability, so multi-year monitoring would be required to distinguish true population trends from inter-annual variability (Lim et al., 2023). The absence of site-level covariates also limited the interpretability of occupancy estimates, particularly for cryptic species whose detection probabilities vary strongly with habitat structure. Collectively, these constraints suggest that the 23 species documented here represent a conservative baseline rather than a complete inventory of INP’s mammalian assemblage. In addition, we note that relative

abundance indices and variation in detection probabilities across methods introduce further uncertainty, and results should be interpreted with caution in light of these methodological limitations.

Notwithstanding these limitations, our study demonstrates that even small, degraded protected areas still retain considerable conservation value for regionally and globally threatened mammals and can act as critical nodes of ecological connectivity in human-dominated landscapes. The photographic confirmation of clouded leopard and the persistent occupancy of Asian elephant and western hoolock gibbon highlight INP's role in sustaining focal elements of Bangladesh's mammal fauna at a time when mammalian populations are declining across tropical Asia (Lacher et al., 2019). The findings argue for an urgent integration of habitat protection, restoration, and community-centered management across the Cox's Bazar Forest matrix in order to secure both biodiversity and human well-being. Implementing the prioritized actions described above would not only mitigate immediate threats but also establish the conditions necessary for the recovery and long-term persistence of the park's most vulnerable species.

3.5. Conclusion

Our study demonstrates that Inani National Park continues to function as a vital refuge and corridor for wide-ranging threatened mammalian species, including the rediscovered clouded leopard, and substantial populations of Asian elephants and western hoolock gibbons. However, escalating anthropogenic pressures, habitat degradation, and resource exploitation pose significant risks to the park's ecological integrity and the persistence of its mammalian communities. Immediate and sustained conservation actions that integrate robust scientific monitoring, policy enforcement, habitat restoration, and community engagement are essential to safeguard these species and maintain functional ecological processes of this forest. Implementing these targeted measures, alongside strengthened law enforcement and long-term monitoring can secure the remaining mammal populations including flagship species in INP and contribute meaningfully to national and regional mammal conservation goals.

Chapter 4

Study 2.

POPULATION INSIGHT OF THE CLOUDED LEOPARD IN FRAGMENTED FORESTS OF SOUTHEASTERN BANGLADESH: CAMERA-TRAP EVIDENCE, OCCUPANCY MODELING, AND CONSERVATION IMPLICATIONS

Abstract

The study reports the first confirmed photographic and field evidence of the clouded leopard (*Neofelis nebulosa*) in Inani National Park (INP), southeastern Bangladesh. Over 4,720 trap-nights across 32 camera-trap stations, the species was recorded nine times at three sites, yielding a Relative Abundance Index of 0.19 detections per 100 trap-nights. Naïve occupancy was 0.09, while model-based analysis accounting for imperfect detection estimated occupancy at 0.20 (95% CI: 0.04–0.39) and detection probability at 0.01 (95% CI: 0.00–0.02), highlighting the species' rarity and cryptic behavior. Activity was primarily nocturnal, peaking between 21:00 and early morning, likely as an adaptation to avoid human disturbance. Photographic, sign, and model-based evidence collectively confirm the persistence of a small relict population in this fragmented landscape. These findings extend the species' known range along the western margin of the Indo-Burma biodiversity hotspot and identify INP as a key habitat node within a transboundary forest network connecting Bangladesh and Myanmar. Given low detection rates and ongoing habitat degradation, immediate conservation actions—including habitat restoration, protection of riparian corridors, and community-based monitoring—are critical to ensure the persistence of this Vulnerable and elusive felid in Bangladesh.

Key words:

Clouded leopard; Inani National Park; Camera trapping; Evidence, RAI; Temporal activity.

Introduction

The clouded leopard (*Neofelis nebulosa*) is a medium-sized, elusive felid distinguished by its cloud-shaped coat markings and exceptional arboreal agility (Pocock, 1939; Sunquist & Sunquist, 2002). Its long canines and relatively short limbs reflect adaptations for arboreal predation and ambush hunting in dense tropical forests (Sunquist & Sunquist, 2002). Once considered a single widespread species, the genus *Neofelis* is now known to include two species: the mainland clouded leopard (Kitchener et al., 2006).

As a mid-sized arboreal predator, the clouded leopard plays an important ecological role by regulating populations of primates, ungulates, and small mammals in tropical forests (Sunquist & Sunquist, 2002). In Bangladesh, where it is locally known as Gecho bagh, Lota bagh, or Lamchita, the species is classified as Critically Endangered due to habitat loss, poaching, prey depletion, and human disturbance (IUCN Bangladesh, 2015). Although it has declined across much of its range, *N. nebulosa* is globally listed as Vulnerable on the IUCN Red List (Gray et al., 2021).

Although the clouded leopard has been known in Bangladesh for over a century, since its first record in the Chittagong Hill Tracts in 1867, information on its distribution and ecology remains limited. Recent camera-trap evidence has confirmed its presence in the Sangu–Matamuhuri Reserve Forest (2018) and Kaptai National Park (2021) (Mongabay, 2024; Creative Conservation Alliance, 2025). Across its range, the species is declining due to deforestation, illegal hunting, and retaliatory killings linked to livestock depredation (Hunter, 2019). As a forest-dependent carnivore, the clouded leopard serves as an indicator of healthy, connected forest ecosystems, requiring dense canopy cover and adequate prey (Wilting et al., 2006). However, data on its population density, habitat use, and activity patterns are scarce in South and Southeast Asia because of its elusive behavior and low detectability (Tan et al., 2017). Understanding its persistence in fragmented landscapes, such as southeastern Bangladesh, is essential for effective management and transboundary conservation (FAO, 2020). The establishment of Inani National Park in Cox’s Bazar provides a valuable opportunity to assess the species’ status in a protected area, where camera trapping remains a reliable tool for detecting this cryptic carnivore and assessing key ecological attributes (O’Connell et al., 2011).

Despite its ecological importance and recent photographic records in Bangladesh, the clouded leopard (*Neofelis nebulosa*) has not been systematically studied in terms of its distribution, occupancy, or activity patterns within protected areas, limiting evidence-based conservation planning. With increasing forest fragmentation in the southeastern hilly areas, we hypothesized that the species persists in isolated refugia such as Inani National Park, where dense canopy cover and riparian habitats meet key ecological needs. The study aimed to (i) confirm the current presence of *N. nebulosa* through camera-trap and sign-based evidence, (ii) estimate its occupancy and detection probability using model-based approaches, (iii) characterize diel activity patterns. The study provides the first quantitative insight into the ecology of *N. nebulosa* in Inani National Park and establishes a baseline for long-term monitoring and targeted conservation within the Indo-Burma biodiversity hotspot.

4.2. Materials and Methods

4.2.1 Study Area

The study was conducted in Inani National Park (INP) in Cox’s Bazar District, southeastern Bangladesh. Covering approximately 7,085 ha, the park lies between the Himchari National Park in the north and Teknaf Wildlife Sanctuary in the south (Uddin et al., 2013) (**Figure 1**). Bounded by the Bay of Bengal to the west and the Chittagong hill ranges to the east. INP is characterized by gently sloping hills with clay, loam, and sandy soils (Miah & Hossain, 2022) dominated by evergreen and semi-evergreen forests. The park supports diverse mammalian fauna, including the critically endangered western hoolock gibbon (*Hoolock hoolock*), Asian elephant (*Elephas maximus*), and other Indo-Malayan mammals (Feeroz, 2016).

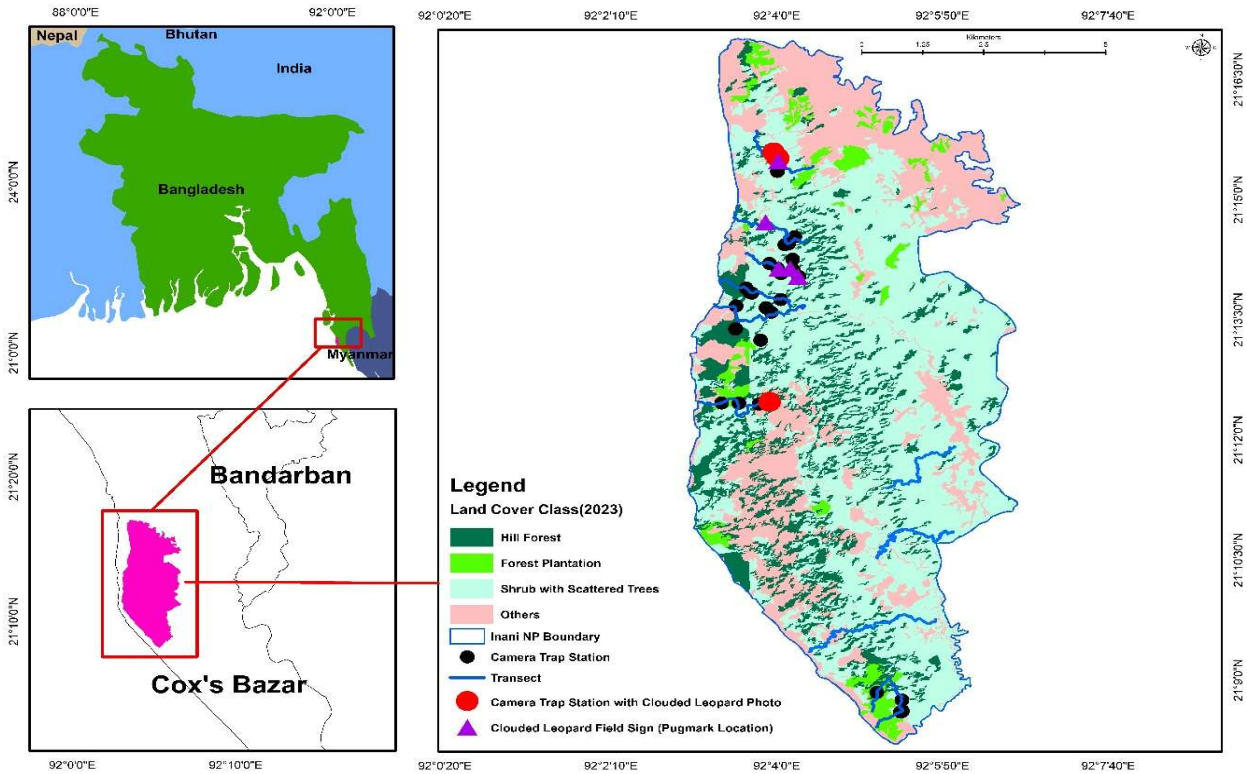


Figure 4.1. Map of Inani National Park, Bangladesh, showing land-cover classes, camera-trap stations, transect lines, and the spatial distribution of confirmed Clouded leopard (*Neofelis nebulosa*) detections (images and pugmarks) recorded during surveys conducted from November 2022 to December 2023

The study area experiences three main seasons—summer (March–June), monsoon (July–October), and winter (November–February) (Shahid & Khairulmaini, 2009; Islam & Kotani 2014) of the average monthly temperature was 26.6 °C, with values 21.6 °C in January to 28.8 °C in July. Total annual rainfall was about 2,400 mm, more than 60% in monsoon season; highest rainfall (872 mm) in August, no rainfall from November 2022 to February 2023. Relative humidity remained consistently high throughout the year, (68% in January 2023 and 90% in August 2023) (Bangladesh Meteorological Department).

4.2.2. Study period and overall design

Field surveys were carried out in Inani National Park from November 2022 to December 2023 to assess mammal diversity and confirm the presence of the clouded leopard (*Neofelis nebulosa*). An integrated approach was used, combining systematic line transects to record direct and indirect signs with camera trapping to monitor medium- and large-sized terrestrial mammals. This multi-method design generated complementary data on species richness, relative abundance, and spatial occupancy while reducing detection bias across seasons and activity periods (O’Connell et al., 2011). All surveys were non-invasive and conducted in compliance with the Wildlife (Conservation and Security) Act, 2012, and national ethical guidelines.

4.2.3. Transect surveys and sign sampling

Transect surveys started with a reconnaissance phase to assess accessibility and species detectability. Of the eleven transects initially assessed, seven standardized transects were selected and repeatedly surveyed throughout the study. Transects followed existing trails and streambeds, measured 2.1–3.5 km in length (mean = 2.8 km), and had a fixed width of 50 m (25 m on each side). Surveys were conducted monthly in seven-day cycles and walked twice daily during peak mammal activity periods (06:00–10:00 and 15:00–18:00). Transects were stratified across major habitat types to capture ecological variation. For direct sightings, we recorded date, time, transect ID, GPS location, species, group size (and age/sex when possible), behavior, estimated perpendicular distance to transect, habitat type, and photographs when available. Indirect evidence (e.g., scats, tracks, feeding signs, dens, scratches, and vocalizations) was documented by recording sign type, quantity, measurements, GPS coordinates, substrate, and photographs.

4.2.4 Camera trapping

Prior to camera deployment, reconnaissance surveys and local interviews were conducted to identify areas of high mammal activity, such as animal trails, stream junctions, and movement corridors (Chakma, 2017). Information was gathered between September and October, 2022 through literature review and interviews with forest officers, staff, local villagers, and community patrol groups familiar with Inani National Park. Trail-based placement was prioritized to enhance detection of elusive carnivores and overall species richness (Greco et al. 2025). In total, 15 automatic CEFC G-Series cameras were deployed on a rotational basis to survey 32 stations across the various habitat types of the park (**Appendix 1**). Cameras were set to capture three consecutive photographs at 5-second intervals whenever motion was detected by the PIR sensor. The survey accumulated a total of 4,771 trap-days between November 2022 and November 2023. Cameras were routinely checked to replace batteries and memory cards, and any non-functional cameras were repositioned to alternative suitable locations. Images were annotated with species, date/time, and location; independent capture events were determined using species-specific time thresholds to minimize pseudo-replication; and multiple images of the same individual within a single event were counted as a single detection for occupancy and relative abundance analyses (O’Connell et al., 2011; Rovero & Zimmermann, 2016).

4.3. Analytical Framework

4.3.1. Relative Abundance Index (RAI)

The Relative Abundance Index (RAI) was used as a measure of detection frequency for *Neofelis nebulosa* and other co-occurring species, providing a standardized proxy for abundance across sampling locations (Rovero & Marshall, 2009). RAI was calculated in the equation: $RAI = (\text{Number of Independent Detections} / \text{Total Camera Traps Nights}) \times 100$. Independent detection events were defined as consecutive photographs of the same species separated by at least 30 minutes to minimize temporal autocorrelation (Kelly, 2008). Camera-trap effort was quantified as the total number of active camera-nights across all stations. Although RAI is not a true density estimate tool, it serves as a robust comparative index of species activity and site use in unmarked populations (Jenks et al., 2011).

4.3.2. Occupancy modelling

Occupancy modelling was employed to estimate the probability of site use by *Neofelis nebulosa* while accounting for imperfect detection (MacKenzie et al., 2018). Each camera-trap station ($n = 32$) was treated as a sampling site. Camera traps operated continuously over a 13-month period, and detection histories were constructed by aggregating camera-trap records into daily (24-hour) sampling occasions. For each site and day, a detection was scored as ‘1’ if at least one independent photograph of *N. nebulosa* was obtained and ‘0’ otherwise.

Analyses were conducted using a single-season occupancy framework implemented in the R package unmarked (Fiske & Chandler, 2011), with occupancy interpreted as probability of site use over the survey period. Naïve occupancy (ψ_n) was calculated as the proportion of sites with detections, while model-based occupancy (ψ) and detection probability (p) were estimated via maximum likelihood methods following standard approaches for rare and cryptic carnivores (Rich et al., 2017). The use of daily sampling occasions was chosen to maximize temporal replication while maintaining consistency across sites with continuous camera operation.

4.3.3. Temporal Activity Patterns

To examine diel activity patterns of *N. nebulosa*, timestamps from independent detections were converted to local time and categorized into nocturnal (19:00–05:00), crepuscular (05:00–07:00; 17:00–19:00), and diurnal (07:00–17:00) periods, following the general framework of Ridout & Linkie (2009). Circular kernel density estimation was performed to visualize activity distributions, and the overlap coefficient (Δ) was calculated to quantify temporal overlap between *N. nebulosa* and other sympatric carnivores (Meredith & Ridout, 2021).

4.4. Results

This study was conducted as part of a larger biodiversity assessment project including diversity of mammals and tree species in INP. During the study period, we recorded 23 mammal species (15 families and 7 orders). Among these, three species are globally endangered: Bengal slow loris (*Nycticebus bengalensis*), western hoolock gibbon (*Hoolock hoolock*), and Asian elephant (*Elephas maximus*) and four are classified as vulnerable: clouded leopard (*Neofelis nebulosa*), northern pig-tailed macaque (*Macaca leonina*), capped langur (*Trachypithecus pileatus*) and greater hog badger (*Arctonyx collaris*) (IUCN, 2025). Notably, our survey provides the first photographic evidence of the *Neofelis nebulosa* in Inani National Park.

The clouded leopard was photographically detected nine times at three of the 32 camera stations in Inani National Park. In addition to the first photographic evidence of the *N. nebulosa* recorded by camera traps, a total of five pugmarks were detected across three separate line transects. The majority (3 out of 5) were recorded along a single transect, while the remaining two were each found in separate transects (**Figure 4.2**). Species identifications were based on regional field guides (Khan, 2018; Menon, 2023) and to minimize misidentification, pugmarks were identified and verified following Pocock (1939) and Sunquist & Sunquist (2002), based on diagnostic features including: Rounded

overall shape with proportionally shorter and broader toes than *Panthera pardus*, relatively small pad size (mean = 7.4 cm, range = 6–9 cm) consistent with adult *N. nebulosa* dimensions, absence of prominent lobe separation at the posterior pad margin typical of *P. pardus*, distinct heel impressions and claw absence, characteristic of felids on firm or muddy substrates.

All pugmarks were attributed to adult individuals based on pad size (>6 cm) and clear morphological consistency with confirmed reference images from regional databases and published descriptions (Hunter, 2019).

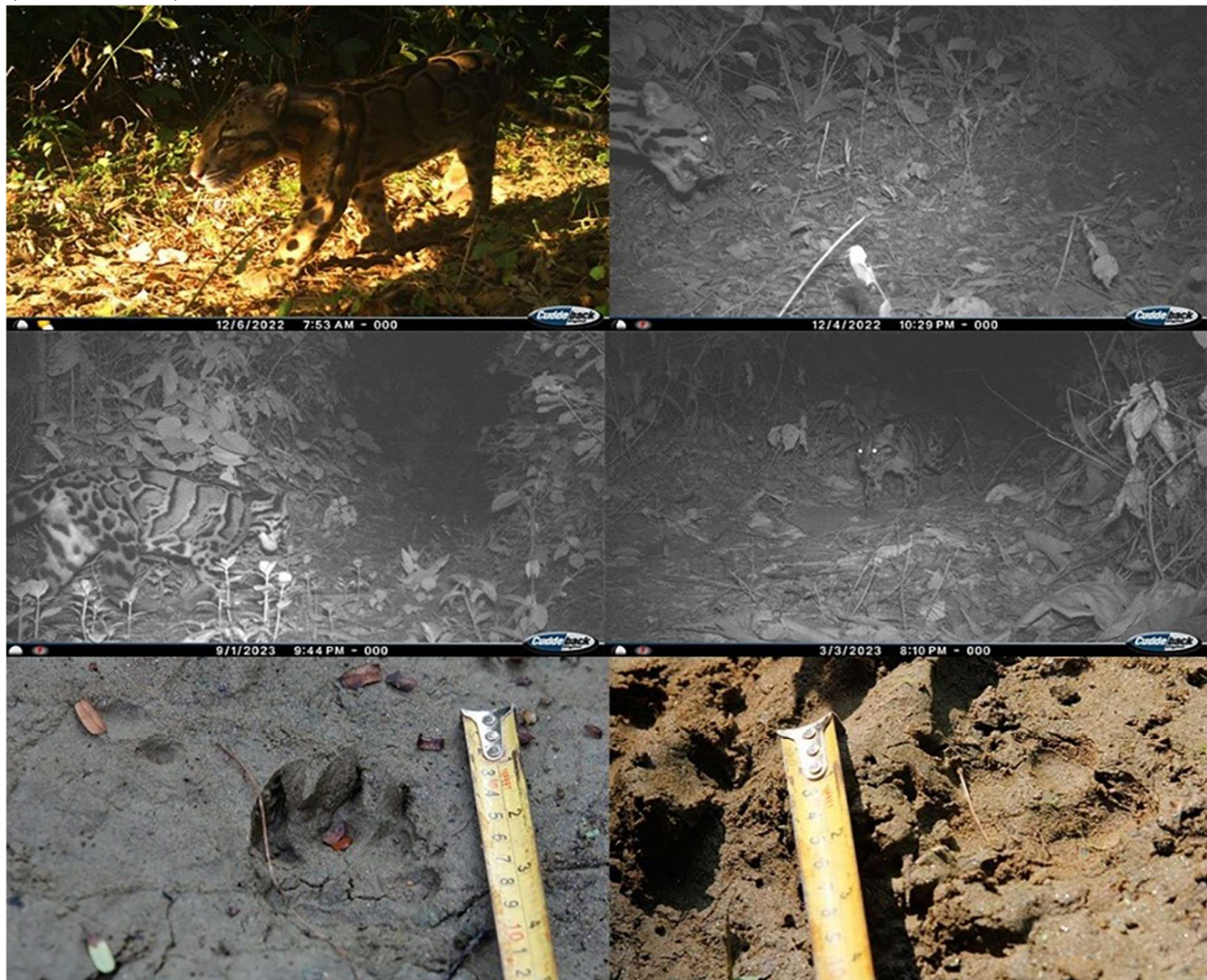


Figure 4.2. Camera-trap images and pugmark records of the Clouded leopard (*Neofelis nebulosa*) documented in Inani National Park during the 2022–2023 survey period

These detections occurred during both the dry season (August–October) and the cooler months (January), indicating that clouded leopards utilize the available habitats year-round. Although INP does not experience pronounced seasonal variation typical of temperate regions, local differences in temperature, humidity, and resource availability- such as reduced water flow and vegetation cover during the dry months versus higher prey activity and human presence in cooler months may influence habitat use and detectability. All signs were attributed to adult individuals based on pugmark

morphology and size (6–9 cm) and pugmarks were found in hilly terrain within middle-canopy forest, on two types of substrates- mud (n = 3) and soil (n = 2) and under varying weather conditions, including sunny and foggy days.

Temporal analysis of independent camera detections indicated a distinctly nocturnal activity pattern for *N. nebulosa*. Kernel density estimation revealed a pronounced activity peak at 21:22 h (9:22 PM), with a secondary, smaller peak between 04:00–06:00 h. Activity during daylight hours was minimal, suggesting avoidance of human activity and thermal stress (**Figure 4. 3**).

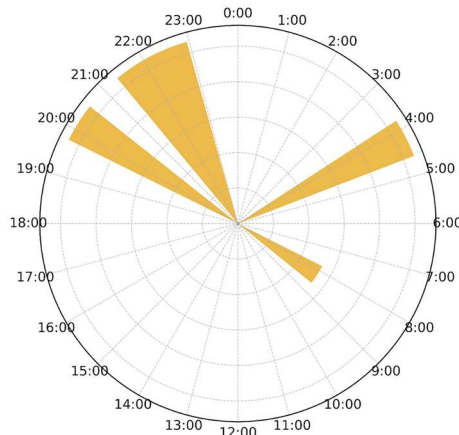


Figure. 4.3. Circular kernel-density plot showing the 24-hour activity pattern of the Clouded leopard (*Neofelis nebulosa*) in Inani National Park, based on time-stamped camera-trap detections.

The Relative Abundance Index (RAI) was 0.19 independent detections per 100 trap-nights, indicating an extremely low encounter rate consistent with the species' cryptic behavior and presumed low population density. Naïve occupancy, representing the proportion of sites with detections, was 0.09, while model-based analysis adjusting for imperfect detection yielded an occupancy probability of 0.20 (95% CI = 0.04–0.39). The detection probability per daily sampling occasion was estimated at 0.01 (95% CI = 0.00–0.02), underscoring the rarity of detections and the difficulty of repeatedly detecting the species even at occupied sites. Similar indices are calculated in case of other wild mammals recorded by camera trapping during the study period (**Table 3.5 in Chapter 3**).

4.5. Discussion

This study presents the first rigorously verified photographic and field evidence of the continued presence of the clouded leopard *Neofelis nebulosa* in Inani National Park (INP). Despite 13 months of intensive camera-trap and transect surveys, detections were extremely rare, indicating very low population density and the species' highly cryptic behavior. The low Relative Abundance Index (0.19 detections per 100 trap-nights) and estimated occupancy ($\psi = 0.20$; 95% CI: 0.04–0.39) align with similarly low detectability reported across the species' range (Jennelle, C.S. et al., 2002). Comparable low encounter rates and low-density estimates from other parts of South and Southeast Asia (e.g. Cheyne et al. 2013), further highlight the rarity of the clouded leopard and the difficulty of monitoring elusive felids in dense and human-disturbed forest landscapes.

The observed activity pattern, with peaks around 21:00 and early morning, is consistent with the clouded leopard's predominantly nocturnal to crepuscular behavior reported in previous camera-trap studies (Kawanishi & Sunquist, 2004). In anthropogenically disturbed habitats, such temporal shifts likely reduce encounters with human and sympatric carnivores such as leopard cats (*Prionailurus bengalensis*), jungle cats (*Felis chaus*), golden jackals (*Canis aureus*), and large civets, all of which occur in and around Inani National Park and may influence activity patterns through interference or exploitative competition. In INP, human activity is largely diurnal, with peak disturbances occurring between 07:00 and 17:00 due to forest patrols, firewood collection, grazing, and tourist movement along accessible trails. The clouded leopard's nocturnal activity therefore appears to be an adaptive strategy to minimize human disturbance. Similar behavioral adjustments have been documented in other carnivores occupying disturbed or fragmented habitats, where temporal segregation reduces conflict and disturbance risk (Ramesh et al., 2012), particularly at the margins of the species' range (Animal Diversity Web, n.d.; IUCN Cat Specialist Group, 2023).

Pugmark records provided additional confirmation of the clouded leopard's presence and habitat use. Tracks, verified through morphological comparison with published references (Pocock, 1939; Hunter, 2019), indicate that adult individuals primarily use mid-elevation hill forests and riparian slopes. Their occurrence across multiple transects and seasons suggests year-round use of the park and possibly overlapping ranges of a small resident population. This pattern echoes the fragmented distribution reported from the Chittagong Hill Tracts and supports the view that Inani National Park functions as part of a relict network of habitat patches linked to other protected areas, such as Kaptai National Park and the Sangu–Matamuhuri Reserve Forest. These findings highlight the importance of maintaining ecological corridors to facilitate movement, gene flow, and long-term population viability (IUCN Bangladesh, 2015; Brown, Mongabay 2024; WildFact forum; Creative Conservation Alliance, 2025). The lack of detections in agricultural and settlement areas within INP further underscores the species' sensitivity to habitat conversion and isolation, a trend widely observed across Southeast Asia (Global Conservation, 2024).

The confirmed occurrence of the clouded leopard (*Neofelis nebulosa*) in Inani National Park provides valuable new insight into the species' distribution at the western edge of the Indo–Burma biodiversity hotspot. Studies from across South and Southeast Asia indicate that the species naturally occurs at low densities, has wide-ranging movements, and can persist in structurally complex forests under human pressure, making infrequent detections ecologically expected rather than evidence of absence (Petersen et al., 2020; Bhatt & Lyngdoh, 2023). Within this context, the photographic and sign-based records from INP represent rare confirmation of the species' persistence in Bangladesh's coastal hill forests. These findings highlight the importance of protecting remaining habitat patches to maintain landscape connectivity (Wang et al., 2025) and regional conservation efforts for this elusive felid.

4.6. Implications for Monitoring and Conservation

The confirmed presence of *Neofelis nebulosa* in Inani National Park marks a significant range extension in southeastern Bangladesh and underscores the conservation importance of this fragmented landscape within the Indo-Burma biodiversity hotspot. Extremely low detection rates and limited spatial occupancy indicate a population under substantial ecological stress. Over the past three decades, escalating human activities have substantially constrained wildlife home ranges in Inani National Park (INP) (Kabir et al., 2021). The conversion of forest land for agriculture, the expansion of human settlements, intensive cattle grazing and the influx of Rohingya refugees along the park's periphery leading to increased habitat fragmentation and the isolation of wildlife populations particularly among small carnivores and medium- to large-bodied herbivores.

Overall, this study provides the first ecological baseline for *N. nebulosa* in a highly threatened landscape, reinforcing INP as a conservation priority and emphasizing the need for integrated, landscape level approaches, long-term systematic monitoring, including expanded camera-trap and sign-based surveys across the Cox's Bazar–Chittagong Forest complex, along with fine-scale habitat and connectivity analyses, is critical to identify movement corridors and maintain gene flow , and the community engagement to secure the future of one of South Asia's most elusive and endangered felids.

Chapter 5

Study 3.

DISTRIBUTION AND RICHNESS OF MAMMALS IN A TROPICAL PROTECTED AREA OF BANGLADESH

Abstract

Biodiversity loss remains a global challenge, with Protected Areas (PAs) serving as the primary strategy for conservation. Spatial modelling approaches are essential for evaluating habitat conditions and guiding effective biodiversity management, particularly in tropical regions where mammal communities respond to complex interactions between natural and human-driven factors. Despite the conservation importance of PAs, spatially explicit assessments of mammalian diversity remain limited. Modelling species distributions and estimating richness, therefore, provides critical opportunities to identify environmental and anthropogenic drivers shaping mammal assemblages. Inani National Park (INP), a tropical PA on the southeastern coast of Bangladesh, offers a valuable case study. Here, we combined species distribution modelling (SDM) using the MaxEnt algorithm with satellite-derived environmental predictors and systematically collected ground-based occurrence data to assess mammalian diversity. The study aimed to: (i) model the spatial distribution of mammalian species using SDMs and remote sensing variables; (ii) identify and map suitable habitats for threatened species within INP; and (iii) determine key environmental factors influencing occurrence patterns. Transect surveys and camera trapping conducted between November 2022 and December 2023 revealed heterogeneous results. The highest richness was concentrated along riparian corridors in the southern park, with additional hotspots near the southern boundary, western forest patches, and isolated northern sectors. These findings underscore the importance of maintaining heterogeneous vegetation and protecting riparian habitats to sustain mammal communities. This study provides the first fine-scale distribution maps of mammals in INP, establishing a baseline for future monitoring, restoration, and landscape-level conservation initiatives in Bangladesh's protected areas.

Keywords: Inani National Park; protected area; environmental variables; species distribution models; mammal biodiversity; conservation planning.

Introduction

The 1972 United Nations Conference on the Environment in Stockholm was the first significant global acknowledgement of the growing human pressure on the biosphere. Since then, many international agreements have sought to address biodiversity loss, with Protected Areas (PAs) becoming the primary global strategy for conserving biodiversity. In 2010, the 193 Parties to the Convention on Biological Diversity (CBD) adopted the Strategic Plan for Biodiversity 2011–2020, which called for expanding PA coverage from 13% to 17% of terrestrial areas by 2020 under the Aichi Biodiversity Targets (Rodríguez-Rodríguez & Martínez-Vega, 2022). Recognizing gaps in previous PA expansion efforts, the CBD now stresses the need to prioritize areas of high biodiversity value and ensure ecological representativeness. Building on Aichi Target 11, the updated Target 3 significantly elevates global conservation goals, aiming to increase the area of protected land from 17% to 30% (Protected Planet Report, 2024).

Despite the global expansion of Protected Areas (PAs), wild mammal populations continue to decline, fueling persistent debates about whether PAs are genuinely effective in maintaining species populations and supporting biodiversity (Laurance et al., 2012; Geldmann et al., 2018; Williams et al., 2022). Evidence shows that protection levels vary widely across PAs (Dudley, 2008). Mammals play pivotal roles in maintaining ecosystem structure, stability, and functional integrity through processes such as seed dispersal, predation, herbivory, and ecosystem engineering, which regulate energy flow and ecological balance. The decline of mammalian diversity is particularly severe in tropical Asia, where escalating human pressures, rapid land-use change, and climatic instability threaten remaining wildlife populations (IUCN Bangladesh, 2015; Tilman et al., 2017). South and Southeast Asia are globally recognized biodiversity hotspots, yet also among the most densely populated and environmentally stressed regions on Earth. In this context, Bangladesh occupies a unique biogeographic position at the intersection of the Indo-Himalayan and Indo-Malayan realms, supporting a remarkable variety of habitats, ranging from lowland floodplains and hill forests to coastal mangroves (IUCN Bangladesh, 2015).

Bangladesh represents an ecologically significant yet highly threatened segment of this broader tropical context. Situated at the intersection of the Indo-Malayan and Indo-Himalayan realms, the country harbors diverse mammalian assemblages across coastal, hill, and floodplain ecosystems. The national Red List identifies numerous species of conservation concern, including globally threatened carnivores, primates, and ungulates whose persistence is jeopardized by rapid forest loss, land conversion, and human-wildlife conflict (IUCN Bangladesh, 2015). These pressures are particularly intense along the southeastern coast, where forested landscapes have undergone extensive degradation due to the expansion of settlements, resource extraction, and agricultural encroachment. Within this dynamic socio-ecological setting, Inani National Park (INP) stands out as a biologically rich but highly vulnerable protected area. Given INP's role as a coastal biodiversity refuge and its exposure to both climatic and human-induced threats (Islam & Mohsanin, 2018), a comprehensive spatial modelling approach is essential for evaluating current habitat conditions and guiding effective conservation strategies. This gap limits not only local conservation planning but also broader ecological understanding of how mammals respond to interacting natural and human-driven factors in tropical hill forests.

Species Distribution Models (SDMs) provide a robust framework for addressing these knowledge gaps by quantifying the relationships between species occurrences and environmental predictors to estimate habitat suitability across landscapes (Phillips et al., 2006). Spatial cross-validation, improved discrimination metrics for rare species, and approaches to address spatial sampling bias have significantly strengthened the reliability of SDM outputs (Valavi et al., 2022). Consequently, SDMs are increasingly employed to evaluate protected-area performance, anticipate distributional shifts, and guide conservation decision-making in rapidly changing tropical landscapes. In total, 341 studies on SDM using Maximum Entropy Model (MaxEnt) were conducted worldwide from 2002 to 2023, with the highest numbers in the USA, China, and Australia (Rathore & Sharma, 2023). Several studies have used SDMs and related methods to analyze environmental data and assess habitat transformation

and the efficacy of conservation measures. For example, Ghaffari used the MaxEnt to assess whether or not amphibian habitats in Iran's PAs were effectively PAs (Ghaffari, H. et al., 2024); Liu Zhengxiao assessed the impact of climate and land use changes on the effectiveness of PAs for bird species in Southeast Asia (Liu, Z. et al., 2023), and Minghao Gong deployed SDM to identify panda habitat changes, thereby analyzing the effectiveness of PA's management (Campos-Cerqueira, M. et al., 2021). Yet similar multi-species approaches remain virtually unexplored in Bangladesh, despite their potential to inform management of fragmented and human-impacted protected areas such as INP.

Given the conservation importance of INP and the lack of spatially explicit assessments of its mammalian diversity, modelling species distributions and estimating richness offer a critical opportunity to understand the environmental and anthropogenic drivers shaping mammal communities in this landscape. Using a combination of species distribution modelling (SDM) through the MaxEnt algorithm, satellite-derived environmental predictors, and systematically collected ground-based occurrence data, the study provides a comprehensive spatial framework for understanding habitat suitability across multiple mammal taxa. Specifically, the objectives are: (i) to model the spatial distribution of mammalian species using SDMs and remote sensing-derived environmental variables; (ii) to identify and map suitable habitats for threatened mammal species within INP; and (iii) to determine the key environmental factors influencing species occurrence patterns.

5.2. Materials and Methods

5.2.1. Study Area

Inani National Park (INP) is located on the southeastern coast of Bangladesh, approximately 26 km south of Cox's Bazar (Kabir, M.T. et al. 2021), covering about 7,085 ha, it lies within the Cox's Bazar South Forest Division and is bounded by Himchari National Park to the north, Teknaf Wildlife Sanctuary to the south, the Bay of Bengal to the west, and the Cox's Bazar–Teknaf Highway to the east (Uddin et al., 2013) (**Figure 3.1 in chapter 3**). The park encompasses gently undulating hills and valleys composed mainly of Pleistocene to Miocene sediments, with clayey to sandy-loam soils shaped by monsoonal runoff and erosion (Hossen & Røskoft, 2021; Miah & Hossain, 2022) with the vegetation of degraded evergreen and semi-evergreen forests which harbors a diverse critically endangered assemblage of mammals.

5.2.2. Data Collection and Species Records

Field surveys were conducted across Inani National Park from November 2022 to November 2023 to document mammalian occurrences. Two complementary approaches were applied: (1) systematic transect surveys for direct sightings and indirect signs, and (2) camera trapping to detect primarily medium- and large-bodied, crepuscular, and nocturnal species. Following an initial reconnaissance to assess accessibility and detectability, seven standardized transects (2.1–3.5 km in length, 50 m survey width) were repeatedly surveyed. Transects followed existing trails, ridgelines, and streambeds to maximize species encounter rates. Camera traps (15 CEFC G-Series units) were deployed on a

rotating basis across 32 stations representing different habitat strata. Placement sites were selected based on animal trails, water sources, and topographic features identified during reconnaissance and local consultations. Cameras were spaced 500 m–1 km apart to minimize spatial autocorrelation and enhance capture efficiency, following regional mammal survey protocols (Chakma, 2017; Hossain et al. 2016).

A total of 23 mammal species under 15 families and 7 orders were recorded using a combination of direct observations, indirect evidence, and photographic detections (Das et al., 2026). Of these, 19 species with ≥ 10 unique occurrence records were retained for modeling to ensure robust species distribution predictions. After cleaning and merging the datasets from both methods, 1,124 georeferenced occurrence points were obtained. Duplicate records and those located within the same grid cell (1 km²) or outside the park boundary were excluded to reduce spatial sampling bias. The final cleaned dataset was formatted for MaxEnt modeling, ensuring only unique, spatially independent presence records were used (**Table 5.1**). In our study, we adopted stratified random sampling method for the vegetation survey. ArcGIS and MS Excel software were used to generate sample points. The National Land Cover Map of 2023 was used for stratification to get a more representative sample clip of the study land cover by using ArcGIS Software. As such, four land cover strata or areas were categorized in the study area namely, *Hill Forest*, *Forest Plantation*, *Shrub with Scattered Trees* and *Others* (including orchards, rural settlement, rivers, lake, multiple crops, single crop etc. (**Appendix 4**).

Table 5.1. Mammalian species presence data from field survey

Sl. No.	Species	Common Name	IUCN Bangladesh Status	IUCN Global Status	Method of observation			Records
					Direct	Indirect	Camera Trap	
1	<i>Canis aureus</i>	Golden Jackal	LC	LC	No	Yes	Yes	38
2	<i>Felis chaus</i>	Jungle Cat	NT	LC	Yes	Yes	Yes	59
3	<i>Neofelis nebulosa</i>	Clouded Leopard	CR	VU	Yes	Yes	Yes	37
4	<i>Prionailurus bengalensis</i>	Leopard Cat	NT	LC	Yes	Yes	Yes	67
5	<i>Urva urva</i>	Crab-eating Mongoose	NT	LC	Yes	Yes	Yes	75
6	<i>Arctonyx collaris</i>	Greater Hog Badger	VU	VU	Yes	Yes	Yes	33
7	<i>Melogale personata</i>	Large-toothed Ferret Badger	NE	LC	No	No	Yes	32
8	<i>Paradoxurus hermaphroditus</i>	Common Palm Civet	LC	LC	Yes	Yes	Yes	52

Sl. No.	Species	Common Name	IUCN Bangladesh Status	IUCN Global Status	Method of observation			Records
					Direct	Indirect	Camera Trap	
9	<i>Viverra zibetha</i>	Large Indian Civet	NT	LC	No	No	Yes	32
10	<i>Viverricula indica</i>	Small Indian Civet	NT	LC	No	No	Yes	34
11	<i>Muntiacus vaginalis</i>	Northern Red Muntjac	EN	LC	Yes	Yes	Yes	42
12	<i>Sus scrofa</i>	Wild Boar	LC	LC	Yes	Yes	Yes	83
13	<i>Megaderma lyra</i>	Greater False Vampire Bat	LC	LC	Yes	No	No	
14	<i>Macaca leonina</i>	Northern Pig-tailed Macaque	EN	VU	Yes	Yes	Yes	39
15	<i>Macaca mulatta</i>	Rhesus Monkey	VU	LC	Yes	Yes	Yes	81
16	<i>Trachypithecus pileatus</i>	Capped Langur	EN	VU	Yes	Yes	Yes	49
17	<i>Hoolock hoolock</i>	Western Hoolock Gibbon	CR	EN	Yes	Yes	No	
18	<i>Nycticebus bengalensis</i>	Bengal Slow Loris	EN	EN	Yes	No	No	
19	<i>Elephas maximus</i>	Asian Elephant	CR	EN	Yes	Yes	Yes	177
20	<i>Hystrix brachyura</i>	Malayan Porcupine	LC	LC	Yes	Yes	Yes	69
21	<i>Callosciurus pygerythrus</i>	Irrawaddy Squirrel	LC	LC	Yes	Yes	Yes	85
22	<i>Petaurista petaurista</i>	Red Giant Flying Squirrel	DD	LC	No	Yes	No	
23	<i>Tupaia belangeri</i>	Northern Treeshrew	NT	LC	Yes	Yes	Yes	40
Total								1124

5.2.3. Environmental Predictor Variables

A total of 27 environmental and anthropogenic variables were initially considered based on ecological relevance and prior literature (**Appendix- 5**). These included 19 bioclimatic variables from the

WorldClim v2.1 database (Fick & Hijmans, 2017), topographic attributes (elevation, slope) from the Shuttle Radar Topography Mission (SRTM, 30 m), land-use/land-cover from the 2023 National Land Cover Map, and remotely sensed spectral indices (NDVI, NDWI, BSI, and NDBI) derived from Sentinel-2 imagery processed in QGIS 3.34.15. In addition, several anthropogenic predictors—distance to Streams/Khals/Lakes, road networks, and settlements, were generated using Euclidean distance functions in QGIS to quantify habitat accessibility and disturbance gradients.

To ensure comparability, all raster layers were projected to WGS 84 / UTM Zone 46N (EPSG 32646) and resampled to a uniform spatial resolution of 30 m. Because coarse-resolution climatic variables ($\approx 1 \text{ km}^2$) exhibited limited spatial variation within the relatively small and topographically complex Inani National Park ($\sim 7,000 \text{ ha}$), they were excluded from final modeling to avoid scale mismatch. The remaining high-resolution environmental layers were screened for multicollinearity using Pearson's correlation coefficient ($|r| > 0.7$) and Variance Inflation Factor ($\text{VIF} < 10$) criteria (Dormann et al., 2013). Strongly correlated indices such as NDWI, BSI, and NDBI, which overlapped in spectral information with NDVI were removed.

The final variable set comprised five ecologically meaningful and non-correlated predictors: (1) Elevation, (2) Slope, (3) Normalized Difference Vegetation Index (NDVI), (4) Distance to Streams and Khals, and (5) Land Cover. This combination captured the key environmental gradients and habitat heterogeneity necessary for fine-scale species distribution modeling within the park.

5.2.4. Species Distribution Modeling (SDM)

Species distribution models were developed using MaxEnt v3.4.4 with parameter settings informed by the literature and preliminary tuning. Models used a regularization multiplier = 1 and feature classes = Auto, and were run for up to 500 iterations (Barnes, M.A. et al., 2014; Phillips, S.J. et al., 2006). A target-group background of 10,000 points was generated to better represent sampling effort and reduce background bias (Steen, B. et al., 2024). To further reduce spatial sampling bias, occurrence records were spatially thinned at $\sim 1 \text{ km}$ (one record per 1 km^2 cell) prior to modeling.

To quantify model uncertainty and variability, each species model was run using a bootstrap resampling approach with 30 replicates; in addition, model robustness was inspected with replicate partitioning. For model evaluation we used Area Under the ROC Curve (AUC) and reported mean and standard deviation of AUC across replicates and considered models to show strong predictive performance when $\text{AUC} > 0.8$. Variable importance was assessed using MaxEnt's percent contribution and jackknife tests, which together identify the relative and independent explanatory power of predictors.

Continuous habitat-suitability outputs (0–1) were converted to binary maps using the Maximum Training Sensitivity plus Specificity (MTSS) threshold to balance omission and commission errors for each species. For each taxon we selected the best-performing model and used its binary map in subsequent richness summation and gap-analysis steps. Finally, species richness maps were generated by summing binary presence–absence maps (for potential richness) across all modeled species, enabling the identification of multi-species habitat hotspots within the park.

5.3. Results

5.3.1. Model Evaluation and Selection

All species distribution models demonstrated strong predictive performance, confirming the robustness of the MaxEnt framework for modeling mammalian habitat suitability in Inani National Park. The Area Under the Curve (AUC) values for the final selected models ranged from 0.801 to 0.855, indicating *very good* to *excellent* discriminatory power (**Table 5.2; Appendix 6**). The Asian Elephant exhibited the highest model accuracy (AUC = 0.855 ± 0.012), followed by the Wild Boar (0.838 ± 0.023) and Malayan Porcupine (0.833 ± 0.032). The Capped Langur showed the lowest AUC (0.801 ± 0.032), though still within the acceptable performance range. Remaining species, including civets, macaques, and small carnivores, displayed intermediate values (0.811–0.831), reinforcing overall model reliability. These results indicate that the environmental predictors and parameterization effectively captured the ecological niches of the modeled taxa, providing a solid foundation for subsequent spatial and ecological interpretation.

Table-5. 2: The value of different species for model accuracy, the Area under the curve (AUC)

Species	Common Name	AUC $\pm$ Standard Deviation
<i>Elephas maximus</i>	Asian Elephant	0.855 $\pm$ 0.012
<i>Muntiacus vaginalis</i>	Northern Red Muntjac	0.818 $\pm$ 0.033
<i>Trachypithecus pileatus</i>	Capped Langur	0.801 $\pm$ 0.032
<i>Neofelis nebulosa</i>	Clouded Leopard	0.815 $\pm$ 0.029
<i>Urva urva</i>	Crab-eating Mongoose	0.831 $\pm$ 0.020
<i>Canis aureus</i>	Golden Jackal	0.820 $\pm$ 0.035
<i>Hystrix brachyura</i>	Malayan Porcupine	0.833 $\pm$ 0.032
<i>Arctonyx collaris</i>	Greater Hog Badger	0.811 $\pm$ 0.032
<i>Callosciurus pygerythrus</i>	Hoary-bellied Squirrel	0.811 $\pm$ 0.029
<i>Felis chaus</i>	Jungle Cat	0.829 $\pm$ 0.027
<i>Viverra zibetha</i>	Large Indian Civet	0.831 $\pm$ 0.026
<i>Melogale personata</i>	Large-toothed Ferret-badger	0.821 $\pm$ 0.033
<i>Prionailurus bengalensis</i>	Leopard Cat	0.829 $\pm$ 0.022
<i>Macaca leonina</i>	Northern Pig-tailed Macaque	0.816 $\pm$ 0.035
<i>Tupaia belangeri</i>	Northern Tree Shrew	0.815 $\pm$ 0.033
<i>Macaca mulatta</i>	Rhesus Monkey	0.809 $\pm$ 0.031
<i>Viverricula indica</i>	Small Indian Civet	0.827 $\pm$ 0.040

Species	Common Name	AUC $\pm$ Standard Deviation
<i>Paradoxurus hermaphroditus</i>	Common Palm Civet	0.828 $\pm$ 0.034
<i>Sus scrofa</i>	Wild Boar	0.838 $\pm$ 0.023

5.3.2. Relative Importance of Environmental Predictors

The variable contribution analysis revealed that a few environmental factors consistently governed the distribution patterns of mammalian species across the study area (**Table 5.3**). Among the 27 tested predictors, Land Cover emerged as the dominant driver for most species, reflecting strong habitat associations with forest, shrubland, and mixed-vegetation zones. For example, Land Cover accounted for the highest contribution in *Wild boar* (68.4%), *Clouded leopard* (65.5%), and *Northern pig-tailed macaque* (63.2%), while relatively lower contributions were observed for *Irrawaddy squirrel* (37.8%) and *Rhesus macaque* (39.6%). The second most influential predictor for most species was proximity to water bodies, indicating the ecological significance of aquatic and riparian habitats in this tropical landscape. Water bodies contributed notably to the distributions of *Malayan porcupine* (31.1%) and *Rhesus macaque* (26.6%), whereas *Clouded leopard* and *Northern pig-tailed macaque* showed comparatively lower sensitivity to this variable (12–13%).

Topographic and vegetation productivity variables showed secondary importance. Slope contributed around 10% to most species, peaking at 19.6% for *Rhesus macaque* and 14.3% for *Northern tree shrew*. NDVI, representing vegetation greenness and productivity, had moderate importance, particularly for *Irrawaddy squirrel* (28%) and *Jungle cat* (15.3%), suggesting species-specific reliance on canopy or vegetation density. Elevation contributed least overall but remained relevant for a few taxa, such as *Greater Hog badger* (10.4%), reflecting tolerance to higher terrain within the hill forest mosaic of Inani National Park.

Table 5.3: Ranked variables importance (%) of the five influential environmental variables for each species

Species	First	Second	Third	Fourth	Fifth
Wild boar	Land Cover (68.4%)	Streams/Khals/Lakes (13.2%)	Slope (7.9%)	NDVI (6.2%)	Elevation (4.3%)
Clouded leopard	Land Cover (65.5%)	Streams/Khals/Lakes (12%)	Elevation (8.6%)	Slope (8.2%)	NDVI (5.8%)
Northern pig-tailed macaque	Land Cover (63.2%)	Streams/Khals/Lakes (13.1%)	Slope (9.8%)	NDVI (8.3%)	Elevation (5.7%)
Small Indian civet	Land Cover (60.6%)	Streams/Khals/Lakes (16.8%)	NDVI (9.6%)	Slope (7.2%)	Elevation (5.8%)
Crab-eating mongoose	Land Cover (59.3%)	Streams/Khals/Lakes (22.1%)	Elevation (7.5%)	Slope (7%)	NDVI (4%)

Species	First	Second	Third	Fourth	Fifth
Greater Hog badger	Land Cover (59.2%)	Streams/Khals/Lakes (15.8%)	Elevation (10.4%)	Slope (10%)	NDVI (4.6%)
Large-toothed ferret-badger	Land Cover (57.3%)	Streams/Khals/Lakes (18.2%)	Slope (9.8%)	Elevation (8.7%)	NDVI (6%)
Asian elephant	Land Cover (56.7%)	Streams/Khals/Lakes (19.9%)	Slope (10%)	NDVI (9.5%)	Elevation (3.9%)
Common palm civet	Land Cover (55.8%)	Streams/Khals/Lakes (20.7%)	Slope (9.5%)	NDVI (7.4%)	Elevation (6.6%)
Large Indian civet	Land Cover (55.4%)	Streams/Khals/Lakes (20.4%)	Slope (10.9%)	NDVI (6.9%)	Elevation (6.4%)
Capped langur	Land Cover (55.2%)	Streams/Khals/Lakes (16.9%)	Slope (10.5%)	Elevation (9.6%)	NDVI (7.9%)
Leopard cat	Land Cover (54.5%)	Streams/Khals/Lakes (23.2%)	Elevation (9.1%)	Slope (7.6%)	NDVI (5.7%)
Barking deer	Land Cover (53.5%)	Streams/Khals/Lakes (20.6%)	Slope (10.4%)	NDVI (8%)	Elevation (7.5%)
Golden jackal	Land Cover (52.5%)	Streams/Khals/Lakes (23.8%)	Slope (8%)	NDVI (8%)	Elevation (7.7%)
Northern tree shrew	Land Cover (51.6%)	Streams/Khals/Lakes (21.8%)	Slope (14.3%)	Elevation (8%)	NDVI (4.4%)
Malayan porcupine	Land Cover (48.4%)	Streams/Khals/Lakes (31.1%)	NDVI (11.6%)	Elevation (4.7%)	Slope (4.3%)
Jungle cat	Land Cover (45.7%)	Streams/Khals/Lakes (25.4%)	NDVI (15.3%)	Elevation (7%)	Slope (6.6%)
Rhesus macaque	Land Cover (39.6%)	Streams/Khals/Lakes (26.6%)	Slope (19.6%)	NDVI (7.2%)	Elevation (7.1%)
Irrawaddy squirrel	Land Cover (37.8%)	NDVI (28%)	Streams/Khals/Lakes (21.7%)	Elevation (6.4%)	Slope (6.1%)

5.3.3. Habitat suitability and Distribution Patterns

The ensemble habitat suitability maps provide a continuous prediction of environmental favorability for each species across Inani National Park, with values ranging from 0 (unsuitable) to 1 (optimal conditions) (**Figure 5.1**). Overall, the predicted patterns show that central and lower-elevation zones, particularly along riverine corridors and gentle slopes, generally support higher suitability for most species. Conversely, high-elevation ridges and fragmented or heavily anthropogenic areas exhibit lower habitat suitability. These spatial patterns reflect the interplay between key environmental drivers, primarily land cover and proximity to water bodies, and the ecological requirements of the mammals studied.

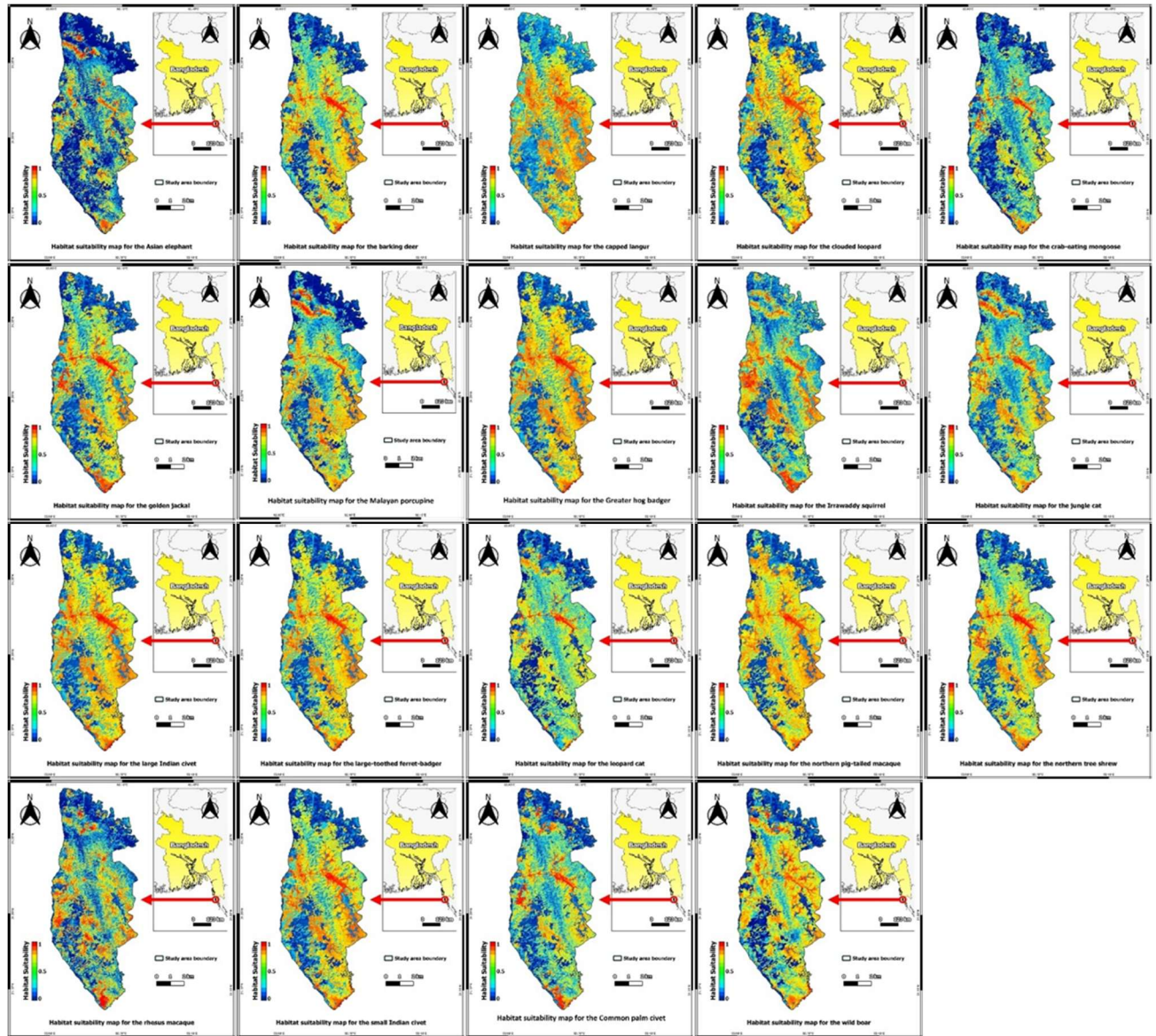


Figure 5.1. Habitat Suitability for different species

The extent of predicted suitable habitat varied considerably among species, reflecting differences in ecological adaptability and habitat specificity (**Table 5.4; Figure 5.3**). *Clouded leopard* exhibited the largest potential range, covering approximately 30,127 ha (43.97% of the park), followed by *Large Indian civet* (26,929 ha, 39.31%) and *Capped langur* (25,076 ha, 36.60%). Species such as *Northern pig-tailed macaque*, *Golden jackal*, and *Wild boar* also occupied broad ranges (>33%), while others like *Jungle cat* (13,428 ha, 19.61%) and *Rhesus macaque* (12,203 ha, 17.81%) were more restricted. Most remaining species had intermediate distributions, with suitable habitat areas between ~23% and 27% of the park. These results underscore significant interspecific variation in habitat breadth, with generalist species exhibiting widespread distributions and habitat specialists or disturbance-sensitive species showing more restricted ranges (**Figure 5.2**).

Table 5.4: Species distribution range of species

Name of the Species	Covering area (m²)	Percentage of National Park
Clouded Leopard	30,127,344	(43.97%)
Large Indian Civet	26,929,056	(39.31%)
Capped Langur	25,075,808	(36.60%)
Northern Pig-tailed Macaque	24,526,704	(35.79%)
Wild Boar	22,870,944	(33.38%)
Golden Jackal	22,747,744	(33.20%)
Northern Tree Shrew's	22,605,696	(33.00%)
Hog Badger	22,419,552	(32.73%)
Large-toothed Ferret Badger	21,924,896	(32.00%)
Asian Elephant	18,986,384	(27.71%)
Himalayan Crestless Porcupine	18,846,864	(27.51%)
Irrawaddy Squirrel	18,491,664	(26.99%)
Small Indian Civet	18,059,680	(26.36%)
Leopard Cat	17,734,992	(25.89%)
Small-toothed Palm Civet	16,876,096	(24.63%)
Barking Deer	16,808,400	(24.53%)
Crab-eating Mongoose	15,764,336	(23.01%)
Jungle Cat	13,427,968	(19.61%)
Rhesus Macaque	12,203,072	(17.81%)

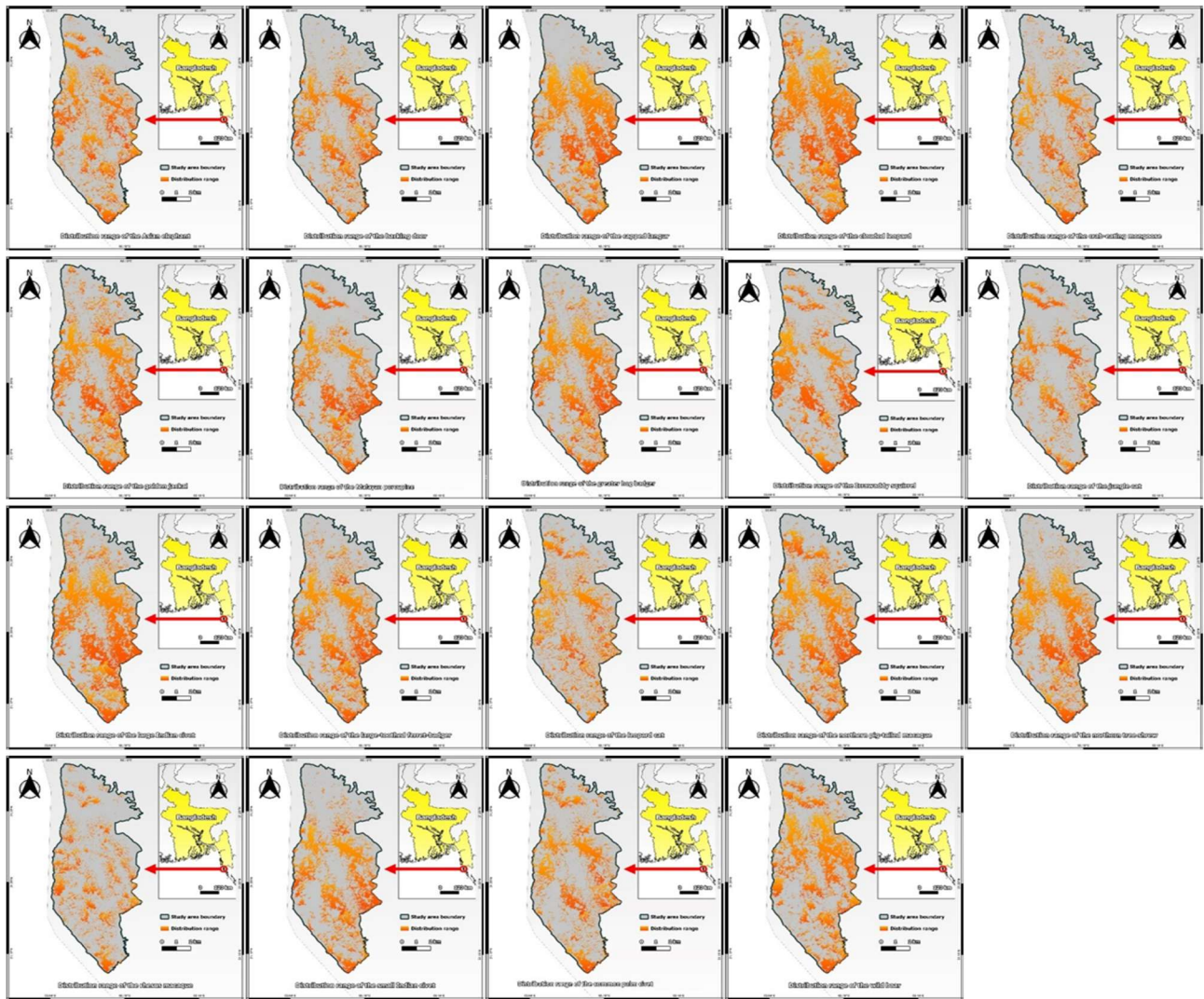


Figure 5.2. Distribution range maps of different species

5.3.4. Habitat preferences by species

Habitat suitability across land-cover types revealed consistent patterns for most mammal species in Inani National Park. Shrub with Scattered Trees provided the largest proportion of suitable habitat for the majority of species, followed by moderate suitability in Hill Forest and Forest Plantation areas. Streams and Khals contributed notably for riparian-associated species, whereas agricultural lands (Multiple Crop) and Rural Settlements were largely unsuitable. Species-specific deviations were observed: the Irrawaddy squirrel utilized NDVI-rich Hill Forest patches more extensively, and the Rhesus macaque exhibited minimal suitability in human-modified landscapes. These patterns highlight the strong reliance of INP mammals on semi-natural and forested habitats while avoiding heavily altered environments (**Table 5.5**).

Table 5.5: Surface covering of suitable habitats of different species

Species Name	Land Cover Strata						Total Area
	Shrub with Scattered Trees	Water Bodies (Stream and Khals)	Hill Forest	Forest Plantation	Rural Settlement	Multiple Crop	
	Suitable	Suitable	Suitable	Suitable	Suitable	Suitable	Suitable
Clouded leopard	2887 ha. (96%)	36.24 ha. (1%)	20 ha.	81.66 ha. (3%)	-	-	3024.90 ha.
Large Indian civet	2500 ha. (93%)	40 ha. (2%)	20 ha.	120 ha. (5%)	10 ha.	-	2700 ha.
Capped langur	2419 ha. (97%)	33.08 ha. (1%)	20 ha.	52.04 ha. (2%)	20 ha.	-	2544.12 ha.
Northern pig-tailed macaque	2330 ha. (95%)	44 ha. (2%)	24.67 ha. (1%)	58 ha. (2%)	-	-	2456.67 ha.
Greater Hog badger	2100 ha. (94%)	40 ha. (2%)	4.8 ha.	89 ha. (4%)	-	-	2233.80 ha.
Large-toothed ferret-badger	2000 ha. (93%)	40 ha. (2%)	20 ha.	100 ha. (5%)	-	-	2160 ha.
Golden jackal	2000 ha. (88%)	60 ha. (2%)	20 ha.	220 ha. (10%)	10 ha.	-	2320 ha.
Northern tree shrew	1970 ha. (87%)	44 ha. (2%)	91.80 ha. (4%)	158 ha. (7%)	04 ha.	04 ha.	2279.80 ha.
Wild boar	1898 ha. (83%)	40 ha. (2%)	184 ha. (8%)	148 ha. (7%)	-	-	2270 ha.
Malayan porcupine	1697 ha. (90%)	40 ha. (2%)	16 ha. (1%)	120 ha. (7%)	08 ha.	08 ha.	1897 ha.
Small Indian civet	1680 ha. (93%)	40 ha. (2%)	5.46 ha.	81.59 ha. (5%)	-	-	1807.05i ha.
Barking deer	1575 ha. (94%)	34.10 ha. (2%)	31.91 ha. (2%)	39.74 ha. (2%)	08 ha.	08 ha.	1712.75 ha.
Asian elephant	1465 ha. (77%)	43.4 ha. (2%)	230 ha. (12%)	159 ha. (9%)	08 ha.	-	1905.4 ha.
Crab-eating mongoose	1352.29 ha.(86%)	44.16 ha. (3%)	14.55 ha. (1%)	165.42 ha. (10%)	-	-	1576.42 ha.
Common palm civet	1350 ha. (80%)	43.9 ha. (3%)	24.80 ha. (1%)	270 ha. (16%)	08 ha.	08 ha.	1708.80 ha.

Species Name	Land Cover Strata						Total Area
	Shrub with Scattered Trees	Water Bodies (Stream and Khals)	Hill Forest	Forest Plantation	Rural Settlement	Multiple Crop	
	Suitable	Suitable	Suitable	Suitable	Suitable	Suitable	Suitable
Leopard cat	1338 ha. (75%)	40 ha. (3%)	370 ha. (21%)	24 ha.	08 ha.	08 ha.	1804 ha.
Irrawaddy squirrel	1216 ha. (66%)	40 ha. (2%)	350 ha. (19%)	184 ha. (10%)	16 ha. (1%)	40 ha. (2%)	1854 ha.
Jungle cat	1150 ha. (86%)	40 ha. (3%)	32.94 ha. (3%)	104.29 ha. (8%)	04 ha.	04 ha.	1339.23 ha.
Rhesus macaque	680 ha. (56%)	16 ha. (1%)	330 ha. (27%)	190 ha. (16%)	10 ha.	20 ha.	1256 ha.

5.3.5. Mammal species richness patterns

Predicted mammal species richness within Inani National Park ranged from 0 to 19 species, revealing strong spatial variation in diversity across the landscape (**Figure 5.3**). Areas of very low richness (0–4 species) were primarily associated with agricultural lands and rural settlements, reflecting degraded or unsuitable habitats. Moderate richness (5–10 species) occurred in transitional habitats and buffer zones, while high to very high richness (11–19 species) identified potential biodiversity hotspots. The highest richness was concentrated along riparian zones of the Inani Canal and adjacent khals, particularly within the “Shrub with Scattered Trees” class, with smaller waterbodies in the southern park boundary also supporting elevated species richness. In contrast, extensive agricultural and settlement areas consistently exhibited low richness, highlighting the influence of habitat modification. Overall, species richness was heterogeneously distributed, emphasizing key areas for conservation prioritization.

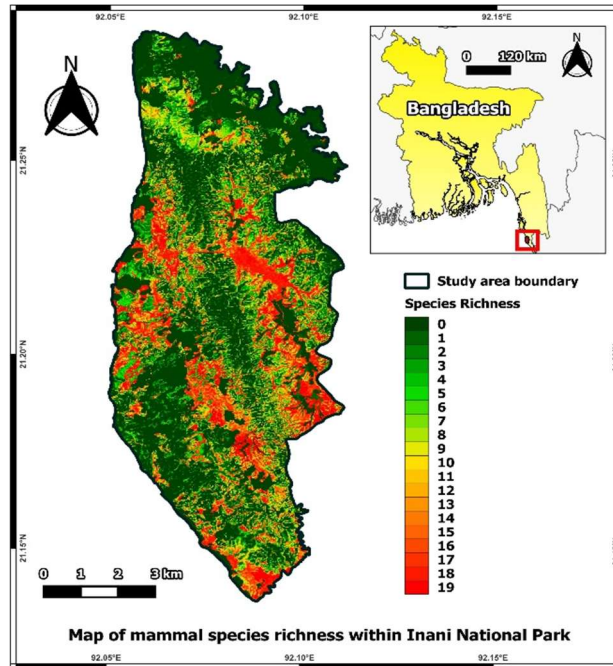


Figure 5.3. Species richness within the Inani National Park

5.3.6 Occurrence of Mammal Species by Land Cover Classes

The species-wise distribution reveals a clear dominance of the *Shrub with Scattered Trees* land cover class across nearly all recorded mammalian taxa. Asian Elephant exhibits the highest single-species occurrence in this habitat (119 records), compared to 22 in Hill Forest, 14 in Forest Plantation, and 22 in Other land cover types. Similarly, Irrawaddy Squirrel records 52 occurrences in shrub habitat versus 15 in Hill Forest, 8 in Forest Plantation, and 10 in Others. Himalayan Crestless Porcupine shows 53 occurrences in shrub landscapes, substantially exceeding Hill Forest (7), Forest Plantation (4), and Others (5). Among carnivores, Leopard Cat records 44 occurrences in shrub habitat compared to 12 in Hill Forest and only 2 in Forest Plantation. Jungle Cat follows a similar pattern with 43 occurrences in shrub areas, versus 7 in Hill Forest and 4 in Forest Plantation. Crab-eating Mongoose demonstrates 51 shrub-based occurrences, markedly higher than Hill Forest (6), Forest Plantation (6), and Others (12). Primates also show strong association with shrub mosaics: Rhesus Macaque records 48 occurrences in shrub habitats compared to 11 in Hill Forest and 19 in Forest Plantation, while Northern Pig-tailed Macaque shows 31 shrub occurrences relative to 5 in Hill Forest and 2 in Forest Plantation. Even small mammals such as Northern Tree Shrew (30 shrub vs. 5 Hill Forest) and Small Toothed Palm Civet (35 shrub vs. 5 Hill Forest) exhibit similar trends.

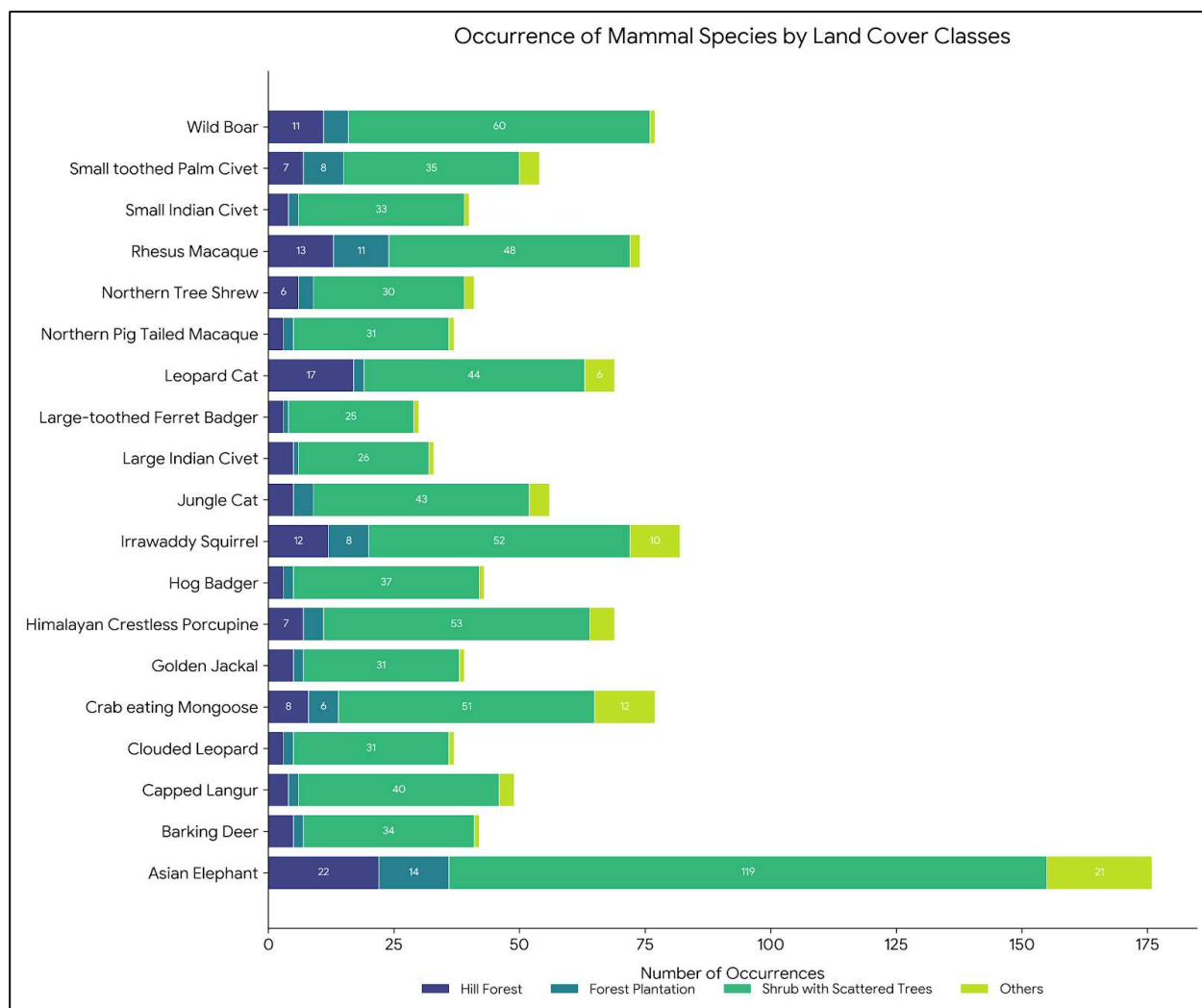


Figure 5.4. Occurrence of mammal species by land cover classes

Across all species, Forest Plantation consistently registers the lowest or near-lowest values, typically below 10 occurrences for most taxa. Hill Forest supports moderate frequencies but does not exceed shrub habitat for any species. These quantitative patterns clearly demonstrate that shrub-dominated landscapes support the highest activity levels for a wide range of ecological guilds.

5.3.7 Total Number of Occurrences by Land Cover Classes

The aggregated occurrence data reveal a highly skewed distribution among land cover categories. Shrub with Scattered Trees accounts for 807 total records, substantially exceeding Hill Forest (141), Others (91), and Forest Plantation (85). This indicates that approximately three-quarters of all recorded mammalian occurrences are concentrated within shrub-dominated landscapes. Forest Plantation contributes the smallest share, reinforcing its comparatively limited ecological role within the study area. The pronounced disparity suggests that shrub habitats function as the primary ecological matrix supporting mammalian assemblages at the landscape scale.

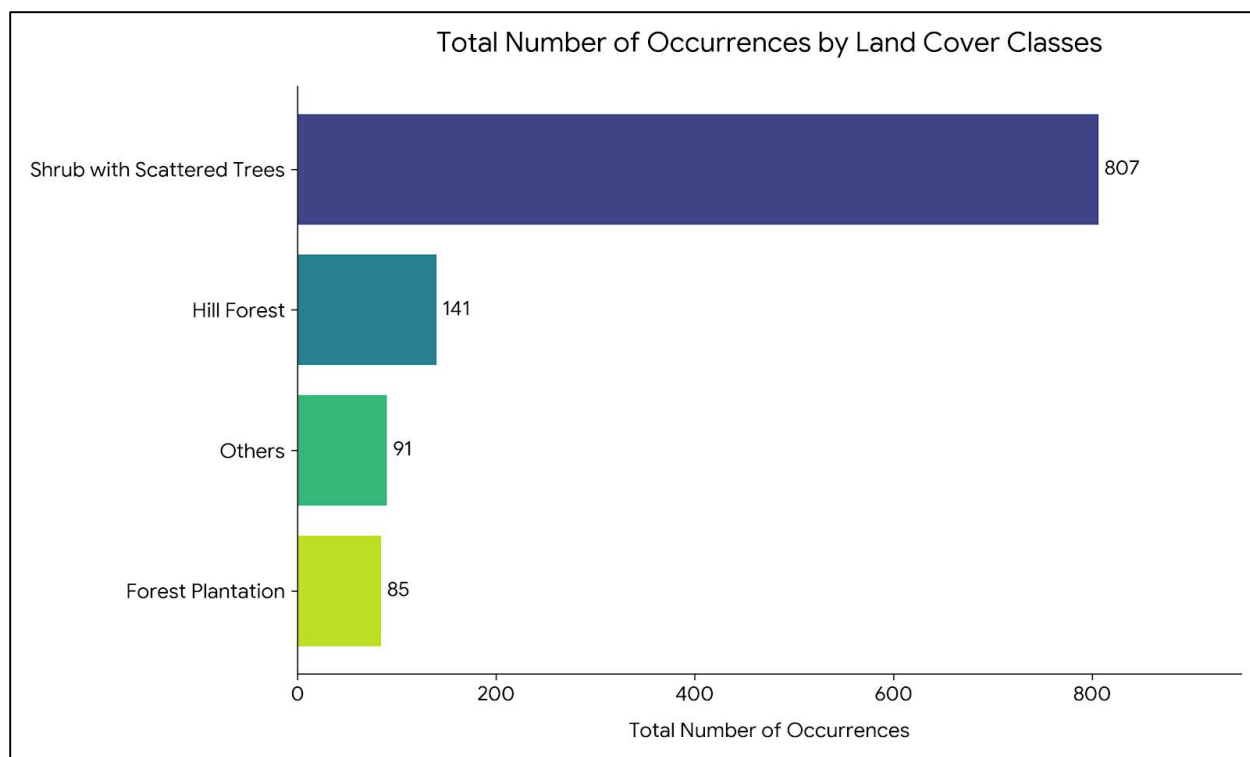


Figure 5.5. Total number of occurrences by land cover class

5.4. Discussion

Our study provides the first comprehensive evaluation of mammalian species distribution and habitat suitability in Inani National Park (INP), integrating field verified occurrences with species distribution models and remotely sensed environmental predictors. We documented 23 mammal species across diverse habitat types, and modeled 19 species with sufficient data, demonstrating that INP supports a high diversity of mammals relative to its size and degree of anthropogenic pressure. Our findings highlight INP as a critical refuge for globally threatened and regionally significant species, reinforcing the ecological value of southeastern Bangladesh in national conservation planning. The consistent importance of land cover and proximity to water bodies across species indicates that both forest structure and hydrological features are essential for sustaining mammalian communities in tropical hill ecosystems. Importantly, this study underscores that protected forest patches embedded within human dominated landscapes can maintain substantial biodiversity provided that natural vegetation and microhabitat heterogeneity persist. By leveraging high resolution field data and rigorous modeling, we reveal previously undocumented spatial patterns of mammal occupancy that are highly relevant for targeted conservation management in a rapidly changing landscape. Our results establish a baseline for long term ecological monitoring, enhance understanding of species habitat preferences in tropical hill forests, and provide actionable insights for landscape scale conservation planning in Bangladesh. Additionally, our findings highlight the sensitivity of mammalian assemblages to habitat edges and areas undergoing rapid land use transformation, suggesting that future declines may occur if current patterns of forest loss and

fragmentation intensify. The spatial patterns identified here are particularly informative for guiding habitat restoration initiatives, improving connectivity between forest blocks, and prioritizing riparian and shrub dominated zones that support disproportionately high species richness. The integration of remotely sensed predictors also demonstrates the feasibility of scalable biodiversity monitoring in data limited regions, offering an approach that can be replicated across other protected forest networks in Bangladesh. Continued investment in community-based management, habitat restoration, and technological monitoring tools will be essential to ensure the long-term persistence of mammal populations within INP and surrounding landscapes.

The patterns observed at INP align with previous ecological research demonstrating that forest structure, topographic diversity, and water availability jointly shape mammalian assemblages in tropical protected areas. Similar to SDM based studies conducted for endangered mammal species in Bangladesh forests under climate change scenarios (Alamgir M. et al. 2015; Hasan N. et al. 2025), our findings support the effectiveness of presence only models for informing conservation in data scarce environments. The strong performance of MaxEnt models in this study aligns with work showing accurate predictions from limited datasets when field verified presence points are used (Pearson R. G. et al. 2007; Wang L. Diao C. et al. 2024). The patterns of higher suitability in semi evergreen forests and shrub dominated hill slopes resemble habitat associations reported for tropical mammals in South and Southeast Asia (Molur et al. 2005). Furthermore, the observed link between habitat fragmentation, species occupancy, and reliance on semi natural patches suggests that species persistence in human altered landscapes depends on the size, connectivity, and quality of habitat patches. However, compared with studies from African savanna mammals that reported marginally higher AUC values (Giliba R. A. et al. 2023), the slightly lower but still strong predictive accuracy in INP likely reflects greater environmental heterogeneity and limited observation records for elusive species. Despite these differences, the overarching convergence with regional and global research highlights the robustness of our findings and the ecological importance of INP within the broader Indo Malayan biodiversity hotspot.

The spatial patterns identified in our models likely arise from a combination of vegetation structure, hydrological features, and terrain characteristics that jointly influence resource availability, microclimatic stability, denning opportunities, and movement pathways. Land cover emerged as the most influential variable for habitat suitability, particularly for species that depend on closed canopy and semi evergreen forest structure for foraging, nesting, and predator avoidance. Higher suitability in shrub dominated hill forests supports the hypothesis that moderate canopy cover combined with understory complexity creates favorable conditions for many mid-sized mammals. Proximity to streams and khals was also a key predictor, reflecting the importance of water sources for thermoregulation, drinking, and prey availability in tropical environments. The role of slope, though moderate, highlights the value of gently undulating terrain for arboreal and semi arboreal species that rely on vertical and horizontal habitat structure. Limited contribution of bioclimatic variables underscores the dominance of fine scale habitat structure over broad climatic gradients at this spatial scale, consistent with previous findings that WorldClim variables may not capture local variation in complex tropical terrain (Bede Fezekas A. et al. 2024). Species ecology also contributed to variation

in predicted distributions; for example, species with generalist foraging behavior such as rhesus macaque and wild boar showed broader habitat associations, whereas habitat specialists like clouded leopard exhibited more restricted suitability patterns tied to intact forest habitat. Overall, these drivers support ecological theory emphasizing the role of habitat heterogeneity, structural cover, and water availability in shaping mammal communities in tropical forest landscapes.

Beyond the environmental predictors included in our models, additional ecological and anthropogenic mechanisms likely influence mammalian distribution patterns in INP. Landscape connectivity and corridor functionality can determine movement and gene flow of wide-ranging species, so that isolated forest patches—despite locally suitable habitat—may function as demographic sinks (Acharya et al., 2016). Human disturbance gradients, including proximity to settlements, roads, and tourism routes, have also been shown to alter mammal occupancy and activity patterns in Asian protected areas (Thu et al., 2023). Similarly, prey availability and interspecific interactions, such as competition and predation, can shape species-specific habitat use, as observed among carnivores and ungulates in tropical forests of India and Thailand (Datta et al., 2008). These mechanisms likely interact with vegetation structure and hydrological conditions to produce the complex spatial patterns observed in INP. Incorporating such biotic and anthropogenic drivers in future multi-scale modeling efforts would enhance predictive accuracy and strengthen conservation planning across Bangladesh's fragmented forest landscapes.

Our results carry important implications for conservation practice and landscape management in Bangladesh. The strong association between mammal distributions and semi natural hill forests highlights the need to maintain and restore native vegetation within and around INP. Conservation actions that prioritize preventing forest encroachment, enhancing habitat connectivity, and protecting riparian corridors are likely to yield the greatest biodiversity gains. As the southern coastal belt and Cox's Bazar region experience rapid infrastructure expansion, strategic land use planning and ecological buffer zones around INP will be essential to mitigate fragmentation risks. Our findings also support the integration of remote sensing and SDM approaches into protected area management frameworks to improve early detection of habitat degradation and inform adaptive planning. Given increasing human wildlife interaction pressures, involving local communities in monitoring programs and promoting eco-tourism that aligns with wildlife conservation goals can strengthen long term stewardship. Failure to act promptly could lead to loss of key species, reduced ecological services, and irreversible landscape degradation, emphasizing the urgent need for proactive biodiversity governance.

While our study provides valuable insights, several limitations warrant consideration. First, although all 1124 presence records were field verified through camera trapping and transect surveys, temporal coverage did not span multiple year, which may influence detectability for some migratory or seasonally active species. Second, despite robust model performance, sample sizes remained limited for a few elusive or rare species, and greater sampling effort would improve parameter accuracy and reduce uncertainty (Moudry V. et al. 2023). Additionally, while MaxEnt has demonstrated strong performance in data constrained contexts, expanding future surveys to include acoustic detection,

environmental DNA, and genetic barcoding would improve species verification and detect cryptic diversity. Long term ecological monitoring integrating remote sensing, landscape change modeling, and participatory community-based wildlife reporting would further enhance conservation outcomes. Despite these constraints, our study offers a rigorous foundation for ongoing biodiversity research and provides a benchmark for future SDM based conservation applications in protected hill forest ecosystems of Bangladesh.

The pronounced concentration of occurrences within shrub with scattered trees habitats (e.g., 119 for Asian Elephant; >50 for Irrawaddy Squirrel and Himalayan Crestless Porcupine; >40 for Leopard Cat and Jungle Cat) suggests that structurally heterogeneous landscapes provide favorable ecological conditions for diverse mammalian communities. Habitat heterogeneity is widely recognized as a driver of increased species activity and richness due to resource complementarity and edge effects (Fahrig et al., 2011). Shrub mosaics likely offer abundant forage for herbivores, intermediate canopy cover for arboreal species, and increased prey availability for meso-carnivores.

The comparatively low occurrence in Forest Plantation (commonly ≤ 8 records per species) aligns with established evidence that monoculture systems generally exhibit reduced structural complexity and limited understory diversity (Brockerhoff et al., 2008). Such environments may constrain trophic interactions and niche availability.

Although Hill Forest supports moderate frequencies (e.g., 22 for Asian Elephant, 15 for Irrawaddy Squirrel, 12 for Leopard Cat), it does not represent the dominant habitat in terms of recorded activity. This may reflect either limited spatial extent, anthropogenic disturbance, or survey detectability differences. Moreover, concentration of wildlife in shrub habitats may indicate landscape-level habitat compression resulting from fragmentation of mature forest systems (Haddad et al., 2015).

Therefore, while shrub-dominated landscapes currently function as primary mammalian activity zones, conservation planning should assess whether this pattern represents true habitat preference or a redistribution effect caused by forest degradation. Maintaining landscape heterogeneity and restoring structurally complex native forests remain essential for long-term ecological resilience.

At the landscape level, the dominance of shrub habitats highlights the importance of habitat configuration and matrix quality in influencing wildlife distribution (Fahrig, 2003). Semi-open habitats often enhance movement permeability and resource accessibility, facilitating higher wildlife activity compared to homogeneous plantation systems. Edge effects associated with shrub mosaics may further increase biodiversity by combining structural elements of both open and forested systems (Ries et al., 2004).

The limited total occurrences within Forest Plantation systems align with global evidence that intensively managed plantation forests typically support lower mammalian diversity than native forests due to simplified vegetation structure and reduced ecological niches (Brockerhoff et al., 2008). Meanwhile, the moderate representation of Hill Forest underscores its continued ecological significance, even if it does not currently represent the highest activity zone.

From a conservation planning perspective, these findings emphasize the necessity of integrating shrubland conservation into biodiversity management frameworks while simultaneously safeguarding primary forests. Maintaining landscape heterogeneity is widely recognized as essential for sustaining biodiversity under increasing anthropogenic pressure (Haddad et al., 2015).

5.5. Conclusion

This study provides the first comprehensive, ground-based assessment of mammal distribution patterns in Inani National Park, combining systematic field surveys with species distribution modeling and environmental predictors originated from remote sensing. By integrating transect data with spatial habitat variables, we identified clear gradients in habitat suitability and mammal richness, offering a spatially explicit understanding of mammal communities in a key protected landscape of southeastern Bangladesh. Our findings highlight riparian zones and structurally complex shrub and scattered tree habitats as core biodiversity areas, with additional important patches located along the southern boundary and isolated northern and western fragments. Habitat suitability declined noticeably in edge dominated zones influenced by human disturbance, emphasizing the urgent need for effective buffer zone management and restoration actions. The results further demonstrate that non climatic environmental layers, including vegetation structure and land cover heterogeneity, are essential for understanding mammal distribution in tropical forest ecosystems where microhabitat variation and anthropogenic pressures strongly shape species persistence. This research establishes a baseline for long term monitoring in Inani National Park and provides a decision support framework for park managers. As land use change and climate stressors intensify in the Coxs Bazar forest belt, the spatial insights generated here can guide priority site protection, habitat restoration, and targeted management interventions that safeguard remaining mammal diversity. The forest in Inani National Park exhibits pronounced structural heterogeneity. Shrub mosaics with scattered trees serve as key habitats for mammals. More broadly, the approach applied here can be extended to other protected and semi protected forest landscapes promoting floristic diversity, and maintaining structurally heterogeneous habitats to sustain biodiversity and enhance landscape resilience across Bangladesh to improve conservation planning and strengthen the national biodiversity knowledge base.

Chapter 6

Study 4.

DIVERSITY AND POPULATION STRUCTURE OF TREE SPECIES IN A PROTECTED AREA ON THE SOUTHEASTERN COAST OF BANGLADESH

Abstract

Inani National Park (INP) is a protected area supporting a variety of threatened and endangered species. However, anthropogenic pressures, including of Rohingya refugees' influx into the Cox's Bazar, have imposed significant stress on its forest ecosystems. This study assessed the composition, structure, and diversity of INP's forests to provide a scientific foundation for conservation and sustainable management. Stratified random sampling was conducted across four forest strata: *Shrub with Scattered Trees*, *Hill Forest*, *Forest Plantation*, and *Others*. Across 131 sampling plots (0.1134 ha each), 455 trees representing 66 species and 33 families were recorded. Fabaceae was the most species-rich family, comprising 10 species. Tree density averaged 30.62 trees ha⁻¹, with the *Forest Plantation* exhibiting the highest density (99.51 trees ha⁻¹) and *Hill Forest* the lowest (17.63 trees ha⁻¹). *Areca catechu* dominated with 28.35% relative density 40.49 IVI.

Diversity indices indicated a moderately diverse ecosystem with heterogeneous species distribution. The Shannon-Wiener index was highest in the *Shrub with Scattered Trees* stratum ($H = 3.572$), while Simpson's index ($D = 0.89$) reflected high species diversity and calculated canopy cover, averaging 45.19%. Despite its ecological significance, INP has experienced substantial disturbances, resulting in 2500 ha forest loss. *Acacia auriculiformis*, *Mangifera indica*, *Areca catechu*, *Artocarpus heterophyllus*, and *Cocos nucifera* were the key indicator species, with the ten families and genera by species richness comprising 59.09% and 27.27% of all recorded individuals. The presence of invasive *Acacia auriculiformis*, indicates ecological imbalance and need for restoration interventions. These findings provide critical insights to guide biodiversity conservation and enhance INP's forest ecosystems resilience.

Keywords: Tree species diversity; Biodiversity conservation; Forest composition; Species richness; Important value index; Protected area.

Introduction

Biodiversity is a cornerstone of ecosystem health, productivity, and resilience, particularly under growing pressures from global climate change and natural disasters. Greater biological diversity increases the probability that certain species will possess adaptive traits necessary to endure environmental perturbations (Li & Wei, 2024). However, human activities continue to profoundly reshape ecological communities, accelerating species invasions and extinctions across scales—from local landscapes to global biomes (Meyer et al., 2016).

Beyond ethical and aesthetic dimensions, biodiversity loss has far-reaching implications for ecosystem functions and the provisioning of essential services upon which human societies depend

(IPBES, 2019). The Convention on Biological Diversity (CBD) and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) emphasize biodiversity not only as a collection of species but also in terms of genetic and functional variation that ensures ecosystem resilience. The IPBES conceptual framework highlights "nature's contributions to people" and the necessity of safeguarding biodiversity for future generations (Bocchi, 2024).

Ecological diversity plays a critical role in maintaining ecosystem stability (Daly et al., 2018), and its continued erosion threatens the delivery of services such as nutrient cycling, climate regulation, and pollination (Cardinale et al., 2012). Since the 1992 Earth Summit, a growing body of research has demonstrated the cascading effects of biodiversity loss on ecosystem functionality and societal wellbeing.

Natural reserve forests are particularly important for biodiversity conservation, as they harbor a high richness of endemic and threatened flora and fauna (John et al., 2020; Chen & Tang, 2016). Defined as complex biotic communities, forests comprise diverse plant and animal assemblages interacting with abiotic factors like soil, topography, and climate (Young & Giese, 2003). These ecosystems provide critical habitats while delivering essential ecological services to human populations (Li & Wei, 2024).

However, various anthropogenic pressures—including illegal logging, overgrazing, agricultural expansion, and urbanization—pose significant threats to forest biodiversity and structural integrity (Usman et al., 2022). The distribution and composition of tree species in these environments are further shaped by environmental gradients such as moisture, temperature, nutrient availability, and geological characteristics (Hossain et al., 2019).

Preserving biodiversity in forested landscapes is not only a conservation priority but also a prerequisite for sustaining the ecological processes that support life on Earth. Tropical regions support an extraordinary range of biodiversity, harboring a significant proportion of the world's plant and animal species. However, widespread deforestation and land-use transformation are causing severe losses in genetic, species, and ecosystem diversity, particularly in biodiversity hotspots. Recent global studies underscore that even degraded forests retain substantial ecological value and biodiversity potential and therefore should be prioritized for protection rather than conversion to plantations (University of Oxford, 2025; Ewers et al., 2024). To mitigate biodiversity loss, accurate assessment of plant diversity is essential for maintaining ecosystem functionality and informing sustainable resource management. In this context, non-parametric estimators have proven useful for evaluating species richness and diversity, contributing to conservation planning (Chao, 1987; Burnham & Overton, 1979).

Bangladesh, situated within the Indo-Myanmar biodiversity hotspot, is home to approximately 7,000 endemic plant species, making it one of the most biologically diverse regions globally (Mittermeier et al., 1998). Despite this significance, forest ecosystems in the country are increasingly degraded due to unsustainable land-use practices and growing human pressures (Rahman et al., 2011). Forest cover has declined to approximately 2.53 million hectares (17.5% of the national land area) with an associated growing stock of 30 million m³ and total biomass of 63 million tons (Altrell et al., 2007),

highlighting the urgency for science-based conservation interventions. These challenges are particularly acute in southeastern Bangladesh, where the influx of Rohingya refugees into the Cox's Bazar region has intensified deforestation, fuelwood extraction, and habitat fragmentation, especially within Inani National Park (INP). Satellite-based analyses have documented extensive forest degradation across the Cox's Bazar–Teknaf Peninsula, underscoring the need for focused ecological assessment and management (Hassan et al., 2023).

Understanding plant diversity and forest structure is central to evaluating ecosystem processes such as carbon sequestration, nutrient cycling, and habitat provision (Hossain et al., 2013). Global research has consistently affirmed biodiversity's role in sustaining ecosystem functions and enhancing ecological resilience (Hooper et al., 2005). Vegetation structure and composition are key determinants of ecosystem stability and are vital for guiding sustainable management (Nath et al., 2000), while functional diversity offers an important dimension of ecological assessment (Pakeman, 2011).

Trees serve as structural pillars in tropical ecosystems, supporting wildlife, regulating ecological processes, and offering key ecosystem services (Cannon et al., 1998; Huston, 1994). However, widespread deforestation, excessive resource extraction, and habitat fragmentation have led to a persistent decline in tree populations throughout Bangladesh (Rahman & Ahmad, 2000). The greater Chittagong region, encompassing INP, is a floristically rich area containing 2,260 of Bangladesh's 3,611 known flowering plant species (Rahman et al., 2019). Despite this richness, insufficient information on species composition and regeneration patterns remains a major constraint to effective conservation and management efforts.

Biodiversity assessment serves as a critical scientific tool for ecosystem monitoring and management by measuring species richness, evenness, and overall heterogeneity (Cardinale et al., 2012). Such metrics are essential for evaluating ecosystem health, identifying vulnerability to species loss, and guiding conservation policy. Commonly used diversity measures such as the Shannon-Wiener index and Simpson index offer critical insights into forest viability and ecosystem resilience (Backéus et al., 2006), particularly when analyzed in conjunction with regeneration and population structure (Verma et al., 1999).

In tropical forests, species diversity is influenced by a combination of environmental heterogeneity, biotic interactions, topographical variation, and soil characteristics (Ram et al., 2004). Understanding these patterns is imperative for restoring degraded landscapes and curbing biodiversity loss. Recent studies emphasize the importance of assessing the current status of tree species diversity, composition, and abundance to improve management strategies and prioritize conservation actions (University of Oxford, 2025; Jeje et al., 2021).

Bangladesh has established several protected areas to conserve its biological resources. Although several studies have examined plant diversity in protected areas of Bangladesh (Motaleb & Hossain, 2011), ecologically important sites such as INP remain poorly documented with respect to tree species diversity, regeneration status, and dominance structure. This knowledge gap is particularly concerning given the park's role as critical habitat for threatened wildlife, including Asian elephants

(*Elephas maximus*), leopards (*Panthera pardus*), and Western hoolock gibbons (*Hoolock hoolock*) (Dampha et al., 2022; Khan, 2018).

Given these gaps, the present study aims to provide a comprehensive assessment of tree species diversity and forest structure in Inani National Park. Specifically, this research addresses the following questions:

1. What is the current tree species composition, density, and diversity across different forest strata in Inani National Park?
2. How do patterns of species dominance and community structure vary among forest strata, particularly in relation to anthropogenic disturbances?
3. To what extent are dominant species, such as *Areca catechu* and *Acacia auriculiformis*, associated with disturbed or managed forest conditions?
4. Does the current sampling adequately capture species diversity and community structure to inform conservation and management decisions?

By addressing these questions, this study seeks to generate robust empirical evidence to support biodiversity conservation, sustainable forest management, and ecosystem restoration in Inani National Park and the broader Indo-Myanmar biodiversity hotspot.

6.2. Materials and Methods

6.2.1 Study Area

The Cox's Bazar Forest Division, covering 940.58 sq. km (or 94,058 ha), is one of Bangladesh's most resource-rich forest regions. Inani National Park, is a designated Protected Area (PA) covering around 7,085.16 hectares, located 26 kilometers south of Cox's Bazar (Sarker & Røskoft, 2011), bordered by Himchari National Park to the north, Teknaf Wildlife Sanctuary to the south, the Bay of Bengal to the west, and the Teknaf-Cox's Bazar highway to the east (**Figure 6.1**) (Uddin et al., 2013). The park contains degraded evergreen to semi-evergreen forests, with distinct soil types ranging from clay and loamy soils to sandy soils (Miah & Hossain, 2022). Its hydrology is influenced by abundant rainfall, runoff from surrounding hills, and numerous streams and wetlands that provide vital habitats for wildlife (Das et al., 2018). INP's forest cover is rich in epiphytes, climbers, bamboo, and a variety of flora.

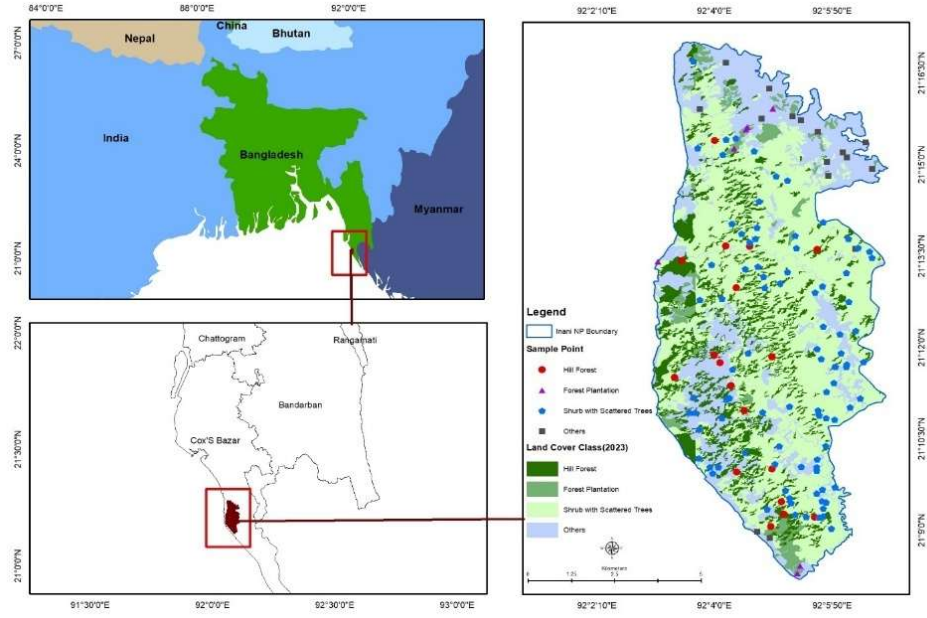


Figure 6.1. Study area and Location of the study Sites.

6.2.2 Sampling Framework and Plot Allocation

In the study, stratified random sampling method was adopted for the vegetation survey. ArcGIS and MS Excel software were used to generate sample points. The National Land Cover Map of 2023 was used for stratification to get a more representative sample clip of the study land cover by using ArcGIS Software. As such, four land cover strata or areas were categorized in the study area namely, *Hill Forest*, *Forest Plantation*, *Shrub with Scattered Trees* and *Others* (including orchards, rural settlement, rivers, lake, multiple crops, single crop etc.) (**Table 6.1**). The following equation was used to determine sample size at 90% confidence interval, 10% standard error and coefficient of variance. The coefficient of variance was derived using National Forest Inventory data, 2018 of Cox's Bazar area (GOB, 2019).

$$n_{i+1} = \frac{1}{\frac{1}{N} + \left[\frac{E}{(t_{n_i-1, \alpha/2}) CV} \right]^2}$$

Where, n_{i+1} is the number of plots needed, N is the population sample size (total area/plot size), E is the allowable error expressed as a percentage of the mean, $t_{n_i-1, \alpha/2}$ is the student's t-value at $n_i - 1$ df, $\alpha = 1 - p/100$ is the probability of a type I error for a stated percent confidence of P , and CV is the coefficient of variation.

Based on above calculation a total number of 131 sample plots were distributed proportionally among different land cover strata (**Table 6.1**). The following equation was used to calculate the number of plots employed for each stratum (where, 'x' = *Hill Forest* or *Forest plantation* strata or *Shrub with Scattered Trees* or *Other* stratum):

$$\text{Number of plots for 'x' strata} = \frac{\text{Total number of plot}}{\text{Total study area}} \times \text{area of 'x' strata}$$

Table 6.1: Distribution land cover strata and sample plots employed for each stratum

SL No.	Strata/Class	Number of Polygon	Average Polygon Area (ha)	Total Area (ha)	Sample plots distributed
1	<i>Hill Forest</i>	391	2.60	1015.89	18
2	<i>Forest Plantation</i>	38	7.61	289.37	7
3	<i>Shrub with Scattered Trees</i>	85	44.54	3785.73	90
4	<i>Others</i>	293	27.87	1767.35	16
Total		807		6858.34	131

6.2.3. Sample Plot Diagram

In the study, a total of 131 randomly selected circular sample plots were laid out in different land cover strata as mentioned above. As this study was part of a greater biodiversity assessment project where a 19 m radius circular plot was used to collect vegetation data following Bangladesh Forest Department (2016) containing three types of circular subplots such as Large (L) subplot of 19-meter radius for measuring trees ≥ 30 cm dbh, medium (M) subplot of 8-meter radius measuring trees < 30 cm to ≥ 10 cm dbh and small (S) subplot of 2.5-meter radius for measuring natural regeneration status (Figure 5.2; GOB, 2019). This study focused on large (L) subplot of 19-meter radius and medium (M) subplot of 8-meter radius for measuring trees species available in each plot. Trees (≥ 10 cm dbh) of all species in each plot were identified and recorded by local and scientific names. The common tree species were identified directly in the field, while the fertile samples of the unknown tree species were collected for the preparation of herbarium specimens for identification later following Ao et al. (2024).

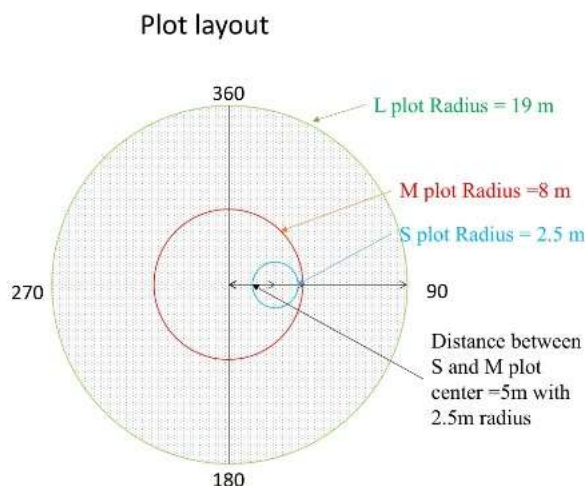


Figure 6.2. Sample Plot Diagram

6.2.4. Data Analysis

The study examined tree species occurring across various land cover strata. For each species, key phytosociological parameters—including relative density (RD), relative frequency (RF), relative dominance (RDo), relative abundance (RA), and the importance value index (IVI)—were calculated following the standard methodologies proposed by Ulfah et al., (2019), Shukla & Chandel (1994), Dallmeier (1992), Krebs (1989), Misra (1968), Click or tap here to enter text. Tree height and diameter at breast height (DBH) measurements were used to characterize the structural composition of the stands. Stem density and basal area for each species were estimated using tree counts and DBH values, following Shukla & Chandel (1994). To comprehensively assess the diversity of tree species within the study area, nine diversity and richness indices were computed. Quantitative analyses were performed using Microsoft Excel and the statistical software R. Data manipulation and import were performed using the packages dplyr v1.1.4 (Wickham et al., 2023), readr v2.1.5 (Wickham et al., 2024) and the tidyverse v2.0 meta-package (Wickham et al., 2019). Figures were generated with ggplot2 v4.0.1 (Wickham, 2016). Community ecology and diversity analyses were implemented using vegan v2.6-10 (Oksanen et al., 2022), sample completeness and diversity metrics ($q = 0, 1, 2$) for the tree community and coverage estimates and asymptotic diversity metrics of sufficient sampling of common species while indicating presence of rare taxa were generated by using iNEXT v3.0.1 (Chao et al., 2014), and indicpecies v1.8.0 (De Cáceres, 2020) has used for Indicator Species Analysis (ISA), while multivariate ordination visualizations were produced with factoextra v1.0.7 (Kassambara & Mundt, 2020). String handling was facilitated by stringr v1.5.0 (Wickham, 2023). The specific formulas and indices applied in these analyses are showed in **Appendix 7**.

6.3. Results

6.3.1. Tree species composition

A total of 455 individual trees ($\text{DBH} \geq 10 \text{ cm}$), representing 66 species distributed across 33 families, were recorded from 131 plots (**Tables 6.2 and 6.3**). Among all families, Fabaceae exhibited the highest species richness with 10 species, followed by Moraceae (8 species), Lamiaceae (4 species), Anacardiaceae, Euphorbiaceae, and Malvaceae (each comprising 3 species), among others (**Table 6.3**). The overall tree density across the study area was 30.62 trees per hectare. The *Forest Plantation* stratum showed the highest tree density ($99.51 \text{ trees ha}^{-1}$), whereas the *Hill Forest* stratum exhibited the lowest density ($17.63 \text{ trees ha}^{-1}$). In terms of species richness, the *Shrub with Scattered Trees* stratum recorded the greatest diversity (52 species from 25 families), while the *Forest Plantation* stratum supported the least (9 species from 5 families). Across all strata, an average of 2.56 dead trees per hectare was documented. The *Hill Forest* stratum contained the highest number of dead trees ($4.90 \text{ trees ha}^{-1}$), followed by the *Forest Plantation* ($5.04 \text{ trees ha}^{-1}$). The highest number of stumps was observed in the *Shrub with Scattered Trees* stratum ($2.06 \text{ stumps ha}^{-1}$), with an overall average of $1.54 \text{ stumps ha}^{-1}$ across all land cover types (**Table 6.2**).

Table 6.2: Strata-wise basic tree information recorded from the study area

Basic information	Forest Plantation	Hill Forest	Shrub with Scattered trees	Others	Overall
Area of each plot size (r=19 m) (ha ²)	0.1134	0.1134	0.1134	0.1134	0.1134
No. of plots studied	7	18	90	16	131
Total no. of individuals	79	36	205	135	455
No. of families	5	17	25	13	33
No. of total species	9	22	52	15	66
Tree density per ha.	99.51	17.63	20.08	74.37	30.62
No. of dead trees per ha.	5.04	4.90	2.35	0.00	2.56
No. of stumps per ha.	1.26	0.49	2.06	0.00	1.54

6.3.2. Phytosociological Characteristics of Tree Species

Forest structure, composition, and dynamics are critical features for developing appropriate silvicultural systems for sustainable forest management (Appanah et al., 1990). In this study, the structural and compositional attributes of the INP forest were assessed through key phytosociological parameters, including tree density, basal area, relative density (RD), relative frequency (RF), relative dominance (RDo), importance value index (IVI), and canopy cover. Among all recorded species, *Areca catechu* emerged as the most dominant, exhibiting the highest tree density (8.68 trees ha⁻¹), basal area (0.096 m² ha⁻¹), relative density (28.35%), and an IVI of 40.49, signifying its strong ecological influence within the forest community. *Acacia auriculiformis* and *Mangifera indica* also showed notable prominence, with IVI values of 24.27 and 20.63, respectively; the latter recorded the highest relative frequency (6.22%). In contrast, *Cassia fistula* demonstrated the greatest relative dominance (15.61%), reflecting its substantial contribution to overall forest biomass. Species such as *Grewia asiatica* and *Artocarpus lacucha* displayed the lowest ecological significance, both with IVI values of 0.80, relative density of 0.22%, and relative frequency of 0.52%, indicating their restricted distribution within the study area (Table 4). The canopy cover across the forest varied considerably, with an average of 45.19%, ranging from 0% to 100%. This variation is likely associated with factors such as natural disturbances, edge effects, and anthropogenic activities, which influence forest structure and regeneration dynamics. Overall, the results underscore the dominance of a few key species, alongside a broad assemblage of less abundant taxa, providing essential insights for biodiversity conservation and the development of sustainable forest management strategies in INP.

Following (Tolmachev's, 1962) floristic-diversity criterion (flora is "diverse" when top 10 families/genera contribute $\leq 50\%$ of total species), the INP flora shows a contrasting pattern between family- and genus-level structure (**Figure 6.3**). At the family level, the top 10 families comprise 39 of 66 species (59.09%), exceeding Tolmachev's 50% threshold; therefore, the INP flora is moderately diverse at the family level and is moderately concentrated, mainly due to Fabaceae (15.15%) and Moraceae (12.12%) which together contribute 27.27%. In contrast, the top 10 genera account for only 18 of 66 species (27.27%), well below 50%, indicating the INP flora is diverse at the genus level with species spread across many genera (**Figure 6.4**).

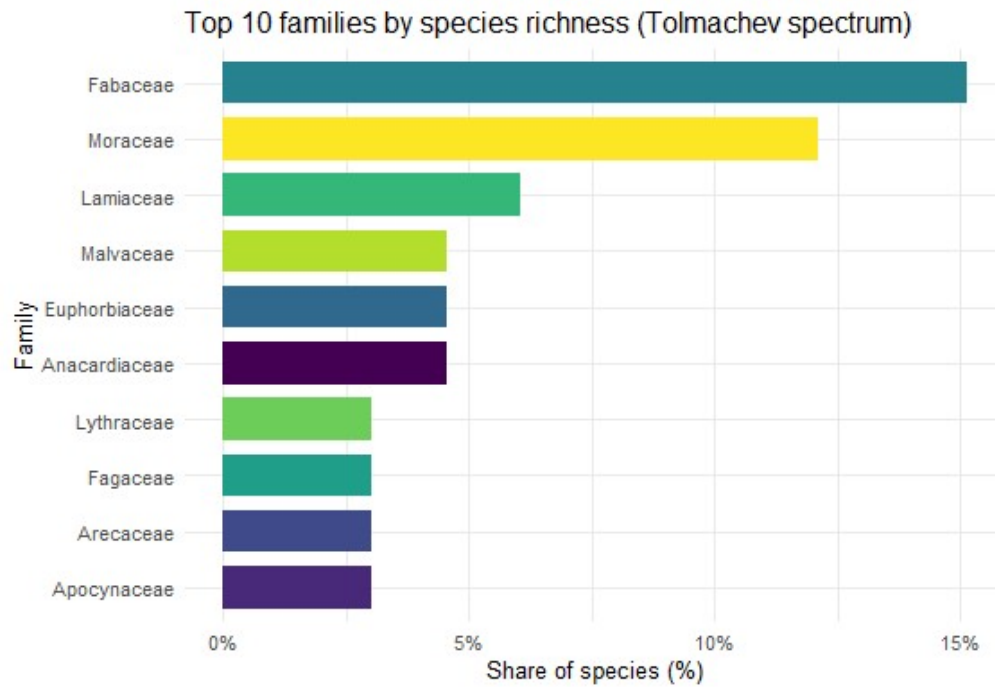


Figure 6.3. Top 10 families by species

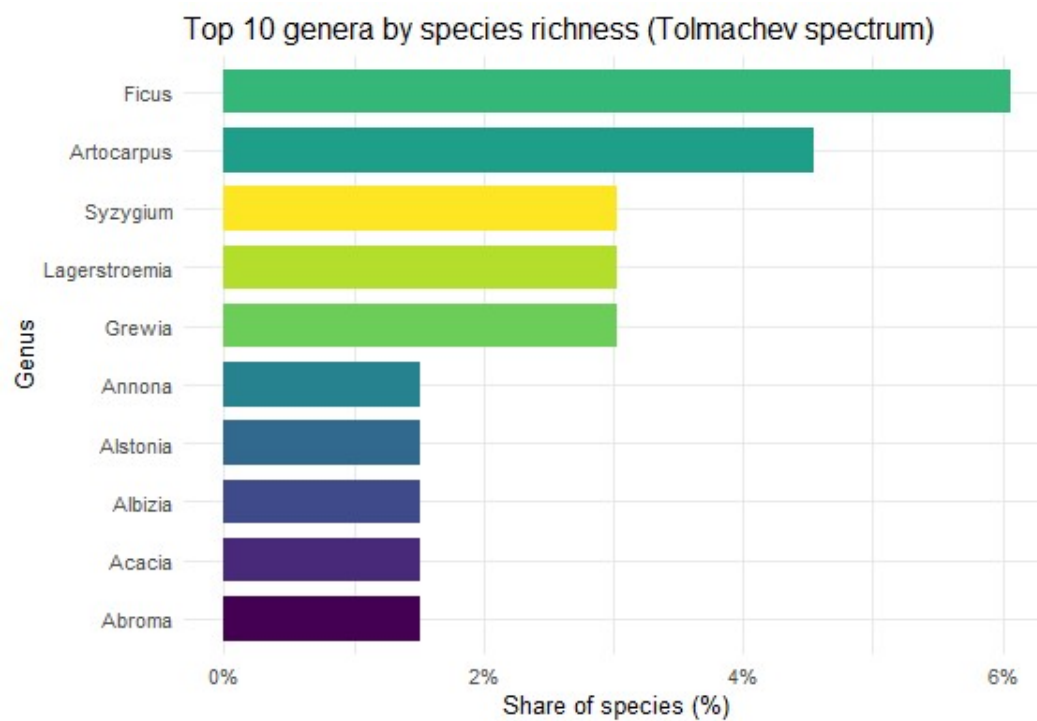


Figure 6.4. Top 10 genera by species

Table 6.3: Phytosociological attributes of recorded tree species in Inani National Park, Bangladesh

Family	Scientific Name	Density (stems/ ha)	Basal area (m ² /ha)	RD (%)	RF (%)	RD _o (%)	IVI
1. Achariaceae	<i>Hydnocarpus kurzii</i>	0.471	0.02	1.538	2.591	1.99	6.119
2. Anacardiaceae (3 species)	<i>Lannea coromandelica</i>	0.135	0.002	0.44	1.036	0.205	1.681
	<i>Mangifera indica</i>	2.019	0.078	6.593	6.218	7.819	20.63
	<i>Swintonia floribunda</i>	0.202	0.003	0.659	1.554	0.325	2.539
3. Annonaceae	<i>Annona squamosa</i>	0.135	0.001	0.44	0.518	0.14	1.098
4. Apocynaceae (2 species)	<i>Alstonia scholaris</i>	0.067	0.003	0.22	0.518	0.255	0.993
	<i>Holarrhena antidysenterica</i>	0.067	0.001	0.22	0.518	0.117	0.855
5. Araliaceae	<i>Trevesia palmata</i>	0.067	0.001	0.22	0.518	0.092	0.83
6. Arecaceae (2 species)	<i>Areca catechu</i>	8.683	0.096	28.352	2.591	9.551	40.494
	<i>Cocos nucifera</i>	0.202	0.013	0.659	1.554	1.312	3.526
7. Bignoniaceae	<i>Stereospermum colais</i>	0.135	0.02	0.44	1.036	1.969	3.445
8. Bombacaceae	<i>Bombax ceiba</i>	0.135	0.004	0.44	1.036	0.41	1.886
9. Burseraceae	<i>Protium serratum</i>	0.471	0.007	1.538	2.073	0.72	4.331
10. Cannabaceae	<i>Trema orientalis</i>	0.067	0.002	0.22	0.518	0.211	0.949
11. Dichapetalaceae	<i>Dichapetalum gelonioides</i>	0.269	0.008	0.879	2.073	0.81	3.762
12. Dilleniaceae	<i>Dillenia pentagyna</i>	0.067	0.002	0.22	0.518	0.19	0.928
13. Dipterocarpaceae	<i>Dipterocarpus turbinatus</i>	0.471	0.015	1.538	2.591	1.493	5.623
14. Elaeocarpaceae	<i>Elaeocarpus floribundus</i>	0.067	0.011	0.22	0.518	1.146	1.884
15. Euphorbiaceae (3 species)	<i>Macaranga denticulata</i>	0.606	0.009	1.978	2.591	0.884	5.452
	<i>Mallotus nudiflorus</i>	0.135	0.011	0.44	1.036	1.081	2.557
	<i>Shirakiopsis indica</i>	0.135	0.001	0.44	1.036	0.083	1.559
16. Fabaceae (10 species)	<i>Acacia auriculiformis</i>	3.837	0.066	12.527	5.181	6.558	24.266
	<i>Albizia procera</i>	0.269	0.03	0.879	1.554	3.036	5.47
	<i>Cassia fistula</i>	0.067	0.156	0.22	0.518	15.609	16.347
	<i>Dalbergia ovata</i>	0.067	0.001	0.22	0.518	0.091	0.828
	<i>Derris robusta</i>	0.74	0.016	2.418	3.627	1.614	7.658
	<i>Erythrina ovalifolia</i>	0.202	0.003	0.659	0.518	0.264	1.441
	<i>Samanea saman</i>	0.135	0.024	0.44	1.036	2.368	3.844
	<i>Senna siamea</i>	0.135	0.004	0.44	1.036	0.388	1.864
	<i>Sesbania grandiflora</i>	1.077	0.014	3.516	3.109	1.422	8.047
	<i>Xylia xylocarpa</i>	0.067	0.001	0.22	0.518	0.073	0.811
17. Fagaceae (2 species)	<i>Castanopsis indica</i>	0.337	0.021	1.099	2.591	2.11	5.8
	<i>Quercus acuminata</i>	0.135	0.001	0.44	1.036	0.117	1.592
18. Lamiaceae (4 species)	<i>Callicarpa macrophylla</i>	0.538	0.053	1.758	2.073	5.31	9.141
	<i>Gmelina arborea</i>	0.471	0.014	1.538	2.073	1.398	5.009
	<i>Tectona grandis</i>	0.269	0.015	0.879	1.554	1.521	3.955
	<i>Vitex glabrata</i>	0.404	0.01	1.319	2.073	0.986	4.378

Family	Scientific Name	Density (stems/ ha)	Basal area (m ² /ha)	RD (%)	RF (%)	RDo (%)	IVI
19. Lauraceae	<i>Phoebe lanceolata</i>	0.067	0.005	0.22	0.518	0.475	1.213
20. Lythraceae (2 species)	<i>Lagerstroemia parviflora</i>	0.471	0.011	1.538	1.554	1.143	4.235
	<i>Lagerstroemia speciosa</i>	0.606	0.013	1.978	3.627	1.32	6.925
21. Malvaceae (3 species)	<i>Brownlowia elata</i>	0.337	0.026	1.099	2.591	2.642	6.331
	<i>Grewia asiatica</i>	0.067	0.001	0.22	0.518	0.064	0.802
	<i>Grewia nervosa</i>	0.471	0.01	1.538	2.591	0.967	5.096
22. Meliaceae (2 species)	<i>Aphanamixis polystachya</i>	0.067	0.001	0.22	0.518	0.07	0.808
	<i>Walsura robusta</i>	0.202	0.02	0.659	1.036	1.964	3.659
23. Moraceae (8 species)	<i>Artocarpus chama</i>	0.067	0.005	0.22	0.518	0.478	1.216
	<i>Artocarpus heterophyllus</i>	0.538	0.016	1.758	1.554	1.616	4.929
	<i>Artocarpus lacucha</i>	0.067	0.001	0.22	0.518	0.065	0.803
	<i>Broussonetia papyrifera</i>	0.067	0.002	0.22	0.518	0.233	0.971
	<i>Ficus benghalensis</i>	0.202	0.032	0.659	1.554	3.149	5.363
	<i>Ficus benjamina</i>	0.067	0.019	0.22	0.518	1.899	2.637
	<i>Ficus carica</i>	0.404	0.007	1.319	1.036	0.693	3.048
	<i>Ficus semicordata</i>	0.875	0.023	2.857	3.109	2.28	8.245
24. Myristicaceae	<i>Knema bengalensis</i>	0.471	0.011	1.538	2.591	1.058	5.187
25. Myrsinaceae	<i>Maesa indica</i>	0.202	0.002	0.659	0.518	0.19	1.367
26. Myrtaceae (2 species)	<i>Syzygium claviflorum</i>	0.067	0.001	0.22	0.518	0.084	0.822
	<i>Syzygium cumini</i>	0.269	0.01	0.879	2.073	1.014	3.966
27. Phyllanthaceae	<i>Glochidion arborescens</i>	0.067	0.001	0.22	0.518	0.081	0.819
28. Rhizophoraceae	<i>Carallia brachiata</i>	0.067	0.002	0.22	0.518	0.156	0.894
29. Rubiaceae (2 species)	<i>Mitragyna rotundifolia</i>	0.606	0.011	1.978	4.145	1.085	7.208
	<i>Neolamarckia cadamba</i>	0.135	0.024	0.44	1.036	2.375	3.851
30. Salicaceae	<i>Flacourtia indica</i>	0.269	0.003	0.879	2.073	0.344	3.296
31. Sterculiaceae (2 species)	<i>Abroma augusta</i>	0.067	0.001	0.22	0.518	0.103	0.841
	<i>Pterospermum acerifolium</i>	0.067	0.004	0.22	0.518	0.414	1.152
32. Verbenaceae	<i>Phyla nodiflora</i>	0.135	0.002	0.44	0.518	0.193	1.151
33. Vitaceae	<i>Leea indica</i>	0.269	0.002	0.879	0.518	0.179	1.576

6.3.3. Hierarchical cluster of the species based on the dominance of the tree species in the INP

To identify natural groupings among the recorded tree species, a hierarchical cluster analysis was performed using the Importance Value Index (IVI) as the classification criterion. The scree plot (**Figure 6.5**) indicated that the optimal clustering solution comprised five distinct groups. The resulting dendrogram (**Figure 6.6**) revealed that *Areca catechu* formed a separate cluster which attains the highest (IVI 40.49), confirming its status as the most ecologically dominant species within the study area. The second cluster included other highly dominant species—*Acacia auriculiformis* (IVI 24.27), *Mangifera indica* (IVI 20.63), - representing a secondary core of influential taxa. Cluster 5 contained *Cassia fistula* alone, which, despite low frequency, exhibited an extremely high basal

Scree plot (elbow) for IVI-based species cluster

Number of clusters (k)	Total within-cluster sum of squares
1	~250
2	~120
3	~80
4	~50
5	~25
6	~18
7	~15
8	~12
9	~10
10	~8

Species clusters based on IVI (k = 5)



6.3.4. Indicator species analysis

Plot-level cluster analysis combined with indicator species analysis identified diagnostic species for two of the clusters. *Acacia auriculiformis* exhibited a very high indicator value for Cluster 1 (IndVal = 0.99, $p = 0.001$), clearly characterizing this cluster as an *A. auriculiformis* plantation. Cluster 3 was defined by four significant indicator species: *Mangifera indica* (IndVal = 0.87, $p = 0.001$), *Areca catechu* (IndVal = 0.58, $p = 0.007$), *Artocarpus heterophyllus* (IndVal = 0.52, $p = 0.006$), and *Cocos nucifera* (IndVal = 0.41, $p = 0.044$). These results indicate that Cluster 1 is strongly dominated by *A. auriculiformis*, whereas Cluster 3 is primarily composed of fruit-bearing and agroforestry species. In contrast, Cluster 2 did not exhibit any strong indicator species, suggesting a more heterogeneous community structure (Table 6.4).

Table 6.4: Important species index in INP

Species	Index	stat	s.1	s.2	s.3	p. value
<i>Acacia auriculiformis</i>	1	0.990	1	0	0	0.001
<i>Mangifera indica</i>	3	0.866	0	0	1	0.001
<i>Artocarpus heterophyllus</i>	3	0.522	0	0	1	0.006
<i>Areca catechu</i>	3	0.582	0	0	1	0.007
<i>Cocos nucifera</i>	3	0.412	0	0	1	0.044

6.3.5. Tree diversity indices

Analysis of tree species diversity within INP revealed marked variations among the different forest strata (Table 6.5). The Species Diversity Index (SDI) was highest in the *Hill Forest* stratum (0.611) and lowest in the *others* stratum (0.111), with an overall mean of 0.145 across all strata. The Shannon Diversity Index (H') ranged from 3.572 in the *Shrub with Scattered Trees* stratum—the most diverse—to 1.229 in the *others* stratum, while the Shannon Maximum Diversity (H_{max}) reached 4.190, with corresponding stratum values of 3.951 (*Shrub with Scattered Trees*) and 2.197 (*Forest Plantation*).

The Simpson's Diversity Index (D) for INP was 0.89, indicating overall high diversity and low species dominance. Among the strata, the *others* stratum exhibited the highest D value (0.485), signifying strong species dominance, whereas the *Shrub with Scattered Trees* stratum recorded the lowest (0.038), reflecting high diversity. The Species Evenness Index (E) was also greatest in the *Shrub with Scattered Trees* stratum (2.082) and lowest in the *others* stratum (1.045). The radar plot (Figure 6.7) further demonstrated that the *Shrub with Scattered Trees* stratum possessed the highest overall biodiversity and evenness, while the *Hill Forest* stratum showed high species richness but lower evenness due to dominance by a few species.

Detailed examination of the indices underscores distinct ecological patterns across the strata. The *Hill Forest* displayed the highest species richness (SDI = 0.611; $R = 5.860$; $D_r = 15.805$) but comparatively low diversity ($H' = 2.924$) and evenness ($E_h = 0.945$; $E = 2.178$), indicating the prevalence of dominant species (Table 5). Conversely, the *Shrub with Scattered Trees* stratum

exhibited the most balanced community structure, with the highest Shannon Diversity (3.572) and Equitability (0.904) and the highest Simpson's Index (0.963), suggesting minimal dominance and a well-distributed species composition. The *Forest Plantation* stratum showed moderate diversity ($H' = 1.251$; $E = 0.569$), reflecting a managed yet compositionally limited stand, while the *others* stratum had the lowest biodiversity ($SDI = 0.111$; $H' = 1.229$) and the greatest dominance ($D = 0.485$), indicating severe ecological degradation.

Collectively, these findings highlight the heterogeneity of forest ecosystems within INP, emphasizing the conservation importance of *Shrub with Scattered Trees* stratum for maintaining biodiversity and the need to enhance species evenness in the *Hill Forest* stratum. Strategies aimed at introducing native species in *Forest Plantation* stratum and restoring degraded areas are essential to improve ecological balance and strengthen overall ecosystem resilience in the region.

Table 6.5: Strata-wise biological diversity indices for the recorded tree species in Inani National Park.

Diversity indices	Forest Plantation	Hill Forest	Shrub with scattered trees	Others	Overall
Species Diversity Index (SDI)	0.114	0.611	0.254	0.111	0.145
Shannon Diversity Index (H)	1.251	2.924	3.572	1.229	3.137
Shannon Maximum Diversity ($H_{\max}$)	2.197	3.091	3.951	2.708	4.190
Shannon Equitability Index (E_h)	0.569	0.946	0.904	0.454	0.749
Simpson's Diversity Index (D)	0.621	0.063	0.963	0.485	0.892
Dominance of Simpson's Index (D')	0.379	0.937	0.038	0.515	0.108
Simpson's Reciprocal Index (D_r)	2.639	15.805	26.151	2.063	9.248
Margalef's Diversity Index (R)	1.831	5.860	9.581	2.854	10.620
Species Evenness Index (E)	0.569	2.178	0.904	1.045	0.75

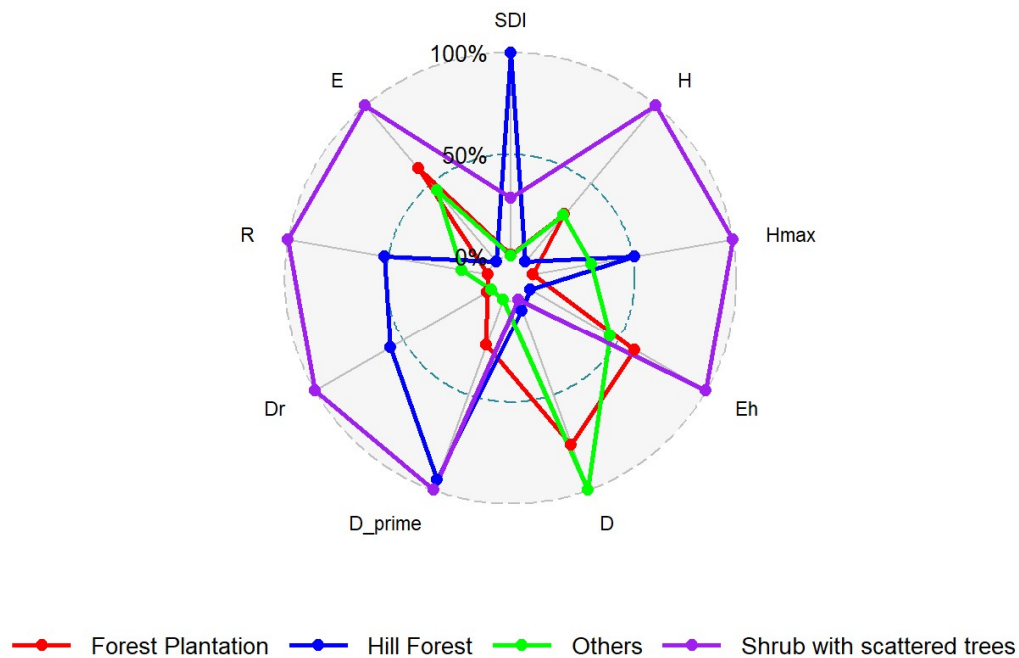


Figure 6.7. Diversity indices across forest types in INP

Note: Species Diversity Index (S_{DI}); Shannon Diversity Index (H); Shannon Maximum Diversity (H_{max}); Shannon Equitability Index (E_h); Simpson's Diversity Index (D); Dominance of Simpson's Index (D'); Simpson's Reciprocal Index (D_r); Margalef's Diversity Index (R); Species Evenness Index (E).

6.3.6. Sample Completeness and Coverage-Based Rarefaction/Extrapolation of Tree Diversity

The iNEXT *DataInfo* results indicated high sampling completeness, with sample coverage (SC) of 0.954, suggesting that 95.4% of the total abundance was represented by species detected in the survey, while only 4.6% was attributable to undetected species (**Figure 6.8**). This high level of coverage implies that further sampling would likely yield few additional species. Frequency distributions showed that 21 species were represented by single individuals (singletons, $f_1 = 21$) and 11 species by two individuals (doubletons, $f_2 = 11$), with progressively fewer species occurring at higher frequencies (f_3 – f_9). Although the presence of singletons and doubletons reflects the occurrence of rare species within the assemblage, their contribution to total abundance was minimal, as evidenced by the high sample coverage ($SC > 0.95$). Overall, the *DataInfo* output confirms that the sampling effort was sufficient to capture most of the species' diversity in the studied forest, providing a reliable foundation for rarefaction and extrapolation analyses (**Figure 6.8**).

The asymptotic diversity estimates further revealed that the observed species richness was 66 species, whereas the estimated asymptotic richness was 86.0 species, with a 95% confidence interval ranging from 66.0 to 107.5 species. This suggests that the true species pool is larger than observed and that

additional rare species likely remain undetected. In contrast, the observed and estimated values for Shannon and Simpson diversity were closely aligned. The observed Shannon diversity was 23.04, with an asymptotic estimate of 25.56 (SE = 1.86; 95% CI = 21.91–29.20), while Simpson diversity showed an observed value of 9.25 and an estimated value of 9.42 (95% CI = 7.71–11.13).

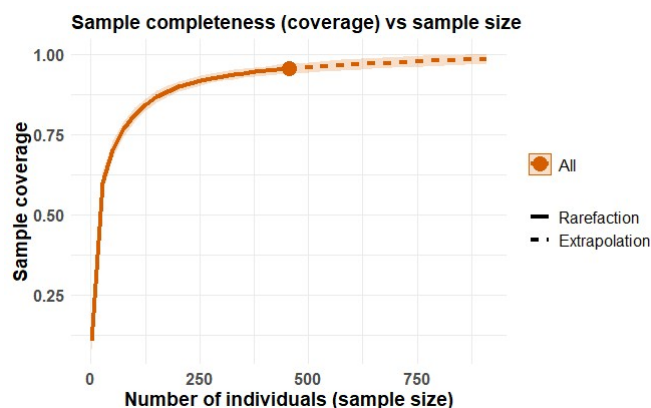


Figure 6.8. Sample completeness vs sample size

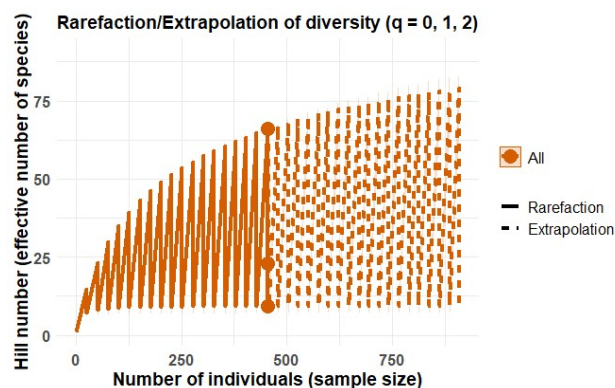


Figure 6.9. Rarefaction vs. extrapolation of diversity

The close agreement between observed and estimated Shannon and Simpson indices indicates that sampling was sufficient to accurately characterize community dominance and evenness. Collectively, these results suggest that although total species richness may be under-sampled, the effective diversity and overall community structure are robustly captured by the current dataset (Figure 6.9).

6.4. Discussion

Ecological theory and empirical evidence consistently demonstrate that biodiversity strongly influences ecosystem structure and functioning through the composition, functional traits, and spatial distribution of organisms (Hooper et al., 2005). The present study revealed that the floral composition of Inani National Park (INP) is relatively diverse, comprising 66 tree species from 33 families, a figure higher than that reported for Fashiakhali Wildlife Sanctuary (32 species) (Das et al., 2018) and Medha Kachhapia National Park (10 species) (Uddin et al., 2020), yet lower than that of Himchari National Park (88 species) (Hossen et al., 2020) and Kamalachari Natural Forest (107 species) (Hossain et al., 2015). This intermediate level of diversity indicates that while INP retains substantial ecological value, it faces ongoing pressures that may constrain species richness and distribution.

The phytosociological assessment identified four dominant species—*Areca catechu*, *Acacia auriculiformis*, *Mangifera indica*, and *Cassia fistula* L.—which collectively contributed nearly 48% of total tree density and 40% of total basal area per hectare. The dominance of these species, particularly the invasive *Acacia auriculiformis*, highlights the ecological consequences of anthropogenic disturbances, including land encroachment, selective logging, and plantation establishment. The expansion of *Acacia auriculiformis*, known for its rapid growth and nitrogen-fixing ability, exemplifies the ecological imprint of human disturbance within INP. While often used in reforestation or plantation programs, its dominance may disrupt soil nutrient balance, impede

native species recruitment, and reduce structural heterogeneity in the understory. The co-occurrence of *Mangifera indica* and *Areca catechu*—species typical of homestead and agricultural systems—further illustrates the anthropogenic replacement of native assemblages with culturally and economically favored taxa, leading to a functional simplification of forest ecosystems.

Plot-level clustering with Indicator Species Analysis identified statistically defensible diagnostic taxa for major assemblages. Cluster 1 shows high fidelity and specificity, confirming it as an *A. auriculiformis* plantation community. Cluster 3 represents a fruit/agroforestry assemblage with multiple species such as *Mangifera indica*, *Areca catechu*, *Artocarpus heterophyllus*, and *Cocos nucifera*. Cluster 2's lack of indicators suggests a mixed composition reflecting environmental and management variations (**Table-6.4**). Conversely, the dominance of *Cassia fistula*, a native species, may serve as an indicator of ecological resilience in certain forest patches, suggesting that some areas retain the potential for natural regeneration under suitable management. However, the large number of species with low IVI values points to the rarity and potential vulnerability of many native taxa, indicating that species diversity is being maintained largely through isolated or remnant individuals rather than stable populations.

The diversity indices further reinforce these structural patterns. The overall Species Diversity Index (SDI = 0.145) indicates low diversity and dominance by a few species, yet variability among forest strata provides important ecological insight. The *Hill Forest* exhibited the highest SDI (0.611), surpassing values reported for Himchari National Park (0.092; Hossen et al., 2020) and Dulahazra Safari Park (0.067; Uddin et al., 2007), reflecting a relatively more balanced community structure in this stratum. Similarly, the Shannon Diversity Index ($H' = 3.137$) for INP exceeded that of Fashiakhali Wildlife Sanctuary (2.06; Das et al., 2018) and Medha Kachhapia National Park (1.16; Uddin et al., 2020) but remained lower than Himchari National Park (3.733; Hossen et al., 2020), indicating moderate diversity at the landscape level. The Shannon Equitability Index ($Eh = 0.749$) indicates moderate species uniformity across the study area. Although lower than that reported for Himchari National Park ($Eh = 0.834$), it exceeds the value observed in Medha Kachhapia National Park ($Eh = 0.21066$; Uddin et al., 2020), suggesting a relatively balanced distribution of species. This moderate evenness reflects a forest structure where certain species exhibit ecological dominance, yet overall diversity remains sufficiently distributed to maintain community stability. The slightly lower evenness compared to Himchari National Park (Hossen et al., 2020) may result from selective pressures or anthropogenic disturbances that favor a few dominant species.

A notable discrepancy was observed between the Shannon Index and Simpson's Reciprocal Index ($Dr = 9.248$). While the Shannon Index is more sensitive to rare species, Simpson's Index gives greater weight to dominant species, and their divergence suggests that the forest supports substantial richness but limited evenness, with a few species disproportionately shaping community composition. The relatively low Dr compared with that of Himchari National Park (25.641) confirms this pattern of species dominance and structural imbalance.

The Margalef's Diversity Index ($R = 10.620$), slightly lower than that of Himchari National Park (12.667; Hossen et al., 2020), suggests a somewhat reduced species richness in INP. Previous studies

(Bohn & Huth, 2017) have emphasized that forest structural complexity—including physiognomic variation, age class distribution, and canopy stratification—is a major determinant of both biodiversity and productivity. The moderate structural diversity observed in INP therefore implies potential constraints on ecosystem functioning and resilience. Despite these limitations, the Shannon Diversity Index of 3.596 compared with 3.440 for Dulahazra Safari Park (Uddin et al., 2007) supports the conclusion that INP maintains relatively high floristic diversity, although its Shannon Equitability Index ($E_h = 0.844$) remains slightly lower, reflecting a somewhat uneven distribution of species across strata.

Importantly, this study provides new insights into the post-2017 floristic structure of INP, following the extensive anthropogenic disruptions associated with the Rohingya refugee influx, which resulted in the loss of approximately 2,500 hectares of forest. The continuing impacts of illegal logging, fuelwood collection, encroachment, and habitat fragmentation have significantly altered species composition and reduced native abundance. The dominance of invasive and cultivated species such as *Acacia auriculiformis*, *Areca catechu*, and *Mangifera indica* illustrates the transition from natural to human-modified ecosystems, characterized by simplified structure and reduced ecological function. Although the forest still hosts a variety of species, their low abundance underscores the urgent need for conservation efforts to restore ecological balance.

Overall, community structure was strongly shaped by the ten most dominant taxa, reflecting a moderately diverse ecosystem. The findings further indicate that, although Inani National Park (INP) maintains moderate levels of biodiversity relative to other protected areas in southeastern Bangladesh, its ecological integrity has been significantly degraded. This underscores the need for targeted conservation interventions. Priority management actions should focus on preventing further encroachment, strengthening law enforcement and co-management frameworks, promoting reforestation with native species, and restoring degraded forest areas to enhance structural complexity and species evenness. Implementing these measures will be critical for conserving biodiversity, increasing ecosystem resilience, and ensuring the long-term sustainability of INP's forest ecosystems.

6.5. Conclusion

Inani National Park (INP) supports considerable plant species diversity despite experiencing intense anthropogenic pressures. The present analysis demonstrates that the *Shrub with Scattered Trees* stratum sustains the highest species diversity across multiple indices, while *Hill Forests* continue to play a crucial role in maintaining overall ecosystem heterogeneity. *Forest Plantations*, although structurally simpler, may contribute to ecosystem recovery if carefully managed and aligned with conservation objectives. Given the extent of forest degradation in INP, ecosystem restoration is essential for enhancing ecological resilience and recovering ecosystem functions (UNEP, 2019).

Restoration and conservation interventions in a protected area such as INP must be guided by conservation ethics and national park management policies. In this context, priority should be given to natural regeneration wherever feasible, as it maintains ecological integrity and minimizes human interference. However, in severely degraded areas where natural recovery is constrained by soil erosion, invasive species dominance, or loss of seed sources, limited and well-regulated active

restoration may be justified. Such interventions should focus on enrichment planting with site-appropriate native species and the gradual removal or control of invasive exotics, rather than large-scale artificial plantations. A phased conservation approach—identifying vulnerable native species, implementing immediate protective measures, and supporting long-term recovery—can effectively balance ecological restoration with protection mandates (Hossain et al., 2020).

This study provides comprehensive baseline information on tree species density, diversity, dominance, and composition in INP, offering a robust scientific foundation for adaptive and sustainable management planning. By emphasizing natural regeneration as the primary strategy and carefully justified, minimal active restoration where degradation is severe, the findings underscore a pragmatic pathway for ecosystem recovery. Overall, the results can inform conservation policies and management decisions aimed at safeguarding biodiversity, improving ecosystem resilience, and ensuring the long-term ecological integrity of Inani National Park and the broader Cox's Bazar landscape.

Chapter 7

Study 5.

REGENERATION POTENTIALS OF TREE SPECIES IN A DEGRADED PROTECTED AREA ON THE SOUTHEASTERN COAST OF BANGLADESH

Abstract

Understanding natural regeneration dynamics is critical for forest conservation and restoration. This study assessed tree species regeneration, diversity, and structure in Inani National Park (INP), Cox's Bazar, Bangladesh. Stratified random sampling was employed across 131 plots (19.64 m² each) within four land cover strata: *Shrub with Scattered Trees*, *Hill Forest*, *Forest Plantation*, and *Others*. A total of 90 regenerating species were recorded, comprising 71 seedlings and 63 saplings. Regeneration varied markedly across land cover strata, with *Shrub with Scattered Trees* exhibiting the highest species richness, diversity, and recruitment, while *Forest Plantation* and *Other* strata showed limited regeneration. Seedlings were more abundant than saplings, reflecting high early-stage recruitment but lower survival to later stages. Species dominance and family composition were habitat-specific, with pioneer and generalist species such as *Acacia auriculiformis* and members of Fabaceae family showing strong recruitment, whereas several late-successional and specialized species exhibited limited regeneration. Human-induced disturbances—including logging, grazing, and pole extraction—alongside environmental stressors, influenced species composition, height-class distribution, and regeneration potential. The findings provide a baseline for conservation planning, supporting biodiversity management and sustainable forest restoration in INP. Targeted interventions, including assisted natural regeneration and enrichment planting, are recommended to enhance recruitment of underrepresented native species and strengthen the long-term resilience and ecological integrity of the forest.

Key Words: Regeneration; Protected area; National Park; Diversity index; Phytosociological attributes; Habitat restoration

Introduction

Natural regeneration, particularly the survival of seedlings and new recruits, is a key biotic process underpinning forest sustainability, especially in tropical hill forests (Battaglia et al., 2018). The dynamics of species regeneration, shaped by both spatial and temporal factors as well as natural and anthropogenic disturbances, regulate forest structure and composition (Kumar & Rajwar, 2009). Globally, more than half of tropical forests have been converted to alternative land uses, resulting in the loss of critical habitats and resources for forest-dependent species and communities, as well as the disruption of essential ecosystem services (Lewis et al., 2015). Historically, tropical forests covered about 12% of the Earth's land area, but this has declined to just 5% (600 million hectares), representing roughly 28% of the land within tropical regions (Brandon, 2014). Forest regeneration surveys provide valuable information on current forest structure, composition, and potential future changes (Malik & Bhatt, 2016). Successful regeneration ensures the gradual replacement of senescent

trees by new individuals, sustaining forest continuity and ecosystem functionality over time (Poudel et al., 2020).

Plant regeneration primarily occurs through seeds stored in the soil and vegetative structures, with the presence of viable seeds or resprouting ability being critical for the process. In naturally regenerating systems, seeds may originate from nearby parent trees (Reid et al., 2015) or emerge from existing soil seed banks or underground vegetative organs such as rootstocks or stolons (Sun et al., 2013). Evaluating regeneration profiles is essential for determining the regeneration status of species, providing key insights for forest conservation and management strategies (Ghimire et al., 2017). The status of natural regeneration also reflects the ecological characteristics of a forest, as trees serve as vital resources and habitats for a wide array of forest-dependent organisms (Cannon et al., 1998).

The natural regeneration potential serves as a vital indicator of forest ecosystem health and sustainability (Hossain & Hossain, 2014). Evaluating regeneration status provides important insights into population dynamics and structural patterns of tree species (Nur et al., 2016), informs forest management practices, including considerations of economic value and regenerative capacity (Wyatt-Smith, 1987), and biodiversity conservation (Verma et al., 1999). Seedling and sapling densities are commonly used to assess a species' regeneration potential, with higher densities indicating adaptability to local conditions (Balwant et al., 2014) and successful natural regeneration (Saxena & Singh, 1984).

Under favorable conditions, tropical forests can regenerate naturally or undergo secondary succession, driven by ecological processes such as species colonization and community development (Chazdon, 2019). This process gradually restores key ecosystem functions, including soil organic matter accumulation, carbon storage, water regulation, nutrient cycling, and pollination, facilitated by the diversity and interactions of canopy and understory vegetation (Poorter et al., 2016). Naturally regenerating species are typically well-adapted to local conditions and often establish alongside mutualistic partners, enhancing biodiversity and spatial heterogeneity (McAlpine et al., 2016). In addition to promoting plant diversity, naturally regenerating forests also offer essential habitats for the conservation of animal species that depend on forest ecosystems (Chazdon et al., 2009). These forests function as complex adaptive systems, characterized by eight fundamental attributes: heterogeneity, hierarchy, self-organization, openness, adaptability, ecological memory, non-linearity, and uncertainty (Filotas et al., 2014) which collectively increase resilience and the ability to withstand or recover from disturbances and environmental shocks (Cumming, 2011).

Natural regeneration is crucial for maintaining biodiversity and sustaining forest ecosystems (Rahman et al., 2011). It drives the development and succession of plant communities, profoundly shaping forest structure (Han & Wang, 2002). This complex ecological process involves both sexual and asexual reproduction, seed dispersal, and seedling establishment, all of which are influenced by environmental conditions. The success of natural regeneration depends on biotic factors, including species composition, seed availability, competition, and predation, as well as abiotic factors such as soil quality, moisture, light, and topography within a given climatic context (Tinya et al., 2019).

Bangladesh, located in the tropical forest region of Southeast Asia, contains approximately 2.5 million hectares of forest managed by governmental and private entities (Sobuj & Rahman, 2011) and harbors around 5,000 angiosperm species (Nath et al., 1998). However, natural regeneration is often constrained by competition from grasses and ferns. Forests in the country are rapidly declining due to socio-economic pressures, biotic factors, and conflicting land-use practices, including population growth, agricultural encroachment, overharvesting of timber and non-timber resources, urban expansion, and ineffective management (Haidar et al., 2017). Dependence on forest resources for livelihoods further exacerbates degradation (Muhammed, et al., 2008).

Conserving and effectively managing the remaining old-growth forests is critical for halting further biodiversity loss (Gibson et al., 2011) and maintain global carbon stocks (Grace et al., 2014). Accurate data on tree composition and distribution are essential for understanding forest structure and guiding conservation strategies (Malik et al., 2014). In forest management, studies on regeneration provide insight into both the current condition and the potential future dynamics of forest composition (Malik & Bhatt, 2016).

The southeastern region of Bangladesh harbors remnants of natural forests that are undergoing rapid degradation, highlighting the need for urgent conservation efforts (Dey & Akther, 2020). Effective management in this region requires evidence-based strategies informed by detailed knowledge of species distribution (Dey & Akther, 2020). Inani National Park, situated in this area, faces significant anthropogenic pressures, including land encroachment, illegal logging, fuelwood collection, and habitat destruction. These pressures intensified following the establishment of Rohingya refugee camps in 2017, resulting in the clearance of approximately 2,428 ha of forest. While several studies have examined forest regeneration in other regions of Bangladesh (Hossain et al., 2020; Rahman et al., 2020), no quantitative assessment has been conducted on the regeneration status of native tree species in Inani National Park. Accordingly, this study aims to evaluate the regeneration status of native tree species within the park using systematic quantitative analysis.

7.2. Materials and Methods

7.2.1. Study Area

Inani National Park (INP), a designated protected area of approximately 7,085 ha located 26 km south of Cox's Bazar ((Kabir, M.T. et al., 2021)), bordered by Himchari National Park to the north, Teknaf Wildlife Sanctuary to the south, the Bay of Bengal to the west, and the Teknaf-Cox's Bazar highway to the east (Uddin et al., 2013; **Figure 6.1 in chapter**). The park comprises degraded evergreen to semi-evergreen forests across several beats, consists of gently sloping hills formed from Pleistocene to Miocene sediments, with soils ranging from clay and loam to sand (Miah & Hossain, 2022). It is characterized by heavy rainfall, hill runoff, streams, and wetlands, which provide critical habitats for diverse wildlife (Das et al., 2018).

7.2.2. Sampling Framework and Plot Allocation

The study adopted stratified random sampling method for the vegetation survey. ArcGIS and MS Excel software were used to generate sample points. The National Land Cover Map of 2023 was used for stratification to get a more representative sample clip of the study land cover by using ArcGIS Software. As such, four land cover strata or areas were categorized in the study area namely, *Hill Forest*, *Forest Plantation*, *Shrub with Scattered Trees* and *Others* (including orchards, rural settlement, rivers, lake, multiple crops, single crop etc.) (**Table 6.1**). The same equation as applied in tree species was used to determine sample size at 90% confidence interval, 10% standard error and coefficient of variance. The coefficient of variance was derived using National Forest Inventory data, 2018 of Cox's Bazar area (GOB, 2019).

$$n_{i+1} = \frac{1}{\frac{1}{N} + \left[\frac{E}{(t_{n_i-1, \alpha/2}) CV} \right]^2}$$

Where, n_{i+1} is the number of plots needed, N is the population sample size (total area/plot size), E is the allowable error expressed as a percentage of the mean, $t_{n_i-1, \alpha/2}$ is the student's t-value at $n_i - 1$ df, $\alpha = 1 - P/100$ is the probability of a type I error for a stated percent confidence of P, and CV is the coefficient of variation.

Based on above calculation a total number of 131 sample plots were distributed proportionally among different land cover strata (Table 7.1). The following equation was used to calculate the number of plots employed for each stratum (where, 'x' = *Hill Forest* or *Forest plantation* strata or *Shrub with Scattered Trees* or *Other* stratum):

$$\text{Number of plots for 'x' strata} = \frac{\text{Total number of plot}}{\text{Total study area}} \times \text{area of 'x' strata}$$

7.2.3. Sample Plot Diagram

In the study, a total of 131 randomly selected circular sample plots were laid out in different land cover strata as mentioned above. As this study was part of a greater biodiversity assessment project where a 19 m radius circular plot was used to collect vegetation data following BFD (2016) containing three types of circular subplots such as Large (L) subplot of 19-meter radius for measuring trees ≥ 30 cm dbh, medium (M) subplot of 8-meter radius measuring trees < 30 cm to ≥ 10 cm dbh and small (S) subplot of 2.5-meter radius for measuring natural regeneration status (**Figure 7.1**; GOB, 2019). This study focused on small (S) subplot of 2.5-meter radius for measuring natural regeneration status where both seedlings (naturally regenerating tree species having a height of > 15 to 135 cm; Martini, 2023) and saplings (naturally regenerating tree species whose diameter at breast height ranges from > 1 to < 10 cm; Rijal et al., 2023) were identified and recorded. Seedlings and saplings of all species in each plot were identified and recorded by local and scientific names. The common tree species were identified directly in the field, while the fertile samples of the unknown tree species were collected for the preparation of herbarium specimens for identification later following Rahman et al. (2020) and Ao et al. (2024).

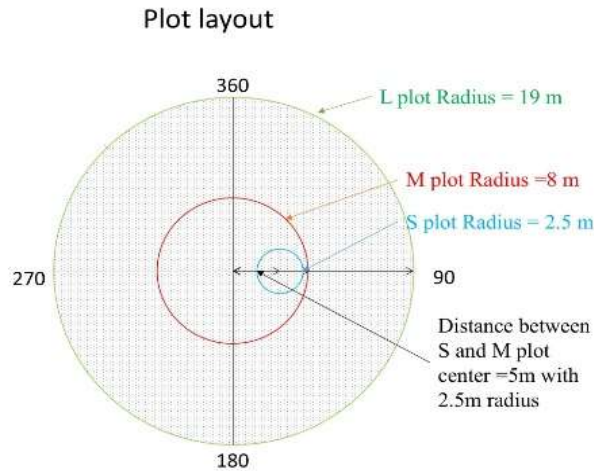


Figure 7.1 Sample Plot Diagram

7.2.4. Data Analysis

The field data were compiled and analyzed for regeneration density, relative density (RD%), relative frequency (RF%), relative abundance (RA%), importance value index (IVI), Shannon-Wiener diversity index (H), Shannon's maximum diversity index (H_{max}), Simpson's diversity index (D), and Margalef's species richness index (R), following Rahman et al. (2011) and Rahman et al. (2020).

The regeneration status of sample species in the forest was analyzed by comparing seedling with sapling and sapling with matured trees data (Bogale et al., 2017; Ao et al., 2024) in the following categories: 1) "good" regeneration, if present in seedling $>$ or $<$ sapling $>$ mature tree; 2) "fair" regeneration, if present in seedling $>$ or $\leq$ sapling $\leq$ mature tree; 3) "poor" regeneration, if a species survives only in the sapling stage, but no seedlings (even though saplings may be $<$, $>$ or $=$ mature); 4) "none", if a species is absent both in sapling and seedling stages, but present only as mature; and 5) "new", if a species has no mature, but only sapling and/or seedling stages.

7.3. Results

7.3.1. Phytosociological attributes of regenerating tree species

The current study examined tree regeneration under two distinct categories: seedlings and saplings. Saplings represent the more mature stage of seedlings and can be regarded as young or newly recruited trees. Overall, 71 species (61 genera and 37 families) were identified in the seedling category, exhibiting a higher density (3074 individuals ha^{-1}) compared to the sapling category, which comprised 63 species (55 genera and 34 families) with a density of 940 individuals ha^{-1} (**Appendix 8**). The findings highlight a varied distribution of regenerating tree species across different land cover strata. Among these, the *Shrub with Scattered Trees* stratum exhibited the highest species richness, with 61 species from 34 families in the seedling group and 55 species from 31 families in the sapling group. This was followed by the *Hill Forest* (28 species and 19 families for seedlings; 20 species and

16 families for saplings), *Others* (16 species and 14 families for seedlings; 2 species and 2 families for saplings) and *Forest Plantation* (11 species and 10 families for seedlings; 5 species and 5 families for saplings) (**Table 7.1**). Species diversity indices exhibited notable variation between seedlings and saplings across the different land cover strata (Table 6. 2). The *Shrub with Scattered Trees* stratum demonstrated the highest diversity for both growth stages (saplings: $H = 3.652$, $H_{max} = 4.007$, $D = 0.034$, $R = 10.421$; seedlings: $H = 3.588$, $H_{max} = 4.111$, $D = 0.038$, $R = 9.487$), indicating a well-balanced species composition and high richness. The *Hill Forest* stratum showed moderate diversity values (saplings: $H = 2.883$, $H_{max} = 2.996$, $D = 0.063$, $R = 5.643$; seedlings: $H = 3.140$, $H_{max} = 3.332$, $D = 0.050$, $R = 5.902$), suggesting relatively stable species distribution across regeneration stages. In contrast, the *Forest Plantation* (saplings: $H = 1.418$, $H_{max} = 1.609$, $D = 0.280$, $R = 1.737$; seedlings: $H = 1.989$, $H_{max} = 2.398$, $D = 0.174$, $R = 2.519$) and *Others* (saplings: $H = 0.692$, $H_{max} = 0.693$, $D = 0.501$, $R = 0.311$; seedlings: $H = 2.099$, $H_{max} = 2.773$, $D = 0.184$, $R = 3.395$) strata exhibited substantially lower diversity indices, reflecting limited species richness and uneven distribution patterns. These results highlight that natural strata, particularly *Shrub with Scattered Trees* and *Hill Forest*, support higher levels of species diversity and ecological heterogeneity compared to more modified or disturbed land cover types.

Marked differences in species density and Importance Value Index (IVI) of dominant species were evident across the various land cover strata (**Tables 7.2–7.5**). In the *Hill Forest* stratum, *Glochidion arborescens*, *Ficus racemosa*, and *Caesalpinia sappan* were the predominant species at the sapling stage, whereas *Ficus racemosa*, *Macaranga denticulata*, and *Syzygium grande* dominated the seedling stage. The *Forest Plantation* stratum was largely characterized by *Acacia auriculiformis* and *Diospyros pilosula* among saplings, and by *Antidesma ghaesambilla* and *Diospyros pilosula* among seedlings. Within the *Shrub with Scattered Trees* stratum, *Macaranga denticulata*, *Sesbania grandiflora*, and *Antidesma ghaesambilla* were dominant at the sapling stage, while *Acacia auriculiformis*, *Ficus racemosa* and *Grewia nervosa* were most abundant among seedlings. In the *Others* stratum, *Acacia auriculiformis* and *Acacia catechu* exhibited total dominance at the sapling stage, whereas *Grewia nervosa*, *Acacia auriculiformis* and *Ficus racemosa* were the principal species at the seedling stage. These patterns reflect stratum-specific differences in species composition and regeneration dynamics across the landscape.

Table 7.1: Phytosociological attributes of different regeneration categories across various land cover strata in Inani National Park

Regeneration type	<i>Hill Forest</i>	<i>Forest Plantation</i>	<i>Shrub with Scattered Trees</i>	<i>Others</i>
Saplings				
Dominant species	<i>Glochidion arborescens</i> Blume	<i>Acacia auriculiformis</i>	<i>Macaranga denticulata</i> (Blume.) Muell.-Arg.	<i>Acacia auriculiformis</i>
Dominant families	Phyllanthaceae	Fabaceae	Euphorbiaceae	Fabaceae
No. of species	20	5	55	2

No. of family	16	5	31	2
Density (individuals ha ⁻¹)	820	727	1007	795
Shannon-Wiener Diversity Index (<i>H</i>)	2.883	1.418	3.652	0.692
Shannon Maximum Diversity (<i>H_{max}</i>)	2.996	1.609	4.007	0.693
Simpson's Diversity Index (<i>D</i>)	0.063	0.280	0.034	0.501
Margalef's Diversity Index (<i>R</i>)	5.643	1.737	10.421	0.311
Seedlings				
Dominant species	<i>Macaranga denticulata</i> (Blume.) Muell.-Arg.	<i>Antidesma ghaesambilla</i> Gaertn.	<i>Ficus racemose</i> L.	<i>Grewia nervosa</i> (Lour.) Panigr.
Dominant families	Euphorbiaceae	Phyllanthaceae	Moraceae	Malvaceae
No. of species	28	11	61	16
No. of family	19	10	34	14
Density (individuals ha ⁻¹)	2743	3855	3156	2641
Shannon-Wiener Diversity Index (<i>H</i>)	3.140	1.989	.588	2.099
Shannon Maximum Diversity (<i>H_{max}</i>)	3.332	2.398	4.111	2.773
Simpson's Diversity Index (<i>D</i>)	0.050	0.174	0.038	0.184
Margalef's Diversity Index (<i>R</i>)	5.902	2.519	9.487	3.395

Table 7.2: Distribution of regeneration density and IVI of 5 dominant species in *Hill Forest* stratum of Inani National Park

Sapling species	Density	IVI	Seedling species	Density	IVI
<i>Glochidion arborescens</i> Blume	84.85	26.69	<i>Ficus racemosa</i> L.	197.98	20.90
<i>Ficus racemosa</i> L.	84.85	25.04	<i>Macaranga denticulata</i> (Blume.) Muell.-Arg.	226.26	18.92
<i>Caesalpinia sappan</i> L.	84.85	25.04	<i>Syzygium grande</i> (Wit.) Walp.	197.98	17.49
<i>Castanopsis indica</i>	56.57	19.59	<i>Glochidion arborescens</i> Blume	197.98	17.49
<i>Protium serratum</i> (Wall. ex DC.) Engler	56.57	19.24	<i>Dipterocarpus turbinatus</i>	197.98	17.27

Table 7.3: Distribution of regeneration density and IVI of 5 dominant species in Forest Plantation stratum of Inani National Park

Saplings			Seedlings		
Species name	Density (individuals ha ⁻¹)	IVI	Species name	Density (individuals ha ⁻¹)	IVI
<i>Acacia auriculiformis</i>	290.90	100	<i>Antidesma ghaesambilla</i> Gaertn.	1163.64	66.10
<i>Diospyros pilosula</i>	218.18	80	<i>Diospyros pilosula</i> (A.DC.) Wall. ex Hiern	727.27	46.67
<i>Syzygium grande</i> (Wit.) Walp.	72.72	40	<i>Cordia grandis</i> Roxb.	581.81	43.86
<i>Ficus racemose</i> L.	72.72	40	<i>Grewia nervosa</i> (Lour.) Panigr.	436.36	33.71
<i>Tectona grandis</i>	72.72	40	<i>Acacia auriculiformis</i>	290.90	25.50

Table 7.4: Distribution of regeneration density and IVI of 5 dominant species in Shrub with Scattered Trees stratum of Inani National Park

Saplings			Seedlings		
Species name	Density (individuals ha ⁻¹)	IVI	Species name	Density (individuals ha ⁻¹)	IVI
<i>Sesbania grandiflora</i> Pers.	62.22	14.67	<i>Acacia auriculiformis</i>	243.23	31.89
<i>Macaranga denticulata</i> (Blume.) Muell.-Arg.	67.87	14.13	<i>Ficus racemose</i> L.	271.51	16.74
<i>Antidesma ghaesambilla</i> Gaertn.	62.22	13.33	<i>Grewia nervosa</i> (Lour.) Panigr.	214.94	13.59
<i>Maesa indica</i> (Roxb.) A. DC.	56.56	12.24	<i>Glochidion arborescens</i> Blume	203.63	13.38
<i>Brownlowia elata</i> Roxb.	45.25	11.47	<i>Mitragyna rotundifolia</i>	135.75	11.75

Table 7.5: Distribution of regeneration density and IVI of 5 dominant species in Others stratum of Inani National Park

Saplings			Seedlings		
Species name	Density (individuals ha ⁻¹)	IVI	Species name	Density (individuals ha ⁻¹)	IVI
<i>Acacia auriculiformis</i>	413.63	153.75	<i>Grewia nervosa</i> (Lour.) Panigr.	922.72	68.39
<i>Areca catechu</i>	381.81	146.24	<i>Acacia auriculiformis</i>	413.63	48.11
			<i>Ficus racemose</i> L..	350.00	33.72
			<i>Syzygium cumini</i> (L.) Skeels	318.18	31.25
			<i>Vitex glabrata</i> R.Br.	95.45	15.21

7.3.2. Regenerating potentials of tree species

The analysis revealed clear variations in regeneration status among the different land cover strata (**Figure 7.2**). In *Hill Forests*, regeneration was more evenly distributed across categories, with moderate proportions of ‘new’ (26%), ‘good’ (20%), and ‘fair’ (13%) regeneration. However, the relatively notable proportion of ‘poor’ (20%) regeneration suggests localized degradation pressures. In *Forest Plantations*, regeneration was primarily categorized as ‘new’ (40%), while 35% of plots exhibited no regeneration, indicating limited natural recovery and a potential dependence on artificial planting. In contrast, the *Shrub with Scattered Trees* stratum exhibited comparatively stronger regeneration potential, as reflected by higher percentages of ‘good’ (28%) and ‘fair’ (22%) regeneration and a lower share of ‘none’ (17%). The *Others* stratum was dominated by ‘new’ (46%) regeneration, though a considerable 39% of plots lacked regeneration, indicating spatial variability in recovery dynamics. Collectively, these findings reveal that natural regeneration capacity and ecosystem resilience differ considerably among land cover types, underscoring the need for stratum-specific management approaches to enhance forest recovery and biodiversity conservation.

Overall, the results indicate that natural regeneration processes are actively occurring across several strata—particularly in *Shrub with Scattered Trees* and *Hill Forest* strata—where favorable microhabitat conditions and ecological interactions appear to facilitate seedling establishment. In contrast, regeneration in the *Forest Plantation* and *Others* strata seems limited, with a high proportion of plots showing no regeneration (35–39%), likely due to restricted seed availability, soil compaction, or management-induced disturbances. The substantial proportion of plots categorized as having ‘none’ (17–39%) or ‘poor’ (4–20%) regeneration highlights the need for targeted silvicultural and restoration measures aimed at enhancing species recruitment, improving habitat quality, and strengthening the long-term ecological resilience and recovery potential of degraded ecosystems within the study area.

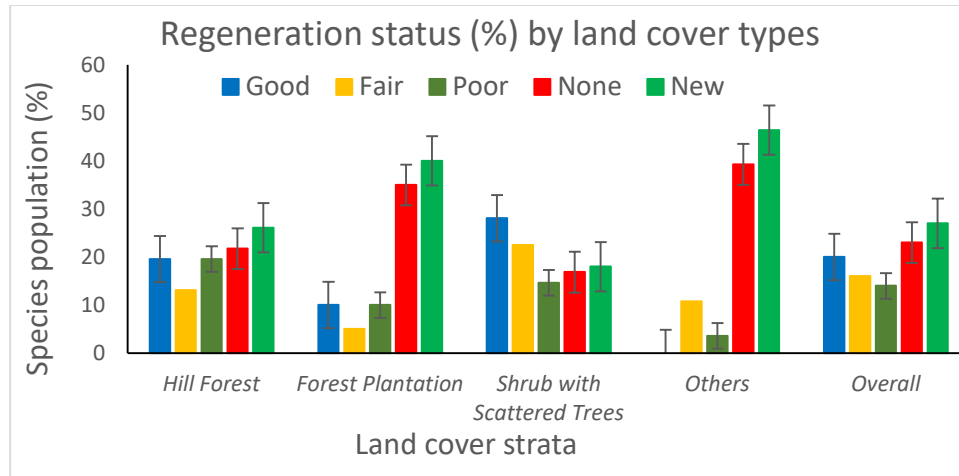


Figure 7.2. Regeneration status (%) of tree species in different land cover strata

7.4. Discussions

In INP, a total of 90 regenerating species were recorded, including 71 seedlings and 63 saplings (**Appendix 5**), indicating relatively good regeneration compared to several other sites in Bangladesh. For example, Dulahazara Safari Park (56 species; Uddin et al., 2023), Khadimnagar National Park and Tilagor Eco-Park (55 species; Rahman et al., 2011b), Sitapahar natural forest (52 species; Hossain, 1994), Tankawati Natural Forest (29 species; Motaleb & Hossain, 2011), and Durgapur hill forest (27 species; Rahman et al., 2011b) all reported lower species richness. Compared to Hazarikhil Wildlife Sanctuary (90 species; Rahman et al., 2019), the species richness in INP is similar, though it remains lower than in Chunati Wildlife Sanctuary (105 species; Rahman et al., 2020) and Dudhpukuria-Dhopachari Wildlife Sanctuary (120 species; Hossain et al., 2013). On a broader scale, INP's regeneration is still limited relative to tropical semi-evergreen forests of Northeast India (124 species; Nautiyal & Manish, 2025) and the Image Forest Reserve in Tanzania (153 species across 59 families and 122 genera; Kayombo et al., 2022), highlighting the potential for further improvement in species recruitment and forest recovery.

Tree regeneration varied markedly across growth stages and land cover types. Seedlings were more abundant (3,074 individuals ha^{-1} , 71 species) than saplings (940 individuals ha^{-1} , 63 species), reflecting high early-stage recruitment but lower survival to later stages. Among land cover strata, *Shrub with Scattered Trees* supported the richest and most diverse regeneration, indicating that heterogeneous and semi-open habitats may provide favorable microsites for both seedling establishment and sapling recruitment. *Hill Forest* exhibited moderate richness and diversity, while *Forest Plantation* and *Other* strata showed limited regeneration, particularly for saplings, suggesting constraints such as canopy closure, competition, or anthropogenic disturbance.

The patterns of species diversity (H , H_{max} , D , R) reinforce these observations. The *Shrub with Scattered Trees* stratum exhibited the highest species diversity across both regeneration stages, reflecting a structurally complex and ecologically favorable environment for tree recruitment. The

high Shannon diversity values ($H = 3.652$ for saplings; $H = 3.588$ for seedlings) and their close correspondence to maximum diversity ($H_{max} = 4.007$ and 4.111 , respectively) indicate a relatively even distribution of individuals among species, suggesting minimal dominance and strong coexistence. The low Simpson's dominance indices ($D = 0.034$ – 0.038) further support the presence of high species heterogeneity and balanced community structure. Similarly, elevated Margalef's richness values ($R = 10.421$ for saplings; $R = 9.487$ for seedlings) point to substantial species richness and recruitment potential.

Ecologically, this pattern implies that the *Shrub with Scattered Trees* stratum offers a mosaic of microhabitats, moderate light availability, and reduced interspecific competition—all conditions that favor seedling establishment and sapling survival. The mixture of shrub cover and scattered canopy trees likely creates an intermediate disturbance regime that maintains species turnover while preventing competitive exclusion. Consequently, this stratum may represent a key transitional habitat supporting both early- and mid-successional species, thereby enhancing overall forest resilience and biodiversity maintenance within the landscape. Similarly, Hossen et al. (2019) noted that mixed shrub–tree stands in Himchari National Park act as successional intermediates between degraded open areas and mature hill forests, hosting species such as *Macaranga denticulata*, *Ficus racemosa*, and *Grewia nervosa*. This structural and floristic pattern aligns with the present observation that the *Shrub with Scattered Trees* stratum fosters both early- and mid-successional species, promoting forest recovery and ecological stability.

The observed variation in species density and Importance Value Index (IVI) across land cover strata reflects underlying differences in microhabitat conditions, successional stages, and resource availability (**Tables 7.2–7.5**). The prevalence of *Acacia auriculiformis* in multiple strata indicates its preference, adaptability and competitive advantage in disturbed or regenerating habitats, where it often acts as a pioneer species facilitating early succession. Similar observations were reported by Hossen et al. (2019). Taken together, both the present findings and previous studies indicate that *A. auriculiformis* plays a transitional or facilitative role in the recovery of disturbed tropical ecosystems. In *Hill Forest*, the dominance of *Glochidion arborescens*, *Ficus racemosa*, and *Caesalpinia sappan* among saplings, and *Ficus racemosa*, *Macaranga denticulata*, and *Syzygium grande* among seedlings indicates stable regeneration and favorable microhabitat conditions supporting both pioneer and shade-tolerant species. In *Forest Plantation*, the prevalence of *Acacia auriculiformis* and *Diospyros pilosula* suggests low diversity and strong plantation influence, with restricted natural recruitment due to canopy closure and soil disturbance. The *Shrub with Scattered Trees* stratum showed active successional development, with diverse dominant species such as *Macaranga denticulata*, *Sesbania grandiflora*, and *Grewia nervosa*, reflecting higher light availability and regeneration potential. The *Others* stratum, dominated by *Acacia* species alongside *Grewia nervosa* and *Ficus racemosa*, indicates early successional recovery in disturbed areas. Overall, these patterns emphasize that regeneration dynamics are shaped by land cover type and disturbance intensity, underscoring the importance of targeted management to promote native species regeneration and ecological restoration in INP—findings consistent with those of Rahman et al. (2011), Hossen et al. (2019), Dey and Akther (2020) and Uddin et al. (2023).

Regeneration patterns also varied markedly across land cover strata (**Figure 7.2**). *Shrub with Scattered Trees* stratum exhibited the strongest regeneration, with higher proportions of ‘good’ and ‘fair’ plots and fewer areas lacking regeneration, reflecting favorable microhabitats and species interactions that promote seedling establishment. *Hill Forest* stratum showed more balanced regeneration, though a notable share of ‘poor’ plots indicates localized degradation pressures. In contrast, *Forest Plantation* and *Other* strata were dominated by ‘new’ or ‘none’ regeneration, highlighting constraints such as limited seed sources, soil compaction, or management-related disturbances. These findings indicate that natural regeneration capacity and ecosystem resilience are highly stratum-specific, emphasizing the need for targeted management and restoration interventions to enhance species recruitment, improve habitat quality, and support long-term recovery of degraded forest landscapes.

At the family level, the dominance of Fabaceae across both seedlings and saplings (Appendix 1) indicates its strong adaptive capacity and ecological significance in the regeneration dynamics of the study area. The prevalence of this family, which includes many nitrogen-fixing species, suggests an important role in improving soil fertility and facilitating the establishment of other plant species during succession. The subsequent representation of families such as Malvaceae, Myrtaceae, Rubiaceae, Moraceae, Lamiaceae, Lauraceae, and Euphorbiaceae reflects a diverse assemblage of both pioneer and late-successional taxa, contributing to structural and functional heterogeneity within the regenerating vegetation. This pattern implies that leguminous and fast-growing pioneer families dominate early regeneration stages, while the presence of shade-tolerant and ecologically specialized families indicates ongoing successional development and ecosystem recovery across the landscape. Many members of these families, particularly Fabaceae and Euphorbiaceae are known for rapid colonization and nitrogen-fixing capabilities, enabling them to thrive in disturbed or open habitats and facilitate early successional processes. This aligns with observations by Joshi et al. (2019), who emphasized that forest community composition and regeneration are strongly shaped by both environmental factors—such as temperature, precipitation, and light—and anthropogenic influences including tree felling, grazing, and fire.

The absence of regeneration from families like Acanthaceae, Crypteroniaceae, Proteaceae, and Vitaceae—despite their presence in the sapling layer—suggests recruitment bottlenecks or environmental constraints affecting seedling establishment. Nur et al. (2016) and Hossen et al. (2020) reported similar patterns of uneven family-level regeneration in Shitalpur and Himchari hill forests, where mature species from late-successional families failed to recruit seedlings due to canopy closure, seed limitation, and soil degradation. Conversely, families such as Bixaceae, Lauraceae, Rutaceae, and Verbenaceae appearing only at the seedling stage may indicate recent colonization or favorable conditions for early recruitment. Collectively, these patterns highlight ongoing successional turnover, where a mixture of pioneer and shade-tolerant taxa coexist, reflecting both disturbance-driven regeneration and the gradual recovery of late-successional elements. Moreover, the multi-family regeneration observed here indicates ecological resilience and adaptive recovery capacity, provided disturbances remain within thresholds that allow natural succession to proceed—a theme echoed by Mamun et al. (2022) and Baul et al. (2025). This dynamic underscore the ecological resilience of INP

and the importance of maintaining environmental heterogeneity to support multi-family regeneration and long-term forest restoration.

However, regeneration dynamics in INP are heavily influenced by anthropogenic pressures. Proximity to forest-dependent communities has resulted in disturbances such as logging, grazing, firewood collection, and intentional burning, which degrade habitat quality and disrupt regeneration. The extraction of saplings for fencing and fuelwood further hampers the progression of younger cohorts into mature classes. Similar observations have been reported by Rahman et al. (2011), Dey and Akther (2020), and Mamun et al. (2022). These pressures can shift forest composition toward disturbance-tolerant and generalist species, reducing overall biodiversity and increasing vulnerability to environmental stressors.

To enhance forest recovery and maintain biodiversity, targeted management interventions are essential. Strategies such as enrichment planting, protection of natural regeneration, and application of site-specific silvicultural treatments can improve species recruitment, particularly for rare or late-successional species absent from both seedling and sapling layers. Maintaining habitat heterogeneity, controlling anthropogenic disturbances, and promoting native species reestablishment will be critical to ensuring the long-term ecological resilience and sustainable recovery of INP's forest ecosystems.

7.5. Conclusion

Inani National Park (INP) supports relatively diverse natural regeneration, with 90 tree species recorded across seedlings and saplings. Regeneration patterns varied among land cover strata, with the *Shrub with Scattered Trees* stratum exhibiting the highest species richness, diversity, and recruitment, the *Hill Forest* stratum exhibiting moderate species diversity, and the *Forest Plantation* and *Others* strata showing limited regeneration. Species dominance and family composition reflected habitat-specific dynamics, with pioneer and generalist taxa, such as *Acacia auriculiformis* and members of Fabaceae, showing strong recruitment, whereas late-successional or specialized species exhibited recruitment constraints. Human-induced disturbances, including logging, grazing, and pole extraction, along with environmental stressors, continue to influence species composition, height-class distribution, and regeneration potential, particularly affecting rare and specialized taxa.

These findings provide a scientific baseline for conservation planning and evidence-based management, supporting biodiversity conservation and sustainable forest management in INP. They also inform future restoration efforts, including assisted natural regeneration and enrichment planting, by identifying native species underrepresented in the seedling layer but present in low densities as saplings. Maintaining habitat heterogeneity and mitigating anthropogenic pressures are essential to enhance forest recovery, sustain biodiversity, and strengthen the long-term ecological resilience of INP.

Chapter 8

Study 6.

COMMUNITY PERCEPTIONS, CONSERVATION ATTITUDES AND GOVERNANCE DYNAMICS IN A BANGLADESHI FOREST PROTECTED AREA

Abstract

Forest Protected Areas (PAs) are the most widely used tool for combating global biodiversity loss. Wild mammals are declining faster than FPAs are expanding, raising ongoing debates about their effectiveness in sustaining populations and enhancing biodiversity. Understanding local perceptions of wildlife and human–wildlife interactions is essential for designing socially grounded conservation strategies in forest-dependent landscapes. This study investigates socio-demographic patterns, perceptions of wildlife significance, and the prevalence and typology of human–wildlife conflict among communities living in and around the Inani Forest Protected Area, Bangladesh. Using structured household surveys ($n = 271$) and a reproducible analytical workflow in R, we examined associations between ethnicity, age, and multiple dimensions of wildlife perception. Most respondents (64.6%) viewed wildlife as beneficial, reflecting strong recognition of its ecological and cultural value, whereas 31.0% perceived wildlife as harmful, largely due to direct negative encounters, such as crop raiding. As noted in the dataset, “a majority of the community (64.6%) views wildlife as beneficial,” underscoring broad conservation support despite conflict pressures. Ethnicity significantly influenced overall wildlife perceptions ($p = 0.006$), while age showed no statistical effect. Bengali respondents demonstrated age-dependent increases in ecological awareness, whereas Indigenous respondents consistently emphasized functional and subsistence values across generations. HWC was reported by 45.4% of households, with conflict types varying significantly by ethnicity ($p = 0.0005$). Spatial analysis identified Rajapalang, Dhochori, and Inani beats as conflict hotspots. Perceptions of wildlife population trends were predominantly negative, with “most respondents identifying wildlife decline through direct observation,” attributing declines to habitat loss, encroachment, and resource scarcity. Stakeholders expressed strong support for co-management, highlighting community-based patrolling and awareness as key conservation mechanisms. Overall, the findings emphasise the need for culturally tailored, spatially targeted, and community-integrated conservation strategies to enhance coexistence and sustain wildlife populations in human-dominated forest landscapes.

Keywords: Forest Protected Area, Wild Mammal, Biodiversity, People Perception, Bangladesh

Introduction:

The 1972 UN Conference on the Environment held in Stockholm marked the first significant global recognition of human impact on the biosphere. Since then, numerous international agreements have sought to tackle biodiversity loss. In this case, Protected Areas (PAs) are the most widely used mechanism for combating global biodiversity loss. In 2010, the 193 Parties to the Convention on

Biological Diversity (CBD)¹ adopted the Strategic Plan for Biodiversity 2011–2020, establishing global targets for PA expansion from 13% to 17% terrestrial coverage by 2020 under the Aichi Biodiversity Targets (Rodríguez-Rodríguez & Martínez-Vega, 2022;). Acknowledging past shortcomings in PA expansion, the latest CBD guidelines emphasize that PAs should focus on sites of high biodiversity importance and ensure ecological representativeness. The set Target 3 of the CBD, building on Aichi Biodiversity Target 11, significantly raises global conservation ambitions, and it is up to us to increase land protection coverage from 17% to 30% (Protected Planet Report, 2024²).

Wildlife (mammals) comprises diverse species (e.g., deer, elephants, bears, and raccoons) that play essential roles in ecosystems worldwide and are a crucial element of Forest PAs (FPAs) ecosystems. Singh (2009, Ch. 1) compiled that the significance of wildlife is vital for ecosystem balance, biodiversity, and human well-being. While FPAs are popular for nature-based tourism and outdoor activities like hiking, mountain biking, and motorized recreation (e.g., all-terrain vehicles, snowmobiles) (Marion et al., 2024). Such activities offer economic and health benefits and influence various environmental components, including terrestrial wildlife (Liddle, 1997). Recreational use can impact wildlife in several ways, either facilitating movement along trails or causing displacement from critical habitats (Marion et al., 2024). The 2024 Living Planet Index³ reports a 73% average decline in wildlife populations from 1970 through 2020, highlighting the ongoing biodiversity crisis. The IUCN⁴ Red List of Threatened Species offers extensive data on the global status of mammal species, with recent assessments indicating that around 27% face the risk of extinction.

However, wildlife declines occur both within and beyond FPAs due to factors such as rapid human population growth, widespread deforestation, habitat loss, land fragmentation, infrastructure expansion, poaching, climate change, disease outbreaks, firearm proliferation, weak law enforcement, governance challenges, overgrazing, poverty, and inequality (e.g., Du et al., 2023; Habibullah et al., 2022). Expanding road networks globally threaten wildlife survival, particularly in PAs (Mtega et al., 2025). Fuelled by demand for food, products, and pets, wildlife trade is a primary global industry, with the illegal trade alone worth US\$ 7–23 billion annually. It affects biodiversity and human societies, as 800 million people in rural tropical regions depend on wildlife for sustenance (Hughes et al., 2023).

Wild mammals are diminishing faster than the expansion of FPAs, raising ongoing debates about their effectiveness in sustaining populations and enhancing biodiversity (Laurance et al., 2012; Geldmann et al., 2018; Williams et al., 2022). Research indicates that not all PAs provide the same protection (Dudley, 2008). Bangladesh's Inani Forest Protected Area (IFPA) is one of them (see section 2) and is classified as a national park under the IUCN Protected Area categories. Being a Party of CBD, Bangladesh is committed to expanding forest PA and conserving biodiversity. This forest

¹<https://www.cbd.int/decision/cop?id=12268>

² <https://digitalreport.protectedplanet.net/?chapter=2>

³ <https://ourworldindata.org/2024-living-planet-index>

⁴ <https://www.iucnredlist.org/>

PA serves as a vital Asian Elephant corridor between Myanmar and Bangladesh, officially recognized in Bangladesh as a key migration route (Kabir et al., 2021; IUCN Bangladesh, 2018). Notably, most Rohingya refugees (forcibly displaced Myanmar nationals) have established settlements in and around Inani PA, which the Bangladesh Government and the UN Refugee Agency manage (details in Kabir et al., 2021). Hence, the Guardian recorded 13 human fatalities against the human-elephant conflicts in this PA region due to the Rohingya settlement (Mukul et al., 2019).

In these circumstances, this study adopted the following two objectives to centralise the local stakeholders' perception on trends and sustainable conservation of wild mammals in the Inani PA.

1. To assess the public standpoints on increasing or decreasing trends in populations of wild mammals within the Inani Forest Protected Area.
2. To analyse the attitudes and motivations of local stakeholders towards sustainable wildlife conservation efforts in the Inani Forest Protected Area.

Concerning the SDG statement that humanity (i.e., Local Stakeholders) coexists with nature (i.e., Forest Protected Areas) and Wildlife, this study employs local stakeholder perceptions, which are crucial in guiding policymakers to make evidence-based decisions for the effective management and sustainable conservation of PA (e.g., Wey et al., 2022). Scholars have argued that conserving and protecting endangered wildlife is essential for maintaining healthy ecosystems, and that local communities' traditional knowledge and perceptions play a crucial role in sustainably conserving rare and threatened wildlife (Thien et al., 2024).

Therefore, this study will explore public perspectives and identify the key factors driving trends in wildlife mammals and conservation willingness using a survey questionnaire. The findings, which have significantly impacted conservation strategies, will inform policy recommendations to support effective conservation.

8.2. Materials and Methods

8.2.1. Study Area

The Inani Forest Protected Area (IFPA), administered by the Cox's Bazar Forest Division, covers around 7,085.16 hectares and is 26 kilometres south of Cox's Bazar (Kabir et al., 2021), boarded by Himchari National Park borders to the north, Teknaf Wildlife Sanctuary to the south, the Bay of Bengal to the west, and the Teknaf-Cox's Bazar highway to the east (**Figure 3.1 in chapter 3**) (Uddin et al., 2013).. This PA was designated in 2019 under Target 11 of the National Biodiversity Strategy and Action Plan (NBSAP) 2016-2021, which aims to expand the country's protected area network by 3% through terrestrial ecosystem (forest) conservation (CBD, 2019). Asian elephants (*Elephas maximus*), Western Hoolock Gibbons (*Hoolock hoolock*), and Phayre's Langur (*Trachypithecus phayrei*) are keystone mammals in this forest PA, which are critically endangered (Kabir et al., 2021). The park contains degraded evergreen to semi-evergreen forests, is marked by gently sloping hills formed by various geological formations, with distinct soil types ranging from clay and loamy soils to sandy soils (Miah & Hossain, 2022). IFPA has vital habitats for wildlife.

8.2.2. Study Design

This research assessed the status of wild mammals, management and conservation issues, and wildlife habitats using a social survey. Face-to-face structured interviews were conducted with local residents using a pre-developed interview guide (Friedrichs, 1990), thereby enhancing the reliability of responses and facilitating data aggregation and comparison (Bryman, 2016). A single-interview approach facilitated confidentiality, thereby encouraging participants to share insights into conflicts of interest and resource allocation. Sampling units were selected based on specific socio-demographic traits and experiences relevant to the research themes (Ritchie & Lewis, 2003).

The study aimed to understand local perceptions of mammal status by collecting local ecological knowledge from communities dependent on forest PAs, which often have valuable insights into the current and historical presence of wildlife (Zayonc & Coomes, 2022). It investigated multiple aspects of mammalian habitats, including wildlife sighting frequency, recent mammal disappearances, human-animal conflicts, conservation threats, forest conditions, human dependency on forests, co-management committee effectiveness, deforestation trends, and the impact of the Rohingya influx on wildlife. Scholars stated that the perception is a widely used social psychology approach in conservation that explores how values and attitudes shape individual behaviour, which is applied in diverse disciplines at the multilevel research (Thien et al., 2024). Experiential wildlife knowledge held by local communities and indigenous peoples enhances understanding of species and habitats, often bridging gaps in scientific data that may be inaccessible through conventional methods (Stern & Humphries, 2022).

A set of structured questionnaires was developed to align with the study objectives through consultations with experts, management authorities, and local stakeholders. They were presented and refined at a seminar, with input from experts and participants. The final version included clear, logically organised multiple-choice and short-answer questions and was built using KoboToolbox, a robust open-source platform suited for offline data collection in challenging environments. The tool was piloted prior to the main survey to confirm its functionality. A total of 271 individuals were interviewed between November 2022 and June 2024 via systematic random sampling, with each respondent signing an attendance sheet. Data were stored on the Kobo server and exported to Excel for cleaning and analysis.

The data were further analysed in long format, linking each coded statement to a unique respondent and stakeholder institution. Data imported from CSV files were cleaned, and respondent distributions were calculated based on the number of unique respondents per category. Challenge and recommendation themes were compared across stakeholder groups using respondent-level prevalence, summarised as proportions and visualised using heatmaps. Institutional differences in theme prevalence were tested using Fisher's exact tests (Fisher, 1922) with Reliability metrics (Cronbach's alpha and KR-20) (Cronbach, 1951; Kuder & Richardson, 1937) were calculated descriptively using binary respondent-by-theme matrices where sample size permitted.

Data analysis was performed using different packages of R, such as dplyr v1.1.4 (Wickham et al., 2023), the tidyverse v2.0 and ggplot2 v4.0.1 (Wickham, 2016). janitor v2.2.1 (Firke et al., 2024), scales v1.4.0 (Wickham & Seidel, 2022), viridis v0.6.5 (Simon Garnier et al., 2023), psych v2.5.6 (William Revelle, 2025) and broom v1.0.11 (Robinson et al., 2025)

8.3. Results

8.3.1. Socio-demographic characteristics of respondents

Table-8.1: Basic information on respondents' demography in the Inani Forest Protected Area

Demographic Particulars	Category	N	Percent
Age	18-30	43	15.90%
	31-40	67	24.70%
	41-50	77	28.40%
	50+	84	31.00%
Gender	Female	37	13.70%
	Male	234	86.30%
Ethnicity	Bengali	218	80.40%
	Indigenous	53	19.60%
Occupation	Business	36	13.30%
	Daily Labour	27	10.00%
	Driver	7	2.60%
	Farmer	154	56.80%
	Fisherman	3	1.10%
	Housewife	29	10.70%
	Job Holder	5	1.80%
	Jobless	3	1.10%
	Purohit	1	0.40%
	Retired	1	0.40%
	Retired	1	0.40%
	Student	3	1.10%
	The aged	1	0.40%
Monthly income	10001-19999	141	52.00%
	20000<	35	12.90%
	<10000	95	35.10%
Union	Jaliyapalang	137	50.60%
	Palangkhali	57	21.00%
	Rajapalang	77	28.40%
Living duration (years)	1 – 10	27	10.00%
	11 – 20	48	17.70%
	21+	196	72.30%

Demographic Particulars	Category	N	Percent
Range	Inani	170	62.70%
	Ukhiya	101	37.30%
Beat	Dhochori	44	16.20%
	Inani	41	15.10%
	Jaliyapalang	44	16.20%
	Mocharkhola	27	10.00%
	Rajapalang	39	14.40%
	Soyankhali	46	17.00%
	Thainkhali	30	11.10%

Table 8.1 briefly describes the respondents of this study area. The demographic profile of respondents indicates a predominantly older, male, and agrarian population with long-term residence in the study area. Nearly one-third of participants were aged 50 years and above (31.0%), followed by those aged 41–50 years (28.4%), suggesting substantial representation of mature and experienced community members. Males constituted the vast majority of respondents (86.3%), while females accounted for only 13.7%, reflecting potential gendered patterns in participation. Most respondents identified as Bengali (80.4%), with a notable proportion of Indigenous participants (19.6%), highlighting ethnic diversity within the area. Farming was the principal occupation (56.8%), followed by business (13.3%), housewife (10.7%), and daily labour (10.0%), indicating strong dependence on natural-resource-based livelihoods. Over half of the respondents reported a monthly income between 10,001–19,999 BDT (52.0%), while more than one-third earned less than 10,000 BDT (35.1%), underscoring generally low to moderate economic status. Spatially, half of the respondents resided in Jaliyapalang Union (50.6%), and most had lived in the area for more than 21 years (72.3%), suggesting deep-rooted connections to the landscape. The majority were from the Inani range (62.7%), with representation across multiple beats, particularly Soyankhali, Dhochori, and Jaliyapalang, ensuring broad spatial coverage of local perspectives.

8.3.2. Perception of the Significance of Wildlife

A majority of the community (64.6%) views wildlife as beneficial, indicating strong local recognition of its ecological and cultural value. However, nearly one-third (31.0%) perceives wildlife as harmful, likely due to direct experiences with human-wildlife conflict like crop raiding. The low level of uncertainty (4.4%) suggests well-established opinions, highlighting that while conservation support is high, mitigating negative interactions is critical for long-term coexistence. (**Figure 8.1**).

Community Perception of Wildlife Significance

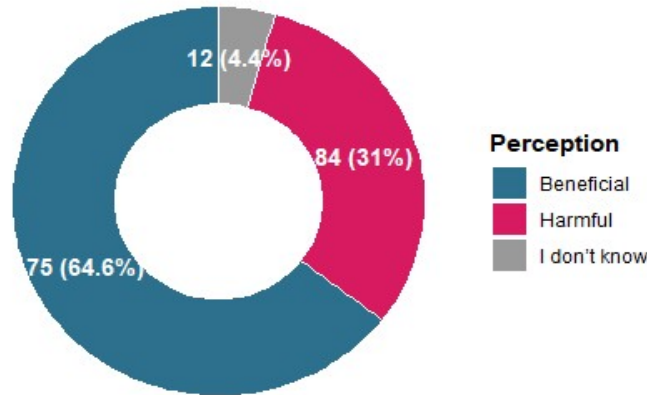


Figure 8.1: The significance of wildlife

8.3.2.1. Ethnic and Demographic Influence on Wildlife Perception

The aggregated classification of respondents' perceptions of wildlife (harmful, beneficial, and undetermined) shows a statistically significant association with ethnicity (Pearson's Chi-squared test with simulated p-values: $X^2 = 10.351$, $p = 0.006$), indicating that perception categories are not independent of ethnic identity (**Figure 8.2**). This suggests that Bengali and Indigenous respondents differ systematically in their views of wildlife, potentially reflecting differences in cultural context, livelihood practices, and historical interactions with wildlife. In contrast, no statistically significant association was observed between age group and wildlife perception ($X^2 = 9.99$, $p = 0.122$), indicating broadly similar perceptions across age categories. These results highlight ethnicity, rather than age, as a more salient factor shaping community perceptions of wildlife.

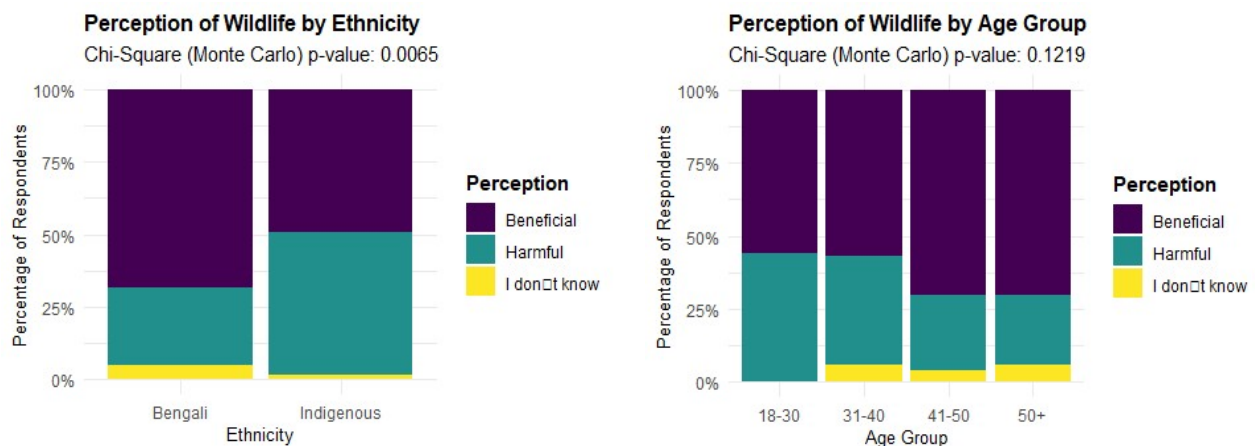


Figure 8.2. Ethnic and Demographic Influence on Wildlife Perception

8.3.2.2. Ethnic and Generational Variations in Ecological and Functional Perceptions

Analysis reveals distinct divergent patterns in the perception of wildlife's ecological and functional significance, mediated by both ethnicity and age (**Figure 8.3**). Among Bengali respondents, recognition of ecological balance correlates positively with age, increasing from 38.9% in the 18–30 cohort to 56.7% in the 50+ group. This suggests that awareness of foundational ecological roles strengthens with longitudinal experience. Furthermore, Bengali cohorts consistently acknowledge wildlife's role in forest protection, with peak recognition among respondents aged 41–50 (39.0%) and 50+ (40.3%). While aesthetic valuation—specifically natural beauty—remained stable (32–36%), specialised ecosystem services such as pollination, seed dispersal, and biodiversity enrichment were poorly understood, generally garnering less than 10% recognition across all Bengali age groups.

Conversely, Indigenous respondents prioritised functional significance, specifically forest protection, which emerged as the dominant perception across all age cohorts (44.4–57.1%). This indicates a deeply embedded, experiential understanding of wildlife as integral to forest integrity. Ecological balance was also highly recognised by both Indigenous youth (42.9%) and elders (41.2%), indicating cross-generational transmission of ecological knowledge. Notably, subsistence value (food supply) was cited more frequently by Indigenous respondents than their Bengali counterparts, particularly among younger and middle-aged groups (16.7–57.1%), highlighting a persistent, utility-based relationship with local fauna.

Ultimately, these findings suggest that while Bengali ecological awareness is progressive and age-dependent, Indigenous perceptions are consistently characterised by functional and subsistence-based values. Such disparities underscore the necessity of tailoring conservation education and engagement strategies to specific cultural contexts and demographic realities.

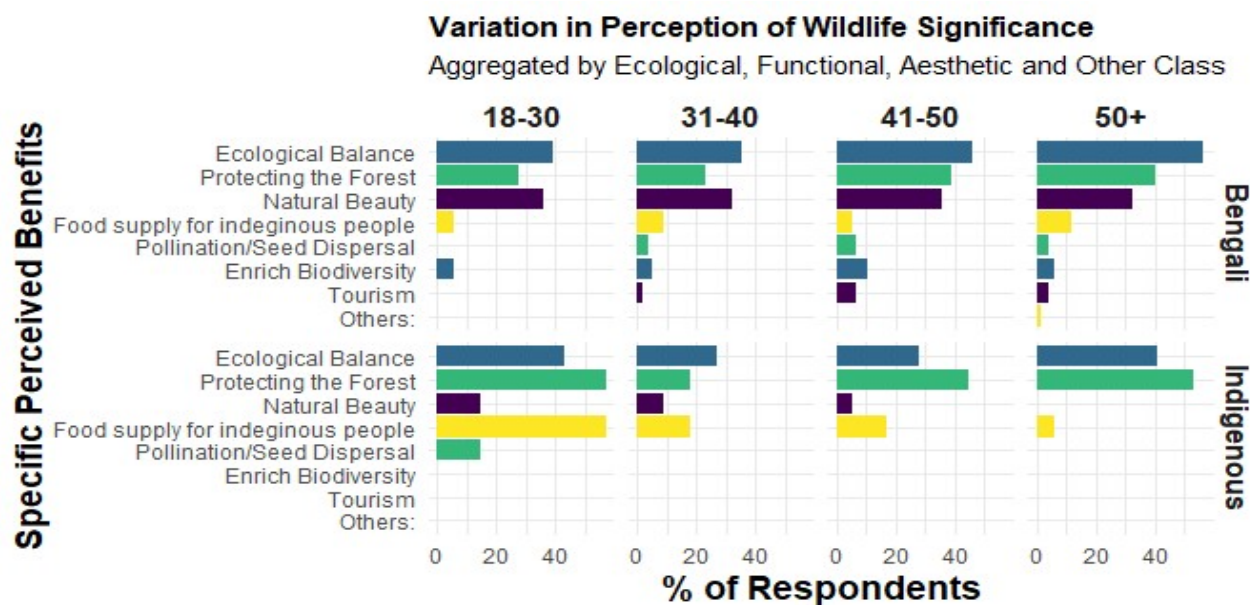


Figure 8. 3. Variations in Ecological and Functional Perceptions

8.3.3. Status of wildlife in Inani National Park

8.3.3.1. Summary of observation (increasing or decreasing)

The majority of respondents (83.8%) perceive wildlife populations as decreasing, while 14.0% believe they are increasing and only 2.2% consider them unchanged (**Figure 8.4**). This indicates a strong local perception of a decline in wildlife in the area.

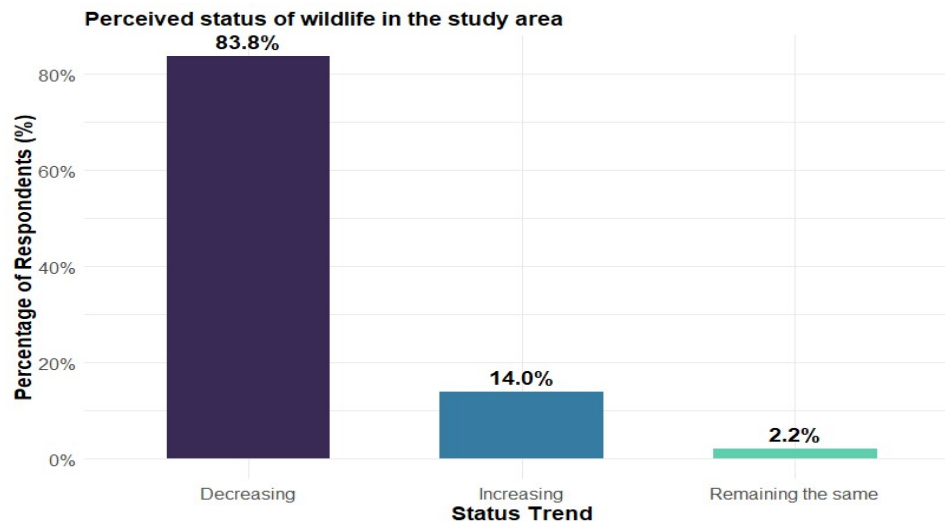


Figure 8.4. Perceived status of wildlife in the study area

8.3.3.2. How do the respondents understand that wildlife is declining, and why?

Most respondents identified wildlife declines through direct observation: 57.5% reported seeing wildlife less frequently (**Figure 8.5**). Others relied on community information (19.2%), noted that wildlife no longer emerges from forests (13.2%), or observed the disappearance of certain species (7.0%). Media and other sources played a minimal role, indicating that perceptions of decline are mainly experience-based.

Respondents also identified multiple drivers underlying the perceived decline in wildlife populations, with habitat-related pressures emerging as the most prominent. Habitat loss was the leading cause (30.1%), followed closely by encroachment into forest areas (25.4%), indicating widespread concern about land-use change and the degradation of natural environments. Ecological stressors such as food scarcity (15.8%) and water scarcity (5.1%) were also frequently cited, reflecting deteriorating habitat quality. A notable proportion of respondents attributed wildlife decline to natural mortality (12.4%), while smaller shares pointed to anthropogenic exploitation, including Indigenous hunting/eating (7.5%) and poaching (2.6%). Overall, the findings suggest that respondents primarily perceive wildlife decline as being driven by habitat degradation and resource scarcity, with direct hunting and illegal activities viewed as secondary but still relevant factors.

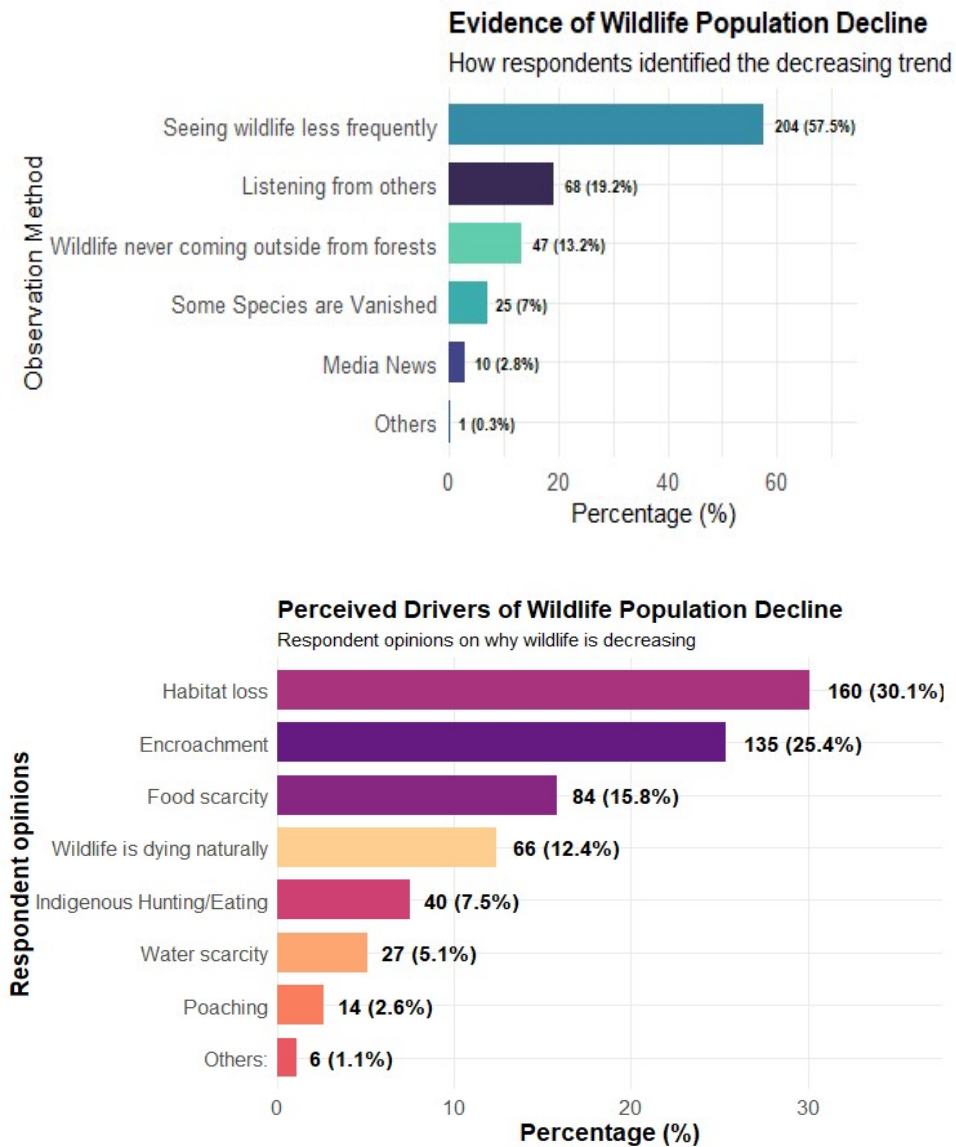


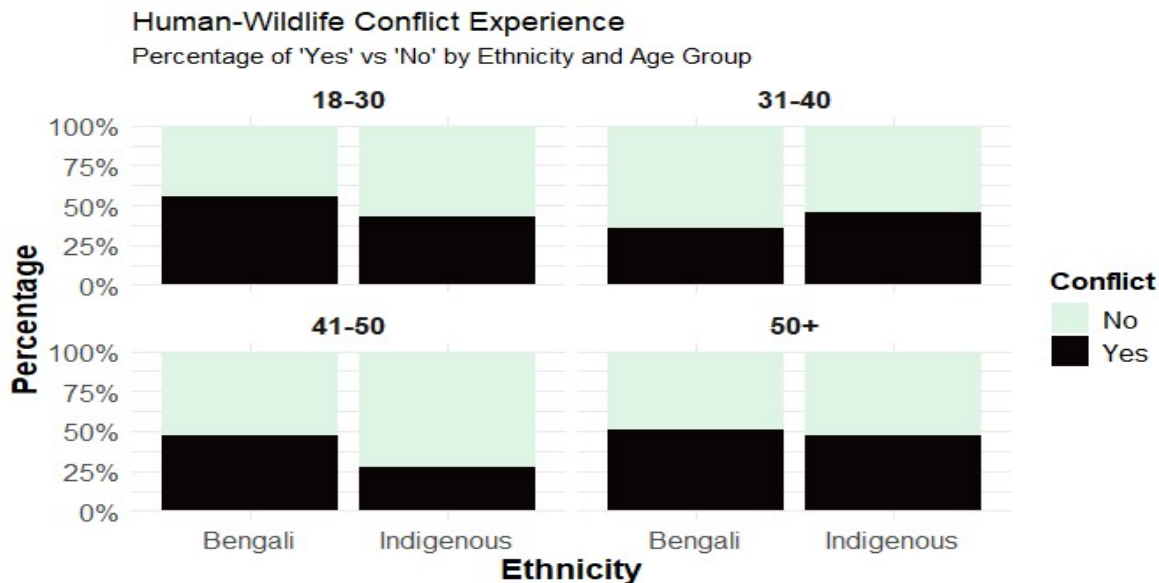
Figure 8.5. Evidence and causes of wildlife declining

8.3.4. Human-wildlife conflict in Inani Protected Forest Area

Human–wildlife conflict (HWC) is a prevalent issue in the study area, with 45.4% of respondents reporting personal or familial conflicts in the preceding decade. While 54.6% of the population reported no such interactions, the substantial minority experiencing conflict indicates a significant interface between local communities and wildlife.

8.3.4.1. Demographic Drivers of Conflict

Analysis of conflict experience by ethnicity revealed moderate variation: 46.8% of Bengali respondents reported HWC incidents compared to 39.6% of Indigenous respondents (**Figure 8.6**). Age-based distributions showed that the 18–30 cohort reported the highest prevalence (53.5%), whereas the 31–40 group recorded the lowest (37.3%). However, inferential statistics confirm that these demographic variables are not primary determinants of conflict exposure. Chi-square test results for both ethnicity ($p = 0.358$) and age group ($p = 0.277$) exceeded the $\alpha = 0.05$ significance threshold, suggesting that the occurrence of HWC is statistically independent of these factors.



8.3.4.2. Typology of Conflict and Ethnic Variation

The primary manifestations of HWC are livelihood-oriented rather than life-threatening. Crop damage is the most frequent conflict type (53.3%), followed by household damage (26.6%) and predation of domestic animals (10.3%). Physical injuries to humans (7.1%) and fatalities or the retaliatory killing of wildlife ($\approx 1\%$) remain rare (**Figure 8.7**).

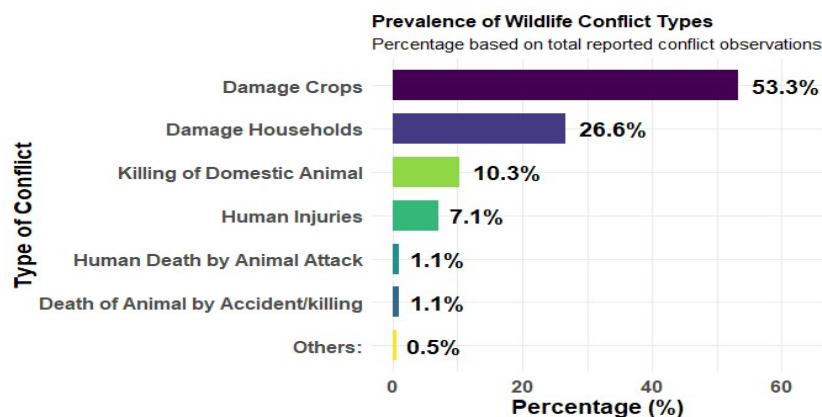


Figure 8.7. Prevalences of wildlife conflict types

Despite the lack of association between ethnicity and the *occurrence* of conflict, the *nature* of the conflict varies significantly by ethnic group (Fisher's Exact Test, $p = 0.0005$). Among Bengali households, crop damage (57.9%) and property damage (28.9%) predominate. In contrast, Indigenous respondents identified the killing of domestic animals (60.0%) as their primary conflict concern, with crop and household damage being markedly less frequent. This divergence highlights distinct patterns of vulnerability and resource use between the two groups.

Conversely, age does not significantly influence the type of conflict experienced ($p = 0.771$). Crop damage remains the leading concern across all age cohorts (47.2%–60.6%), though older respondents (50+) reported a slightly broader range of incidents, including a higher relative frequency of human injuries (10.4%) (**Figure 8.8**).

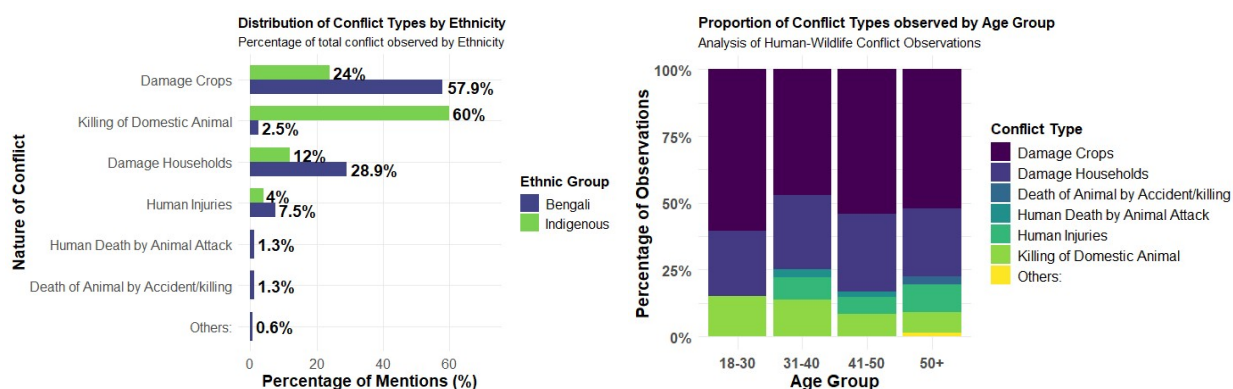


Figure 8. 8. Observation varied in conflicts between ethnic groups and age groups

8.3.4.3. Spatial Distribution and Management Implications

Conflict incidents exhibit significant spatial heterogeneity at the administrative beat level. Rajapalang (18.1%, $n = 49$), Dhochori (16.3%, $n = 44$), and Inani (11.1%, $n = 30$) were identified as primary conflict hotspots. Moderate levels were recorded in Soyankhali (8.9%) and Thainkhali (5.6%), while Mocharkhola (4.8%) and Jaliyapalang (3.3%) reported the lowest frequencies (**Figure 8.9**).

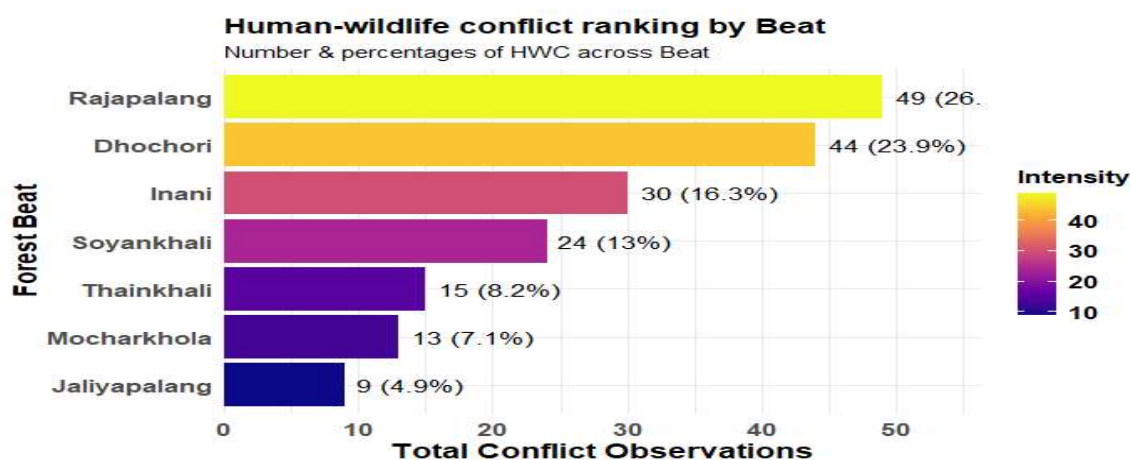


Figure 8. 9. Beat-wise (Local Forest office) human-wildlife conflict

These findings underscore the necessity for the Forest Department to implement spatially targeted mitigation strategies, prioritizing high-Figure 8.10. incidence beats to effectively reduce human-wildlife friction.

8.3.5. Perceptions of Wildlife Conservation Initiatives

Stakeholders proposed a diverse set of conservation initiatives, with strong emphasis on habitat- and resource-based interventions. Habitat improvement emerged as the top priority (29.6%), followed by food-providing plantations (23.9%), indicating widespread recognition of the need to enhance habitat quality and resource availability for wildlife (**Figure 8.10**).

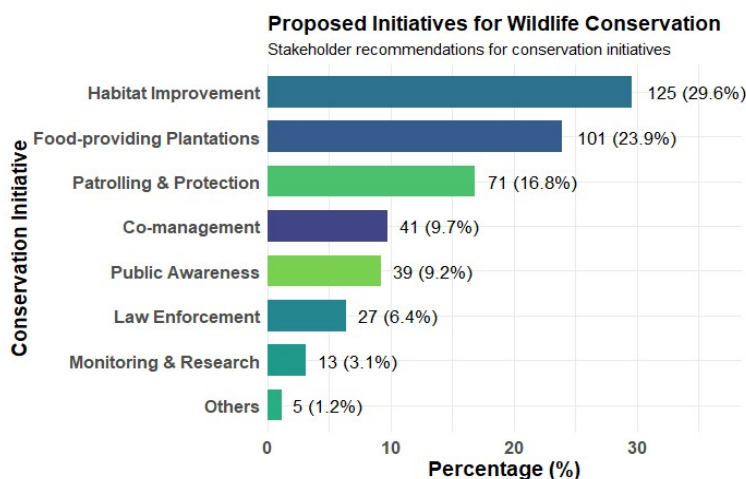


Figure 8.10. Perception-based wildlife conservation initiatives

Management and protection measures were also prominently suggested, including patrolling and protection (16.8%), reflecting concerns over illegal activities and disturbance. Community-oriented approaches such as co-management (9.7%) and public awareness (9.2%) received moderate support, highlighting the perceived importance of local involvement and education. Fewer respondents emphasized law enforcement (6.4%) and monitoring and research (3.1%), while only a small proportion proposed other measures (1.2%). Overall, the recommendations suggest that stakeholder's priorities practical habitat enhancement and on-ground protection, complemented by participatory and awareness-based strategies.

A Kuder-Richardson 20 (KR-20) coefficient was computed to assess the internal consistency of respondents' choices regarding conservation initiatives. The resulting coefficient ($\alpha = 0.04$) indicates very low internal consistency. This suggests that the proposed conservation initiatives represent a diverse set of independent strategies rather than a unified scale. Stakeholders prioritized distinct, heterogeneous interventions, ranging from habitat-based to enforcement-based solutions.

A binary logistic regression was performed to identify predictors of human-wildlife conflict within the study area. The lowest official unit of the Bangladesh Forest Department (Beat) was a significant predictor of conflict, whereas ethnicity was not ($p = 0.242$). Specifically, respondents in Jaliyapalang Beat were significantly less likely to experience conflict than the reference category (OR = 0.131, $p < 0.001$), corresponding to an 86.9% reduction in odds. Similarly, the Soyankhali Beat showed a significantly lower likelihood of conflict (OR = 0.415, $p = 0.048$) (Figure 8.11).

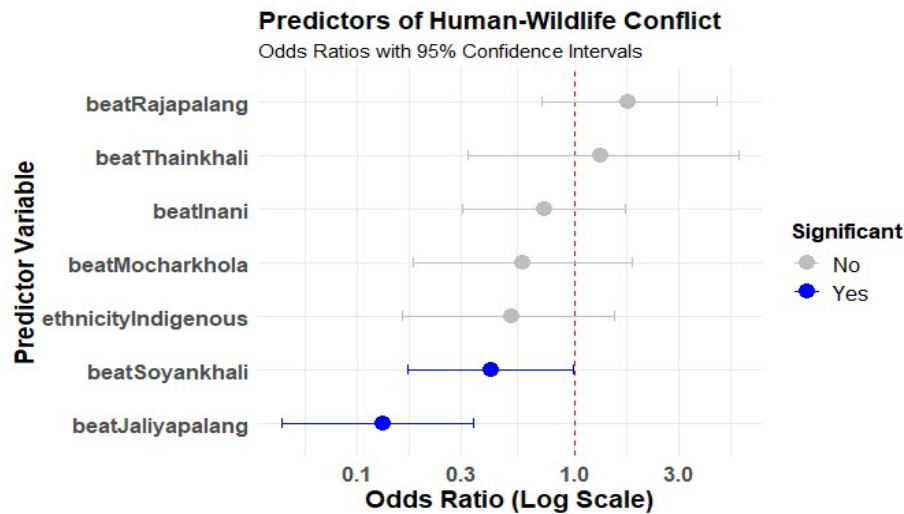


Figure 8.11. Predictor of Human-Wildlife Conflict

These findings suggest that conflict risk is strongly localized and influenced by spatial or environmental factors unique to specific forest beats.

8.3.6. Effectiveness of co-management and community-based forest conservation in wildlife conservation

Stakeholders' perceptions of the effectiveness of co-management and community-based forest conservation in protecting forest resources. The vast majority of respondents (90.0%) affirmed that such approaches are effective, indicating strong local support for participatory and collaborative management frameworks (Figure 8.12).

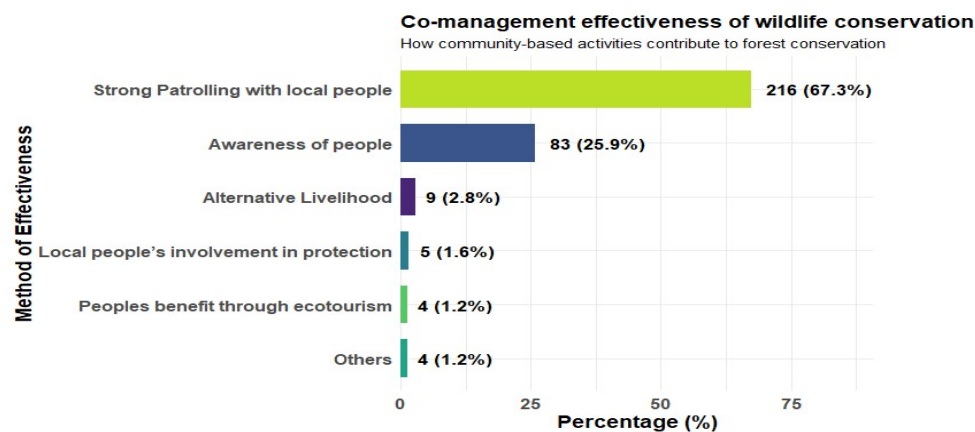


Figure 8.12. Co-management effectiveness of wildlife conservation

A small proportion of respondents were unsure (9.6%), suggesting some uncertainty or limited exposure to the outcomes of these initiatives, whereas only 1 respondent (0.4%) perceived them as ineffective. Overall, these findings highlight broad stakeholder confidence in co-management and community-based strategies as viable and impactful tools for forest conservation, underscoring their importance for future policy and programmatic interventions.

Stakeholders identified community-based patrolling as the most influential mechanism through which co-management contributes to wildlife and forest conservation, with over two-thirds of respondents (67.3%) emphasising the importance of strong local patrolling. This highlights the perceived importance of joint surveillance and on-ground collaboration between communities and management authorities. Awareness-raising among local people was the second most frequently cited contribution (25.9%), indicating recognition of education and sensitisation as key drivers of positive conservation behaviour. In contrast, relatively few respondents cited alternative livelihoods (2.8%), direct local involvement in protection (1.6%), or benefits from ecotourism (1.3%), suggesting that these aspects are either less visible or less developed in practice. Overall, the findings suggest that co-management is viewed primarily as effective through strengthening local patrolling and awareness, reinforcing the central role of community engagement in wildlife conservation.

8.4. Discussion

8.4.1. Perception of the Significance of Wildlife

Most respondents recognize wildlife as beneficial, reflecting a strong appreciation of its ecological and cultural importance to the community. At the same time, nearly one-third view it as harmful, probably stemming from direct negative encounters such as crop raiding and other forms of human-wildlife conflict (**Figures 8.1, 8.2 & 8.3**). In India, many communities perceive wildlife as both ecologically valuable and culturally significant, even when conflicts arise (Karanth & Nepal, 2012). In Nepal, local populations often express strong cultural reverence for wildlife, rooted in religious and traditional beliefs (Bhattarai & Fischer, 2014). Across Africa and Latin America, communities recognise wildlife as essential for ecosystem functioning and cultural heritage (Marchini & Macdonald, 2012). Crop raiding by elephants, wild boar, and monkeys is a major driver of negative perceptions in Sri Lanka, India, and Nepal (Fernando et al., 2005; Barua et al., 2013). In Bangladesh, negative encounters—especially crop damage—strongly shape attitudes toward wildlife (Chowdhury et al., 2014). Human-wildlife conflict is a leading cause of negative attitudes worldwide, particularly in regions where livelihoods depend on agriculture (Inskip & Zimmermann, 2009).

The study analysis identifies clear divergent patterns in how respondents perceive the ecological and functional importance of wildlife, with these differences significantly influenced by ethnicity and age. Ethnic groups in Nepal and India differ significantly in their perceptions of wildlife, shaped by cultural norms, traditional knowledge, and livelihood strategies (Rohini et al., 2016). Sociodemographic factors—especially ethnicity, age, and livelihood—strongly shape attitudes toward wildlife across continents (Kansky & Knight, 2014). On the other hand, age influences attitudes: younger respondents often show more conservation-oriented views, while older individuals

may prioritise livelihood security (Sekhar, 2003). In Bangladesh, villagers frequently associate wildlife with ecosystem health and cultural identity (Shawon et al., 2025).

Most importantly, wildlife tourism emphasises the emotional, psychological, and physical benefits of wildlife-focused travel, offering a distinct and valuable insight into a rapidly expanding market (Curtin, 2005). PAs attract around 8 billion annual visitors globally, highlighting their key role in nature-based tourism, especially wildlife tourism, which offers valuable insight into how biodiversity supports recreation (Arbieu et al., 2018). In this study, respondents neglected the significance of tourism.

8.4.2. The trend of Wildlife in the study area

84% of respondents strongly perceived that wildlife is declining within the Inani FPA due to multiple factors (**Figures 8.4 & 8.5**). In this case, the Living Planet Index (LPI)⁵ monitors nearly 35,000 populations across 5,495 vertebrate species from 1970 to 2020. Freshwater ecosystems have experienced the most dramatic decline, at 85%, followed by terrestrial populations at 69% and marine populations at 56%. Mahmood et al. (2021) also studied the widespread defaunation that has dramatically altered the distribution of Asian megafaunal species, with many PAs losing all or most of their historically present mammals. Striking examples include the complete loss of species in the Tonle Sap Biosphere Reserve (Vietnam), the Dahongshanyinxing and Poyanghuhouniao Nature Reserves (China), Wu Ling Yuan (China), and several sites in India, Pakistan, and Iran—illustrating a broader trend evident across numerous other PAs.

However, respondents reported that encroachment, food scarcity, habitat loss, hunting, poaching, water scarcity, natural mortality, deforestation, and jhum cultivation are the primary factors contributing to declines in wildlife in the study area. Habitat loss is the leading cause of the decline in wild mammal populations due to the inducing factors, e.g., shifting cultivation, illegal logging, hill cutting, growing natural invasive species (e.g., *Mikania cordata*) and fuel wood collection. Field observations corroborated the documented habitat loss activities, which were photographed (**Figure 8.13**). This result also supports that habitat degradation—primarily driven by deforestation for development—is the leading human-induced factor behind species extinctions, with agriculture as the foremost global driver, followed by urban expansion, logging, mining, and certain fishing practices (Primack, 2006). Furthermore, invasive species harm ecosystems in many ways — they drive extinctions, change species communities, and alter ecosystem functions. Climate change and land-use changes facilitate their spread (Crowl et al., 2008). Another root cause was identified, i.e., encroachment, which is associated with settlement, agricultural expansions, betel leaf plantations, and road construction inside the Inani PA. In this case, expanding human populations and escalating resource demands are intensifying pressures on PAs, with land-use change as a key indicator of the scale and severity of these impacts (Watson et al., 2015).

Community members noted that food scarcity is one of the contributing factors to the decline in wild mammals, associated with tree cutting, overexploitation, a lack of prey species, and the destruction

⁵ [Catastrophic 73% decline in the average size of global wildlife populations in just 50 years reveals a ‘system in peril’ | Press Releases | WWF](#)

of nests, eggs, and nesting trees. Natural death, along with illegal hunting, stands out as a minor contributing factor to declining wildlife. Respondents mentioned that natural death occurs due to natural threats, including cyclones, forest fires, floods, siltation, climate change effects (i.e., increase of CO₂ due to forest fires and burning of habitat), and different types of diseases among wildlife. Collins & Kays (2011) reported that anthropogenic factors accounted for the highest proportion of known mortality (51.8%), closely followed by natural causes (predation – 35%, disease – 4%, starvation – 3%, and other natural – 6%) at 48% in North America. Additionally, extreme temperature shifts were linked to higher local extinction rates of mammals such as gibbons, macaques, tigers, and water deer, with researchers suggesting that historical cooling affected northern and western tiger subspecies, whereas current global warming may drive their extinction in southern China (Wan et al., 2019). A 2023 study found that by 2100, climate-induced aridification under the high-emissions SSP5–8.5 scenario could lead to habitat loss for 50.3% of mammals—with 9.5% losing over half and 3.2% losing all of their habitat—while these impacts lessen under the intermediate SSP2–4.5 and high-mitigation SSP1–2.6 scenarios, affecting 38.27%, 4.96%, 2.22% and 22.65%, 2.03%, 1.15% of species respectively (details in Liu et al., 2023).

The respondents perceived that illegal hunting contributes to the decline in wild mammal populations in the study area. Extensive research shows that anthropogenic threats such as logging, hunting, cropland conversion, and livestock grazing severely impact wildlife both inside and outside FPAs, causing sharp declines in mammal populations—up to 80% from hunting and 30% due to land use changes—and disrupting ecological networks, especially in tropical forests and savanna biomes (Rija et al., 2020). However, the 40 years of global research revealed that 294 mammal species were illegally hunted across 155 PAs in 48 countries, based on 81 studies involving 988 species-site combinations (Rija et al., 2020). In contrast, few respondents attributed declines in local mammal populations to water scarcity, poaching, or other minor factors. Although no robust scientific evidence supports the purported therapeutic efficacy of products derived from endangered species—such as rhino horn, bear bile, tiger bones, or pangolin scales—these items continue to be valued in certain traditional medicine systems, perpetuated by longstanding cultural beliefs and myths. Such persistent demand sustains illegal wildlife trade and poaching, thereby accelerating population declines and contributing substantially to global biodiversity loss (Abdulabad et al., 2025).



Habitat Loss: Invasive species and Illegal logging



Encroachment: Betel leaf cultivation and building houses inside the Protected Area

Figure 8.13. Field observation captured some photos of threatening activities for declining wild mammals

8.4.3. Perceptions of Wildlife Conservation Initiatives

Local communities are willing to conserve wild mammals, and a suggested number of initiatives should be implemented within the IFPA. Habitat improvement and food-providing plantations are prioritised, followed by patrolling and protection, co-management, public awareness, law enforcement, monitoring, and research (**Figure 8.10**). Respondents believe that habitat improvement could contribute to wildlife conservation and preservation through ecological restoration, such as reforestation, erosion control, and water source management, which are critical for sustaining mammal biodiversity. Mérő et al. (2015) argued that a patchwork of restored and well-managed grasslands with tall vegetation offers the greatest potential for sustaining small mammal populations in rapidly changing landscapes. Mammal and bird species tend to be more diverse and abundant in plantations with a well-developed understory than those lacking vegetative layers (Ramírez & Simonetti, 2011; Simonetti et al., 2013).

On the other hand, local communities emphasized food-providing plantation as wildlife management and conservation initiatives. This reflects that establishing native vegetation and fruit-bearing trees helps supply consistent food sources for wild animals, supports habitat restoration, and reduces human-wildlife conflict. Species richness and abundance in forestry plantations are closely linked to structural complexity—such as understory vegetation, native remnants, and multiple strata—which supports a greater diversity of native fauna including birds, small mammals, and invertebrates (Ramírez & Simonetti, 2011). A systematic literature review across nine countries found a shared commitment to wildlife conservation for biodiversity preservation, though public awareness strategies vary culturally and institutionally, with effective approaches including mass media campaigns, educational programs, and locally inspired storytelling to engage communities (Altamira & Koester, 2024).

Prioritization suggests that patrolling and protection are considered the cornerstones of the conservation strategy, likely aimed at deterring poaching, illegal hunting, and encroachment. As Bruner et al. (2001) studied 93 PAs in 22 tropical countries and argued, patrolling is effective only when integrated with broader ecological management and community engagement. BFD has been practicing the Community Patrol Groups (CPGs) mechanisms associated with the BFD's personnel since 2006 in several PAs in Bangladesh, which were legislated in 2017 through adopting PA management rules, even though field observation experienced huge debates of proper CPG functionality due to insufficient patronization from BFD and mistrust between local communities and BFD personnel.

Law enforcement and co-management received limited attention from local people, shockingly, suggesting that participatory governance and a legal framework could undermine the effectiveness of conservation. A co-management governance mechanism has been implemented in the IFPA since 2009⁶. Co-management is widely embraced for its collaborative approach to resolving resource conflicts, but faces criticism for design flaws, elite dominance, and limited community influence, especially in top-down systems. However, that result aligns with the fact that, though applied in

⁶ [Alternative livelihoods boosting Inani Forest conservation](#), accessed on 15.06.2025

Bangladesh for over two decades with reported successes, doubts remain about its long-term effectiveness and equity, emphasizing the need to strengthen social capital for lasting and inclusive governance (see details in Baten, 2024). Historically, the BFD's inability to enforce legal mandates has been primarily attributed to persistent understaffing and its reliance on short-term development projects, which account for over 80% of its budget, thereby compromising financial independence and sustainable long-term planning (Sarker & Rodrigo, 2014; Sarker et al., 2017).

Importantly, respondents were asked separately about co-management effectiveness; the majority identified community-based patrolling as the most influential conservation mechanism (**Figure 8.11**). Contemporary studies show that co-management frameworks significantly strengthen forest protection by enhancing local surveillance, reducing illegal extraction, and improving rule compliance (Jashimuddin et al., 2022; Islam et al., 2022). In Bangladesh's forest protected areas, CPGs have been particularly effective in reducing forest degradation and wildlife poaching, mirroring the dominant preference for patrolling observed in this study. Overall, the results reinforce a growing regional consensus that co-management is most effective when it strengthens local stewardship and participatory monitoring, while livelihood diversification and equitable benefit-sharing require greater institutional investment to achieve long-term conservation outcomes.

Surprisingly, a limited number of respondents mentioned monitoring and research, indicating a limitation in local communities' ability to assess conservation outcomes and adapt strategies accordingly. Monitoring and research can only detect that terrestrial and semi-aquatic mammals are increasingly threatened by a range of human-induced pressures, including habitat loss, fragmentation, environmental pollution, climate change, and the spread of non-native invasive species (Pacifici et al., 2020). This conservation initiative can accurately quantify species distributions and conservation status, a foundational component of evidence-based conservation planning, enabling targeted strategies to mitigate biodiversity loss and prioritise effective management interventions.

8.5. Conclusion and policy implications

The Inani Forest Protected Area, located within the Indo-Burma biogeographic transition zone of southeastern Bangladesh, remains a critical refuge for threatened mammal species. However, stakeholder perceptions indicate a persistent decline in wildlife, driven primarily by habitat degradation, encroachment, deforestation, illegal resource extraction, and human–wildlife conflict. These locally observed pressures are consistent with broader global evidence identifying land-use change and weak governance as central drivers of biodiversity loss in protected areas (Laurance et al., 2012; Pacifici et al., 2020).

Addressing these challenges requires integrated and context-specific management interventions. Priority actions include controlling habitat fragmentation, strengthening law enforcement against poaching and encroachment, removing invasive species, and institutionalizing systematic monitoring and patrolling. Ecological restoration through afforestation and reforestation is essential to enhance habitat quality and resilience (Primack, 2006). At the same time, mitigating human–wildlife conflict

through spatially targeted and livelihood-sensitive measures is critical for sustaining community support (Inskip & Zimmermann, 2009).

The study highlights strong local endorsement of participatory governance, particularly co-management and community-based patrolling. Evidence from Bangladesh and other tropical contexts demonstrates that inclusive governance frameworks can enhance compliance, reduce illegal extraction, and improve conservation outcomes when supported by clear mandates and accountability mechanisms (Jashimuddin et al., 2022; Islam et al., 2022). Strengthening institutional capacity—through professional training, financial sustainability, and investment in research and adaptive monitoring—remains fundamental for effective protected area governance.

In sum, sustainable conservation in IFPA depends on integrating ecological restoration with strengthened governance, participatory management, and development-sensitive conflict mitigation, supported by coordinated multi-stakeholder engagement and long-term institutional commitment.

Chapter 9

Study 7.

FOREST GOVERNANCE IMPLEMENTATION CHALLENGES IN PROTECTED AREAS OF SOUTHEAST BANGLADESH

Abstract

Protected areas are central to global biodiversity conservation strategies, yet their effectiveness is often shaped more by governance conditions than by ecological design. This study examines governance dynamics in Inani National Park (INP), a newly gazetted protected area in southeastern Bangladesh. Drawing on 43 semi-structured interviews with stakeholders from government agencies, law enforcement authorities, local administrations, community-based organisations—including local elites and resource users—and national and international non-governmental organisations, we assess perceived management challenges, coordination gaps, and pathways for improvement. Findings indicate that inadequate logistical support and staffing capacity within the Bangladesh Forest Department represent the most critical constraints (54.6%), followed by broader governance inefficiencies (27.3%) and weak inter-agency coordination (18.2%). Stakeholder recommendations focused on strengthening institutional capacity (63.6%), enhancing law enforcement effectiveness (29.6%), and expanding alternative livelihood opportunities to reduce pressure on forest resources (22.7%). Lessons derived from stakeholder experience underscore the importance of co-management arrangements, meaningful community participation, and local government engagement, alongside recognition of biodiversity conservation as a shared global responsibility. By situating these findings within international debates on the conservation “implementation gap,” this study demonstrates how institutional capacity, participatory governance mechanisms, and cross-sectoral collaboration interact to shape conservation outcomes in newly designated protected areas. The INP case advances global scholarship on protected area governance and offers practical insights for aligning national conservation commitments under the Convention on Biological Diversity and the Sustainable Development Goals with site-level realities in the Global South.

Keywords: Protected area governance; Co-management; Institutional capacity; Stakeholder participation; Implementation gap; Global South.

Introduction

Protected areas (PA) remain one of the most widely adopted strategies for conserving biodiversity, sustaining ecosystem services and strengthening climate resilience (Watson et al., 2014; Dudley, 2008). However, despite their widespread growth worldwide, many P A fail to achieve their conservation objectives, often due not to ecological limitations but to governance challenges, institutional weaknesses and limited stakeholder engagement (Coad et al., 2019). Consequently, conservation research increasingly highlights the central role of PA governance—the frameworks of rules, decision-making processes, institutions, and accountability arrangements that guide management—in shaping both ecological and social outcomes (Borrini-Feyerabend et al., 2013).

From this perspective, governance quality is not a secondary concern but a core determinant of legitimacy, equity, and effectiveness in PA management (Oldekop et al., 2016).

Governance challenges are especially acute in the Global South, where biodiversity conservation often intersects with poverty alleviation, land-use conflicts and fragile political institutions (Laurance et al., 2012; Bennett & Dearden, 2014). In many protected areas across South and Southeast Asia, these challenges are clearly evident. Although policy reforms have promoted co-management and participatory governance approaches, their practical effectiveness is frequently undermined by overlapping institutional responsibilities, limited financial resources, weak enforcement capacity, and ongoing tensions between conservation goals and local livelihoods (Persha et al., 2011). As a result, an “implementation gap” emerges, as described by Clement (2010), in which progressive governance arrangements are formally adopted but struggle to translate into meaningful outcomes due to constraints such as unequal power relations, insufficient resources, and limited social legitimacy.

Forest governance is a critical component of effective conservation, encompassing the interactions among state and non-state actors, the institutional frameworks within which they operate, and the processes through which decisions are made (Hayes & Persha, 2010). According to Kanowski et al. (2011), sound forest governance is characterized by core principles such as accountability, inclusive participation, and transparency.

Co-management has emerged as a widely adopted approach to local-level forest governance across several Asian and African countries, with evidence of positive conservation outcomes in multiple contexts. For instance, community-managed forests in Bhutan have been shown to support sustainable resource extraction while promoting forest regeneration (Moktan et al., 2016). Similarly, community-managed forests often exhibit superior forest structural conditions compared to those under exclusive state management. In India, an assessment of four Joint Forest Management (JFM) models in Odisha reported an overall forest governance performance of 77%, with an identified governance gap of 23% (Mohanty & Sahu, 2012). In Nepal, community forestry initiatives have contributed significantly to reducing deforestation and enhancing forest cover (Shrestha et al., 2018). Comparable findings have been reported from Tanzania, where community-based forest management outperformed state-led management in terms of forest outcomes (Mbwambo et al., 2012). Likewise, a study from Malawi indicated that most respondents perceived co-management to have improved forest conditions, countering a broader trend of forest degradation (Chinangwa et al., 2017). However, despite its overall potential, the effectiveness of co-management arrangements varies across contexts, largely influenced by pre-existing institutional conditions and community perceptions and interpretations of the management framework.

Conversely, in several countries, co-management arrangements have not succeeded in meeting their intended goals and objectives. For example, Magessa et al. (2020) found that participatory forest management in Tanzania failed to deliver effective governance outcomes or achieve meaningful devolution of authority. Similarly, evidence from Malawi indicates continued forest cover loss within co-managed forests (Gondwe et al., 2020). In Indonesia, community-based forest management initiatives were unable to ensure social equity or provide adequate logistical and institutional support to participating communities (De Royer et al., 2018). Cronkleton et al. (2012) further argued that co-

management systems may fail when responsibilities are transferred to non-state actors without corresponding rights, incentives, or benefits. Additionally, a regional assessment from the Greater Mekong Sub-region identified persistent challenges to good forest governance, particularly in relation to implementation, enforcement, and regulatory compliance (Gritten et al., 2019).

Numerous studies in Bangladesh have examined the outcomes and effectiveness of protected area (PA) co-management across diverse contexts, yielding mixed results. Several assessments have reported limited or negative conservation outcomes. For instance, Islam et al. (2019a) found that co-management approaches failed to halt or significantly reduce forest cover loss in several key co-managed PA. Similarly, Ahmed et al. (2020) documented continued forest cover decline in co-managed forests, contrasting with forest cover gains in conventionally managed areas. Islam et al. (2020) further reported that reserve forests without co-management interventions exhibited higher biodiversity status than co-managed PA. In addition, multiple studies have highlighted institutional, social, and operational constraints affecting co-management effectiveness in Bangladesh (Islam et al., 2021). In contrast, other studies have documented positive outcomes of co-management as a form of local-level forest governance. Chowdhury et al. (2020) reported increases in forest cover within certain co-managed PA. Moreover, co-management initiatives have been shown to enhance community participation in conservation and to positively influence species richness and abundance, particularly in Lawachara National Park (Ferdous, 2015). Positive conservation outcomes were also observed in Teknaf Wildlife Sanctuary, where co-management was found to improve management effectiveness and forest conditions (Alam et al., 2015).

Bangladesh represents a critical case within this broader context. As part of the Indo-Burma biodiversity hotspot, the country has designated many protected areas under the Wildlife (Conservation and Security) Act, 2012. However, many of these sites are newly established and located in resource-constrained regions where institutional and socio-economic challenges are severe (Rahman, 2022). In Bangladesh, community involvement in natural resource management can be traced back to the 1980s through participatory forestry initiatives. However, co-management was formally institutionalized in 1999 with the implementation of the Management of Aquatic Ecosystems through Community Husbandry (MACH) project in three wetland sites, with financial and technical support from USAID. Lessons learned from the MACH experience informed the pilot introduction of co-management in forest protected areas in 2004, initially covering five sites—Lawachara National Park, Rema-Kalenga Wildlife Sanctuary, Satchari National Park, Chunar Wildlife Sanctuary, and Teknaf Game Reserve—under the USAID-funded *Nishorgo Support Project* (NSP). Since its adoption, a substantial body of research has documented the positive contributions of co-management to livelihood enhancement, biodiversity conservation, and the reduction of land-use conflicts in Bangladesh (Jashimuddin et al., 2022; Mukul et al., 2012). These findings are broadly consistent with assessments by the Forest Department, which highlight improvements in local socioeconomic conditions and conservation outcomes under co-management regimes. Nevertheless, other studies have questioned the long-term sustainability and governance robustness of co-management, identifying persistent challenges related to equitable power sharing, land tenure insecurity, and the limited political empowerment of local communities (Kabir et al., 2021; Ullah et al., 2022).

Although co-management frameworks have been introduced through initiatives such as the Nishorgo Network and the Protected Area Management Rules (2017), marks its transition from experimental phases to an established method for managing protected areas (USAID, 2019), their implementation has often been uneven, with difficulties in ensuring meaningful community participation, inter-agency coordination and long-term sustainability. Despite this, relatively few empirical studies have systematically examined how newly gazetted PA in Bangladesh navigate these governance realities in relation to global goals like those set by the CBD or SDGs.

This study addresses this gap by investigating governance challenges in Inani National Park (INP), a recently declared PA in southeastern Bangladesh. Notably, the majority of Rohingya refugees—who are forcibly displaced nationals from Myanmar—have settled in and around INP, which is jointly managed by the Government of Bangladesh and the UN Refugee Agency (Kabir et al., 2021). This large-scale displacement has had important implications for both biodiversity conservation and the overall management of the park. The large-scale influx of Rohingya refugees has posed profound challenges to protected area (PA) governance and co-management in southeastern Bangladesh, generating wide-ranging ecological pressures across forest, water, soil, wildlife, and land-use systems (Martin, 2005, cited in Haque, 2018; MoEFCC, 2018). In Cox’s Bazar, the rapid and largely unplanned expansion of refugee settlements covering approximately 2,283 ha has resulted in extensive forest clearing, habitat fragmentation, and disruption of ecosystem processes in and around protected forests (Hassan et al., 2018). Remote-sensing analyses using multiple classification algorithms have confirmed substantial forest loss and land-cover transformation following the influx (Ahmed et al., 2019).

These pressures have critically undermined co-management arrangements by intensifying resource extraction and weakening enforcement capacity. Daily fuelwood demand from displaced populations has been estimated at nearly 750,000 kg, placing severe strain on both protected forests and adjacent social forestry plantations (Hoque et al., 2019). The rapid establishment of camps alone has been associated with the loss of approximately 1,876 ha of forest land (Rashid et al., 2021). More recent assessments indicate that total forest cover loss in the region reached 12,807 ha between 2017 and 2020, with 1,337 ha directly attributable to Rohingya settlements (Dampha et al., 2022). Collectively, these impacts highlight the limitations of existing PA governance and co-management frameworks in responding to large-scale humanitarian crises, underscoring the need for adaptive, cross-sectoral, and crisis-responsive conservation governance.

By incorporating perspectives from government agencies, law enforcement authorities, community-based organizations, and local residents, the study moves beyond identifying site-specific challenges to engage with broader global discussions on conservation governance. It demonstrates how institutional capacity, coordination among agencies, and meaningful participatory processes interact to influence governance outcomes in newly established protected areas. In doing so, the research generates lessons that are applicable to other regions confronting comparable socio-political and ecological challenges, particularly in relation to meeting international biodiversity commitments and sustainable development goal.

9.2. Materials and Methods

9.2.1. Study Area

This study was conducted in Inani National Park, located in the Cox's Bazar District of southeastern Bangladesh. Covering an area of approximately 7,085 hectares, it is administered by the Cox's Bazar South Forest Division. The park is ecologically contiguous with Himchari National Park to the north and Teknaf Wildlife Sanctuary to the south, together forming an interconnected network of protected areas along Bangladesh's southeastern coastal belt (Uddin, 2013; **Figure 3.1 in chapter 3**). It is shaped by gently sloping hills, narrow valleys and seasonal streams that originate in the uplands and drain westward toward the Bay of Bengal and dominated by evergreen and semi-evergreen forests, much of the area has experienced extensive degradation due to logging, agricultural expansion, settlement encroachment and resource extraction.

The park's combination of ecological connectivity, habitat diversity and human-induced pressures makes it a critical site for evaluating protected area governance, conservation challenges and the effectiveness of stakeholder engagement in a rapidly changing landscape.

Concern for the conservation of biodiversity in Bangladesh has a long-standing history, and the country has demonstrated a strong commitment to biodiversity protection at national, regional, and global levels. This commitment is reflected in Bangladesh's endorsement and ratification of numerous national, regional, and international conventions, treaties, and protocols related to biodiversity conservation. In response to accelerating forest degradation and in fulfilment of its obligations to both national priorities and the international community, the Government of Bangladesh intensified efforts to designate and establish a network of biodiversity-rich protected areas—including national parks, wildlife sanctuaries, and game reserves—under the provisions of the Wildlife Preservation Act of 1973.

One area identified by the Forest Department for inclusion in the expanded PFA network lies within portions of the Inani and Ukhia Ranges on the Teknaf Peninsula in Cox's Bazar District. In 2006, the Forest Department proposed the conservation of approximately 7,000 hectares of remaining natural tropical forest in this landscape, with the intention of declaring it a National Park under the PFA system. To support this initiative, a USAID-funded project was implemented in the Inani Protected Forest Area between September 2009 and September 2011. The project focused on community mobilization, the formation and strengthening of Co-management Committees (CMCs), capacity building of both CMC members and Forest Department staff, and training local stakeholders in alternative livelihood options (Annual Progress Report on Inani PFA Co-management Project, June 2009–July 2012; Evaluation Report on Inani PFA Co-management Project). Following the successful completion of the initial phase, a subsequent one-year phase was undertaken to enhance the sustainability of the co-management structures established by the project. Subsequently, with continued support from USAID, the *GREEN LIFE* (Greening Environment through Livelihoods Improvement and Forest Enrichment) Project was launched in May 2020 and implemented through April 2023. This initiative aimed to mitigate the adverse impacts of the large-scale influx of Forcibly Displaced Myanmar Nationals (FDMN), estimated at nearly one million individuals, on local livelihoods and natural resources in Ukhiya Upazila of Cox's Bazar District. The project addressed

key objectives related to environmental conservation and climate change, livelihood development and WASH, promotion of alternatives to fuelwood, and strengthening of local institutional capacity (Annual Report on GREEN LIFE, Year 3, May 2022–April 2023).

9.2.2. Study design and Data analysis

This study employed a qualitative research approach to investigate governance challenges, stakeholder dynamics and management issues in INP, a newly gazetted protected area in southeastern Bangladesh. Its primary aim was to capture nuanced multi-stakeholder perspectives on biodiversity conservation, institutional effectiveness, inter-agency coordination, financial/logistical constraints and strategic recommendations for strengthening protected area governance.

Data were collected using a semi-structured questionnaire designed to capture both standardized responses and in-depth qualitative insights. The instrument was organized around key thematic areas, including biodiversity conservation challenges, institutional governance and law enforcement, financial and logistical constraints, inter-agency coordination, stakeholder-driven recommendations, and lessons learned. Drawing on established governance research (Omoding et al., 2020), the semi-structured format ensured comparability across interviews while retaining flexibility to explore context-specific perspectives. Prior to field implementation, the questionnaire was reviewed by subject-matter experts to ensure clarity, validity, and contextual appropriateness.

Using purposive sampling, key informants with direct or indirect involvement in the governance, management, or resource use of Inani National Park were selected. In total, 43 interviews were conducted (**Table 9.1**), encompassing six stakeholder groups: the Bangladesh Forest Department (26%); co-management bodies (9%); local administration at the Union Parishad and Upazila levels (26%); community-based organizations, including local elites and resource users (23%); and representatives from national and international NGOs (7%), as well as the Upazila Nirbahi Office (including the UNO, AC Land, and law enforcement agencies) (9%). This approach is consistent with sampling strategies used in comparable protected area governance studies (Oliva & Montiel, 2016; Omoding et al., 2020), ensuring that a broad range of perspectives was effectively captured.

Table 9.1: Showing different categories of KII interviewed during the survey

Category of respondents	Number of respondents	Percentage
Bangladesh Forest Department	11	25.58
Co-management Body	4	9.30
Local administration (Union Parishad and Upazila-level elected persons)	11	25.58
Community Based Organization (local elites and resource users)	10	23.25
National and International NGO	3	6.79
Upozila Nirbahi Office (UNO, AC Land, Law enforcement)	4	9.30
Total	43	100

Interviews were conducted primarily through face-to-face interactions, with remote methods used when necessary. With participants' consent, all interviews were recorded, transcribed verbatim, and analyzed thematically. An inductive coding approach was applied, whereby responses were grouped into themes aligned with the core analytical areas (e.g., challenges, governance, coordination), while also allowing for the emergence of sub-themes. Where relevant, comparisons across stakeholder groups were undertaken to examine variations in perceptions. This analytical process follows established practices in governance research based on stakeholder perspectives.

In addition, respondent-level prevalence was calculated for both challenge and recommendation themes by counting the number of unique respondents who mentioned each theme and dividing this by the total number of respondents, with results expressed as percentages. Themes were subsequently ranked in descending order of prevalence for challenges and recommendations.

The data were further analysed in long format, linking each coded statement to a unique respondent and stakeholder institution. Data imported from CSV files were cleaned, and respondent distributions were calculated using unique respondents per category. Challenge and recommendation themes were compared across stakeholder groups using respondent-level prevalence, summarized as proportions and visualized using heatmaps. Institutional differences in theme prevalence were tested using Fisher's exact tests (Fisher, 1922) with Benjamini–Hochberg (Benjamini & Hochberg, 1995) correction for multiple comparisons. Reliability metrics (Cronbach's alpha and KR-20) (Cronbach, 1951; Kuder & Richardson, 1937) were calculated descriptively using binary respondent-by-theme matrices where sample size permitted. For threat assessment, severity rankings were analysed using paired Wilcoxon signed-rank tests (Wilcoxon, 1945) to examine differences in composite threat severity, while Kruskal–Wallis tests (Kruskal & Wallis, 1952) were used to assess variation in severity across institutions.

Data analysis was performed using different packages of R such as dplyr v1.1.4 (Wickham et al., 2023), readr v2.1.5 (Wickham et al., 2024) and the tidyverse v2.0, ggplot2 v4.0.1 (Wickham, 2016). factoextra v1.0.7 (Kassambara & Mundt, 2020). stringr v1.5.0 (Wickham, 2023). Tidyr v1.3.1 (Wickham H, Vaughan D, Girlich M., 2025), janitor v2.2.1 (Firke et al., 2024), Forcats v8.24.0 (Hyndman R. et al., 2025), scales v1.4.0 (Wickham et al., 2025), viridis v0.6.5 (Simon Garnier et al., 2023), psych v2.5.6 (William Revelle, 2025), skimr v2.2.1 (Waring et al., 2025), rstatix v0.7.3 (Kassambara, 2025), FSA v0.10.0 (Ogle et al., 2025).

9. 3. Results

9.3.1. Key Governance and Conservation Challenges

Stakeholder responses highlight that operational and institutional constraints are the main challenges to biodiversity conservation in Inani National Park. The most commonly reported issue was a shortage of logistics and manpower, noted by 18 of 43 respondents (41.9%) (Fig. 2). Environmental degradation (12/43; 27.9%) and governance and policy-related concerns (10/43; 23.3%) were also frequently cited. Other notable challenges included administrative bottlenecks (8/43; 18.6%) and limited inter-agency coordination (7/43; 16.3%), emphasizing the need for effective management and

collaboration. Enforcement and land-related pressures, such as inadequate support for crime control and land management, were each reported by 5 respondents (11.6%), while ecological and community-related issues, including habitat loss and resource overuse, were mentioned less often (4/43; 9.3% each) (**Figure 9.1**). Overall, these results indicate that strengthening institutional capacity, governance, and coordination is perceived as critical for improving biodiversity outcomes.

The prioritization of governance and institutional challenges over ecological threats aligns with findings from other regions, including Nepal (Baral & Heinen, 2007), Uganda (Omoding et al., 2020), and Mexico (Oliva & Montiel, 2016), where deficiencies in institutional capacity, rather than ecological limitations, were identified as the primary obstacles to effective protected area management.

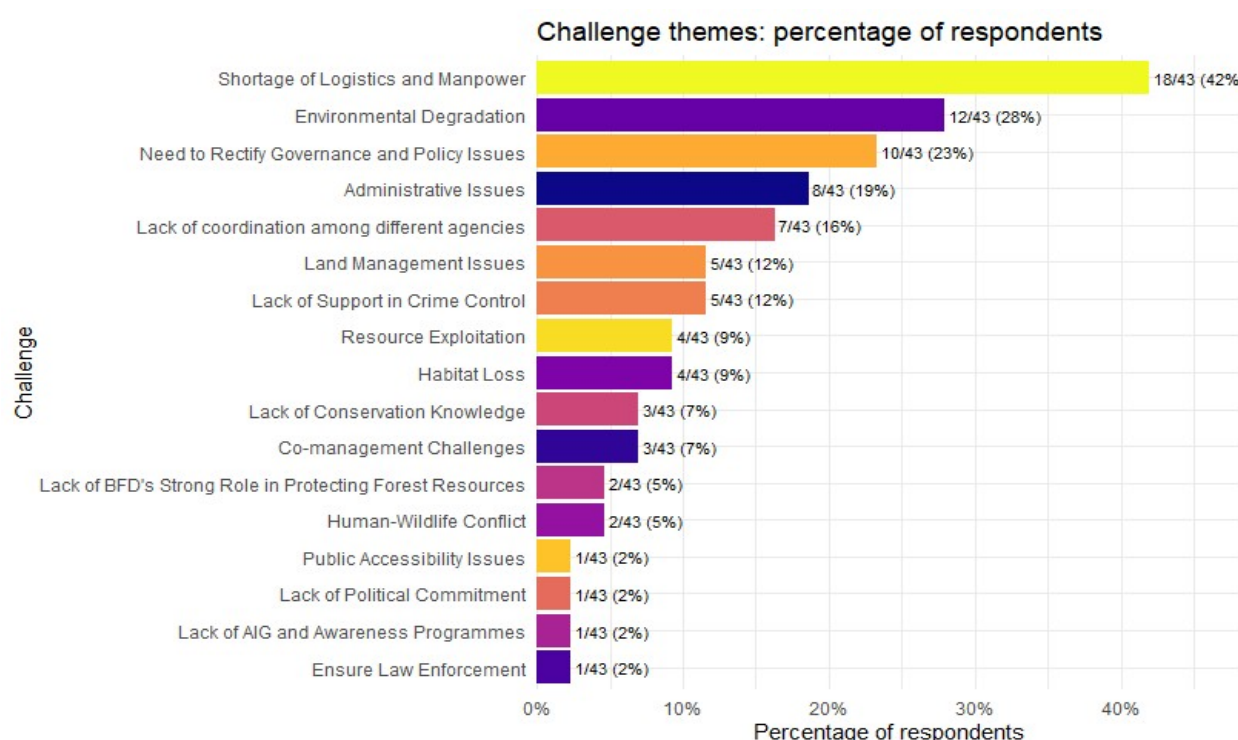


Figure 9.1. Stakeholder responses: Challenges in Biodiversity conservation

The nature of challenges varies notably across stakeholder groups. Among Bangladesh Forest Department (BFD) respondents (n=11), the most pressing issue is a shortage of logistics and manpower, reported by 9 of 11 respondents (81.8%). Other frequently cited concerns include governance and policy gaps (7/11; 63.6%), administrative bottlenecks, and environmental degradation (6/11; 54.5% each), with insufficient support for crime control and land management also highlighted by nearly half of respondents (5/11; 45.5% each) (**Figure 9.2**).

Local government respondents (n=11) most commonly identify a lack of coordination among agencies (4/11; 36.4%), followed by environmental degradation and shortages in logistics and manpower (3/11 each; 27.3%), and resource exploitation (2/11; 18.2%). Community-facing groups

emphasize different priorities: Co-management Bodies (n=4) primarily note co-management challenges (2/4; 50%), while Community-Based Organizations (n=10) most frequently report habitat loss and shortages in logistics and manpower (2/10; 20.0% each) (Fig. 3).

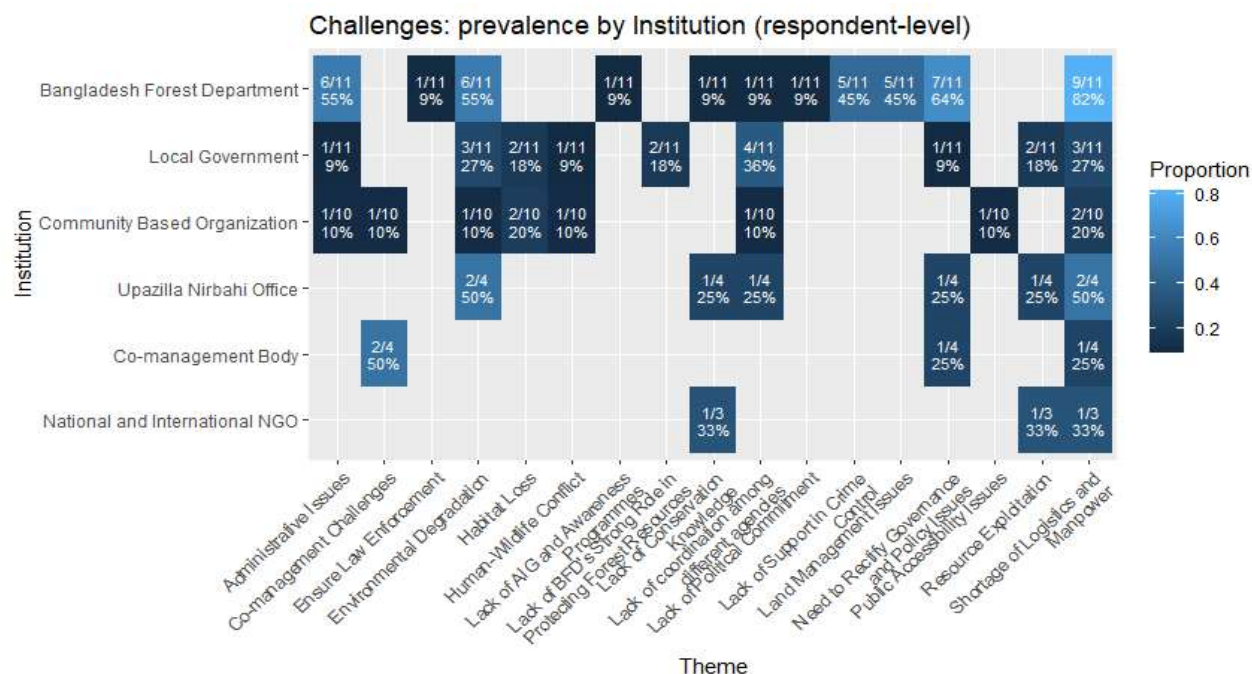


Figure 9.2. Challenges: prevalence by Institution (respondent-level).

Institution-wise analysis using Fisher's exact tests revealed that several challenge themes differ significantly across stakeholder groups ($p < 0.05$). Notably, the need to address governance and policy issues ($p = 0.007$), lack of support in crime control ($p = 0.010$), and land management issues ($p = 0.010$) vary significantly by institution. Additional themes showing significance at the 5% level include co-management challenges ($p = 0.031$), shortage of logistics and manpower ($p = 0.043$), and administrative issues ($p = 0.048$). In contrast, lack of conservation knowledge was not significant ($p = 0.124$). These findings highlight that the relative importance of key challenges depends on stakeholder category, emphasizing the value of reporting results stratified by institution.

Reliability analysis across institutions indicates that challenge themes should not be treated as a single coherent scale. Cronbach's alpha was negative for Local Government (-0.209 ; $n = 11$) and Community-Based Organisations (-0.120 ; $n = 10$), and low for the BFD (0.256 ; $n = 11$), suggesting weak internal consistency. KR-20 values were very high (e.g., 42.53; 116.28) but are numerically unstable due to small, sparse subgroup matrices.

9.3.2. Stakeholder Recommendations for Strengthening Conservation

Stakeholder recommendations for improving biodiversity conservation primarily focus on enhancing capacity and leadership. The most commonly suggested action is increasing manpower and logistics, reported by 15 of 43 respondents (34.9%), followed by the need for strong leadership commitment

(11/43; 25.6%) and ensuring AIG support (10/43; 23.3%) (Fig. 4). Law enforcement is also emphasized by a notable proportion (8/43; 18.6%), indicating that effective enforcement is considered a key complement to capacity-building efforts. Institutional measures, although less frequently mentioned, include administrative reforms (5/43; 11.6%), interagency coordination, and increased community awareness or strategic planning (each 4/43; 9.3%). Environmental and financial interventions appear less prominent, such as environmental protection (3/43; 7.0%) and measures like nature financing or fuelwood alternatives (each 2/43; 4.7%) (**Figure 9.3**). Overall, these results suggest that respondents view improvements in operational and governance mechanisms as the most immediate means to enhance conservation outcomes. These patterns are consistent with findings from South Asia and East Africa, where governance and livelihood considerations often take precedence over ecological interventions in shaping stakeholder conservation priorities (Persha et al., 2011; Bennett & Dearden, 2014)

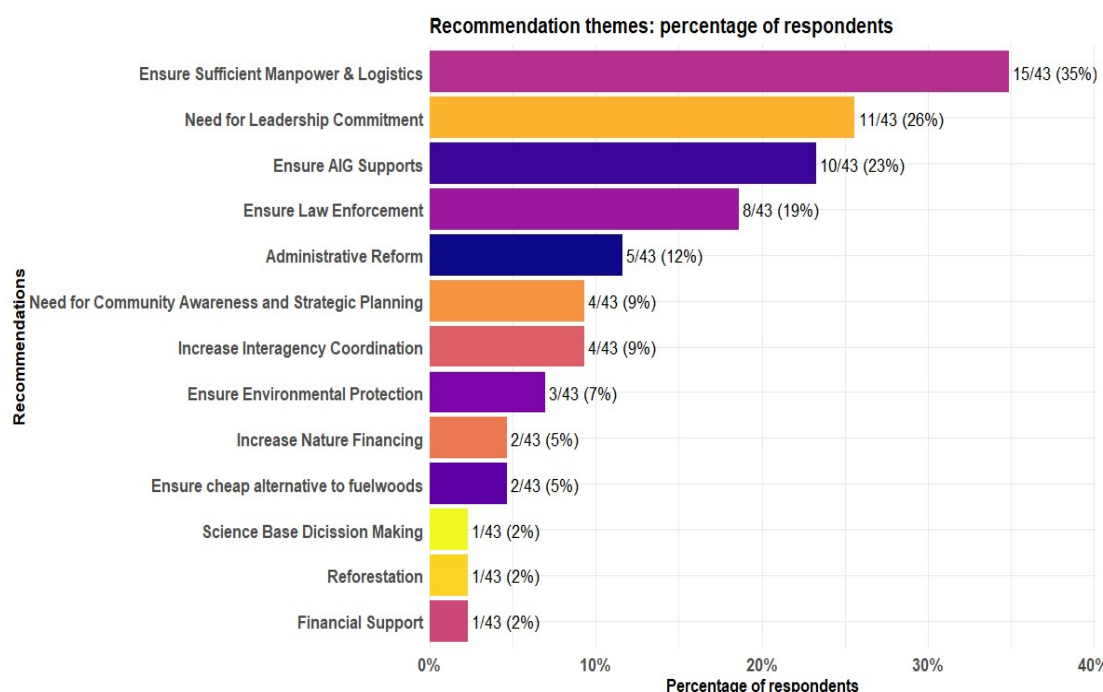


Figure 9.3. Stakeholder responses: Recommendations in Biodiversity conservation.

Institutional priorities for recommendations differ notably among stakeholder groups. Among Bangladesh Forest Department (BFD) respondents (n=11), the top priorities focus on strengthening operational capacity and governance: ensuring sufficient manpower and logistics (7/11; 63.6%) ranks highest, followed by securing AIG support and leadership commitment (6/11 each; 54.5%), and administrative reform (5/11; 45.5%) (Fig. 5). Local government respondents (n=11) emphasize practical enforcement and capacity measures, including ensuring law enforcement (4/11; 36.4%) and sufficient manpower and logistics (2/11; 18.2%), with smaller proportions recommending fuelwood alternatives, interagency coordination, community awareness, and nature financing (each 2/11; 18.2%).

Community-Based Organizations (CBOs, n=10) present a more dispersed set of priorities, most frequently suggesting sufficient manpower and logistics, leadership commitment, and environmental protection (each 2/10; 20%). Co-management Bodies (n=4) mainly highlight AIG support and law enforcement (each 2/4; 50%) (Figure 9.4).

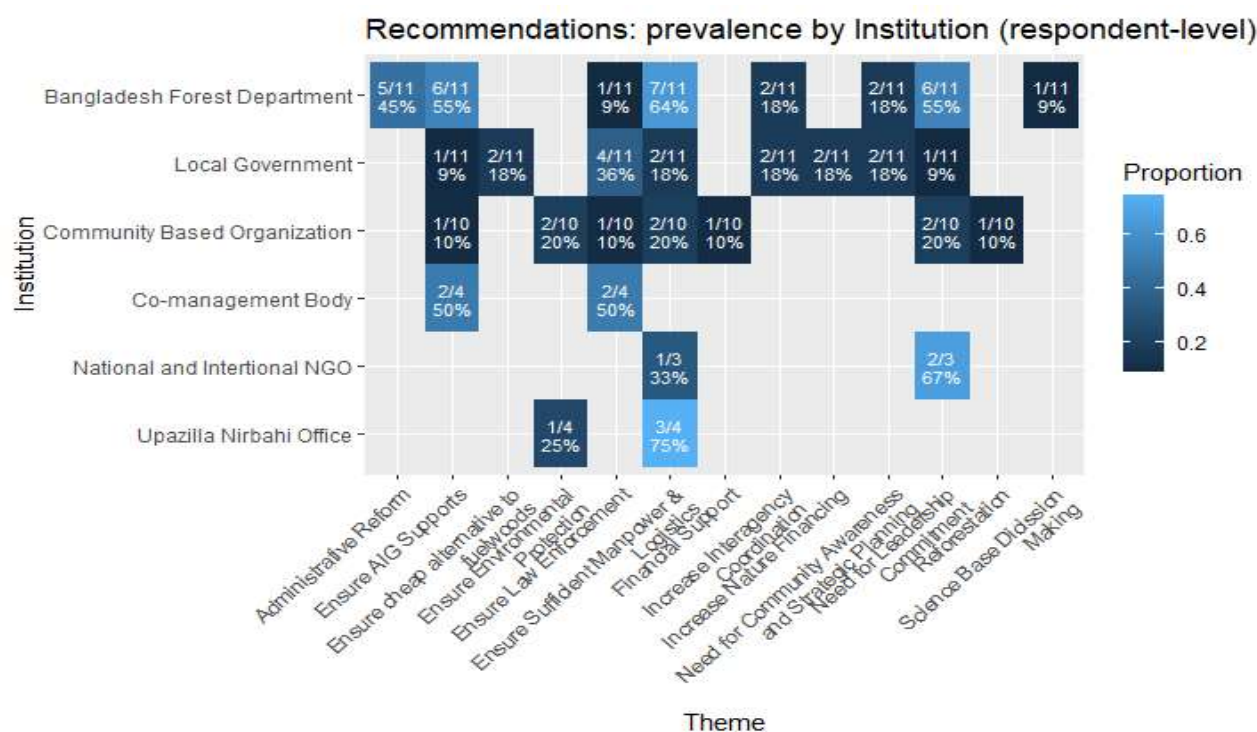


Figure 9.4. Recommendation: prevalence by Institution (respondent-level).

The institution-wise Fisher's exact test demonstrates that several recommendation themes differ significantly across respondent categories ($p < 0.05$). Administrative reform exhibits the most pronounced institutional difference ($p = 0.0103$), while ensuring sufficient manpower & logistics ($p = 0.0456$), need for leadership commitment ($p = 0.0445$), and ensuring AIG supports ($p = 0.0444$) also differ significantly by institution. In contrast, ensuring environmental protection is not statistically significant ($p = 0.2593$), highlighting that recommended actions are not uniform across stakeholder groups. These results underscore that institutions prioritize distinct strategies, supporting the interpretation that pooled recommendations should account for respondent composition.

Reliability analysis further indicates weak internal consistency for recommendation themes. Cronbach's alpha is negative for Local Government (-0.251 ; $n = 11$) and Community-Based Organizations (-0.120 ; $n = 10$), and remains low for the BFD (0.280 ; $n = 11$). Extremely large KR-20 values (e.g., 45.23; 116.28) are numerically unstable due to sparse subgroup matrices. Overall, recommendation themes are best viewed as distinct, stakeholder-specific priorities rather than components of a single psychometric scale.

9.3.3. Coordination and Financial Barriers

Financial and institutional limitations were also identified as significant barriers to long-term conservation (**Figure 9.5**). A lack of sustained funding and limited access to modern conservation technologies was reported by 11.4% of respondents, while 4.6% reported insufficient operational support from local administrations and enforcement agencies. Capacity deficits among community-based organizations were noted by 6.8%, and the absence of formalized stakeholder coordination platforms by 2.3%. These findings are consistent with research from Uganda (Omoding et al., 2020), which demonstrates that fragmented financial and institutional support can undermine the effectiveness of co-management arrangements.

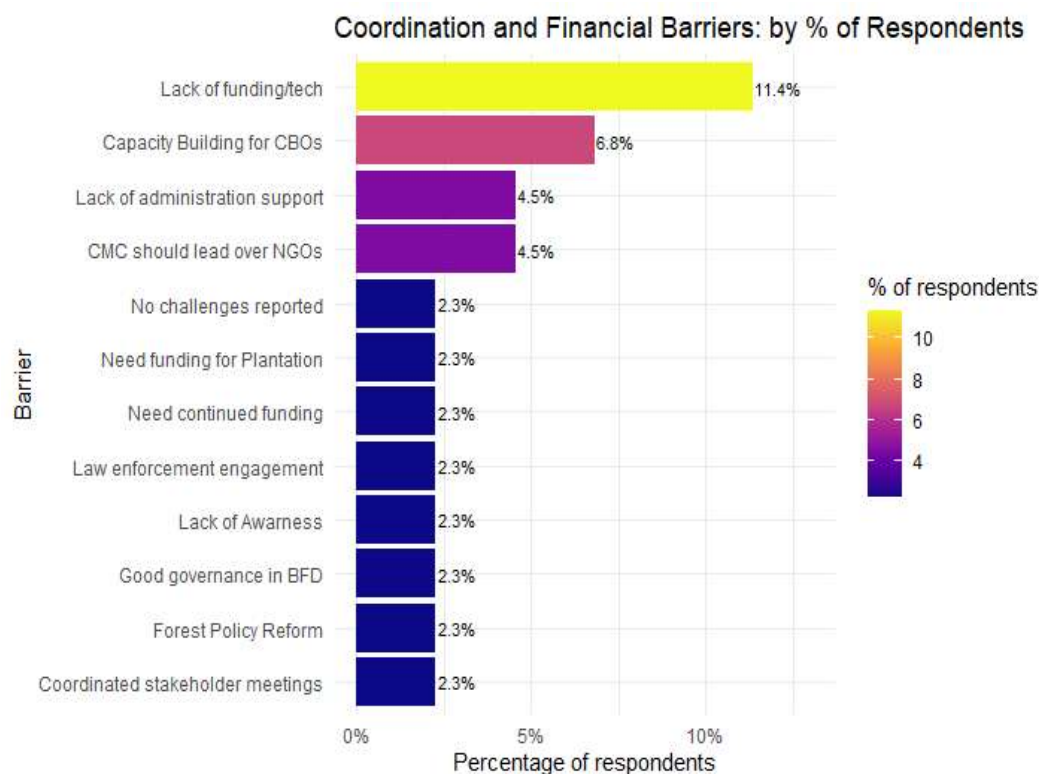


Figure 9.5. Stakeholder responses: Coordination and financial issues.

9.3.4. Threat severity for Rohingya influx and settlement and increase population after Rohingya influx

Respondents rated both threats as highly important and impactful, with mean scores ranging from approximately 4.30 to 4.49. Frequency of occurrence was slightly lower but remained elevated (means $\approx$ 3.70–3.88) and showed greater variability (SD $\approx$ 1.22–1.32). Median scores were 4–5 for importance and impact, and 4 for frequency, indicating that responses were generally clustered toward the high end and reflecting substantial perceived threat severity (**Figure 9.6**).

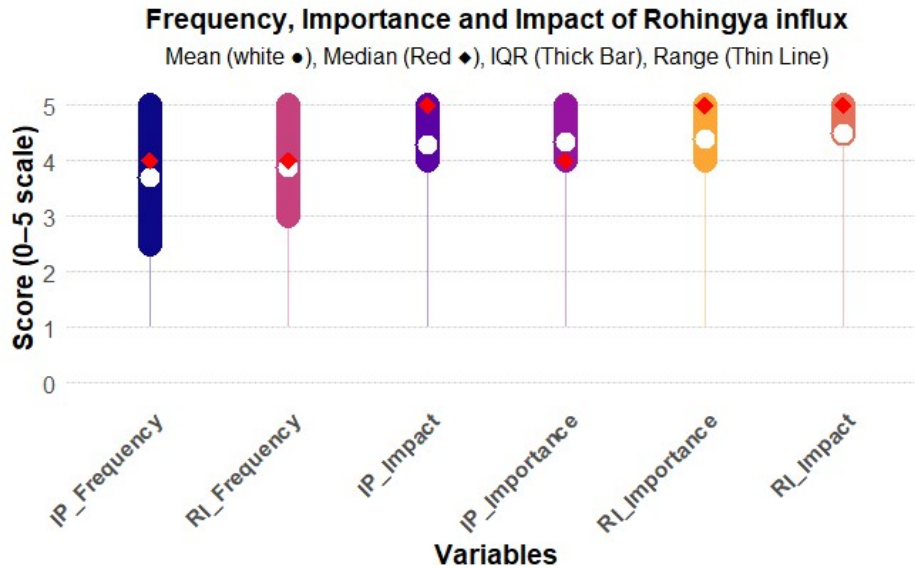


Figure 9.6. Summary of mean, median, IQR (thick), Range (thin)

Across 43 respondents from multiple institutions, the composite “threat severity” score—calculated as the mean of importance, occurrence frequency, and ecological impact on a 0–5 scale—indicated that both threats are perceived as highly consequential for forests, wildlife, and biodiversity in the Cox’s Bazar South Forest Division. Rohingya influx and settlement received a slightly higher severity rating (mean = 4.26, median = 4.33, range = 1.0–5.0) compared to the subsequent increase in population (mean = 4.12, median = 4.00, range = 1.0–5.0). Responses were strongly skewed toward the upper end of the scale: 36 of 43 ratings for Rohingya influx and settlement fell within the high-to-very-high range (≥ 4.0), while 31 of 43 ratings for increased population were ≥ 4.0 , with a larger proportion of moderate scores (3.0–3.9) for the latter (**Figure 9.7**).

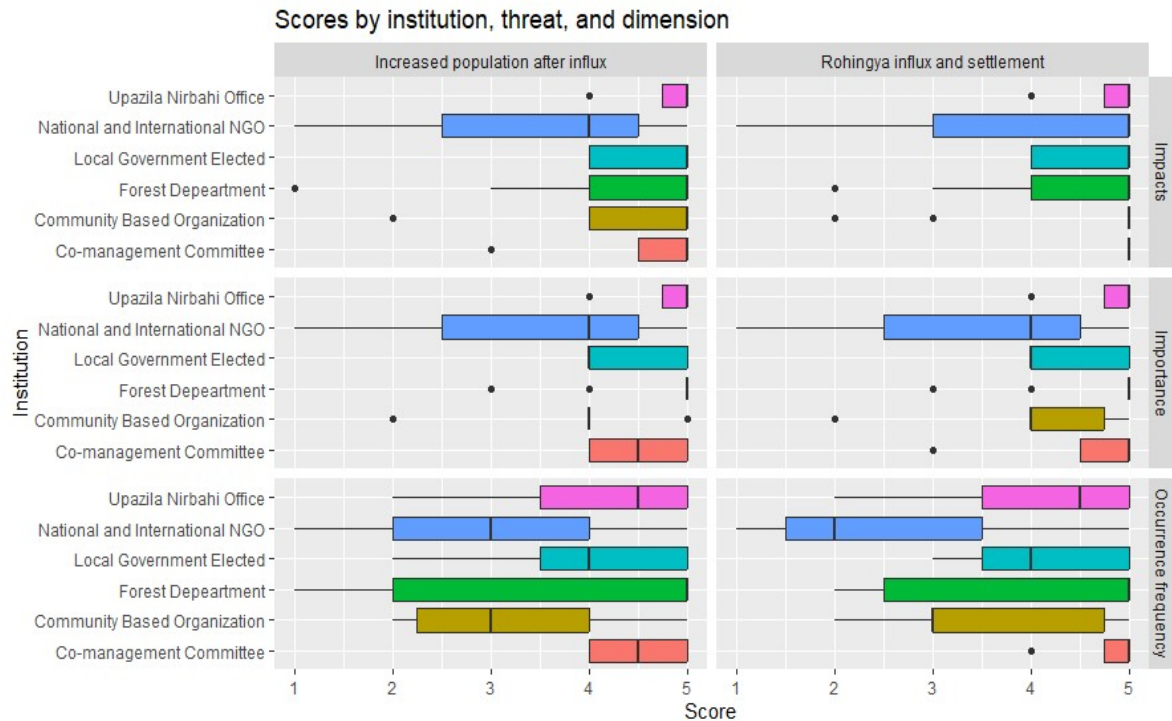


Figure 9.7. Scores by institution, threat, and dimension.

Within-respondent comparisons revealed substantial overlap in perceived severity: 31 respondents assigned identical scores to both threats, 11 rated Rohingya influx and settlement higher, and only 1 rated increased population higher, resulting in a small positive average paired difference of +0.14 in favor of Rohingya influx and settlement. Institution-level averages mirrored this pattern, with consistently high mean severities reported by public and management bodies, including the Upazila Nirbahi Office (4.50), the Co-management Committee (4.63), the Local Government (4.36), and the Forest Department (4.21). In contrast, community and NGO groups exhibited greater heterogeneity, with lower means among Community-Based Organisations (3.95) and National/International NGOs (3.22; the latter based on a smaller subgroup) (**Figure 9.7**).

Overall, these findings indicate broad agreement that both refugee settlement and the associated population growth exert significant ecological pressures, with respondents slightly more inclined to perceive the influx and settlement process as the more severe driver.

The paired Wilcoxon signed-rank test revealed a significant difference in composite severity between the two threats ($V = 76$, $p = 0.00398$) (**Figure 9.8**), indicating that respondents' median ratings differ, with Rohingya influx and settlement perceived as more severe than increased population following the influx. Within-respondent comparisons of the individual components showed significant differences for Impacts and Occurrence frequency (Holm-adjusted $p = 0.0403$ for both), whereas Importance did not differ significantly ($p = 0.424$). This suggests that while both threats are considered similarly important, they are perceived to differ in terms of frequency and ecological impact intensity.

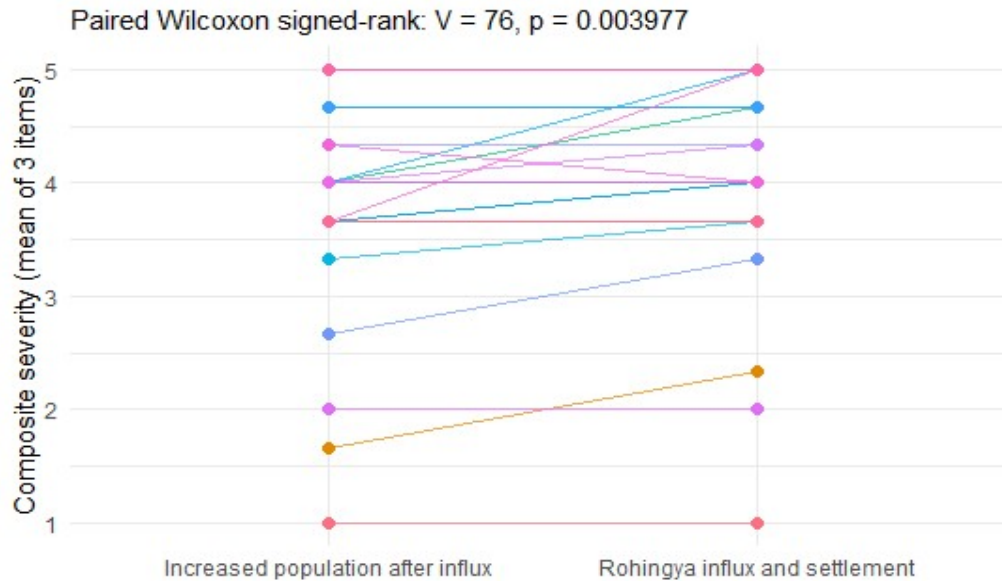


Figure 9.8. Paired composite severity ratings by threat

Kruskal–Wallis tests for each threat revealed no significant differences in severity across institutions (Increased population: $H = 3.50$, $df = 5$, $p = 0.623$; Rohingya influx and settlement: $H = 4.02$, $df = 5$, $p = 0.546$) (**Figure 9.9**), indicating broadly consistent perceptions of threat severity across institutional groups and obviating the need for post-hoc pairwise comparisons.

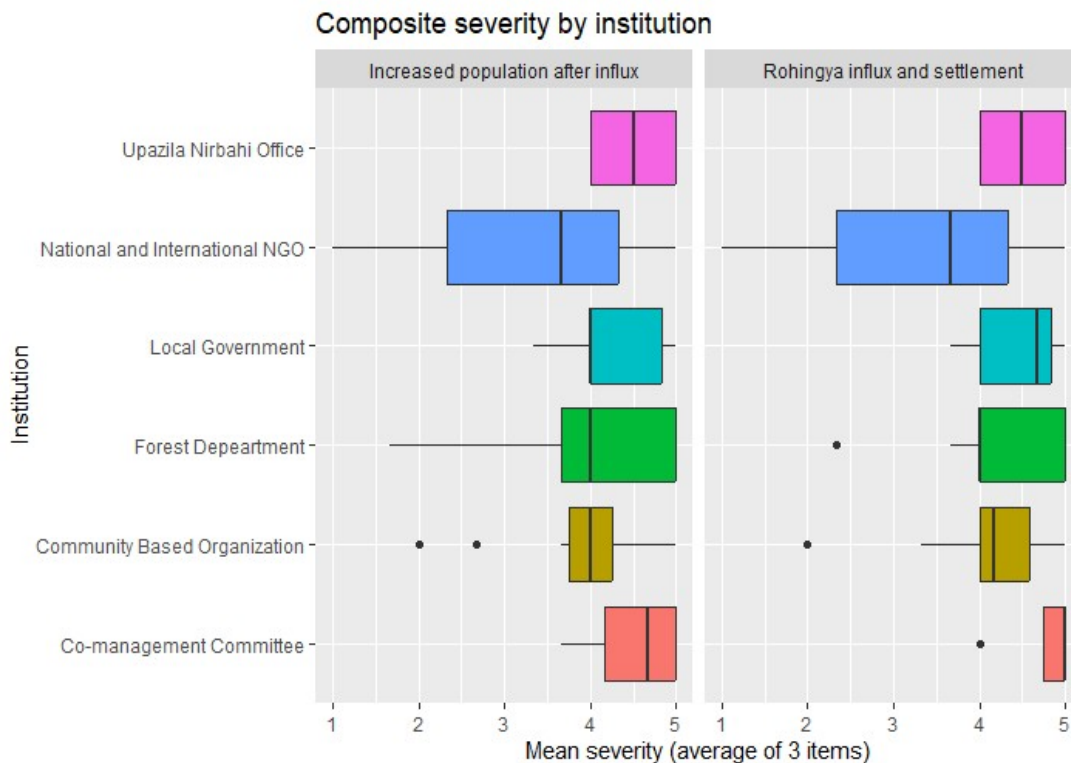


Figure 9.9. Composite severity by institution

9.3.5. Lessons Learned from Stakeholder Engagement

Participants identified several overarching lessons from their conservation experience. The most frequently cited insight (34.1%) was that biodiversity conservation cannot be addressed in isolation and requires coordination across multiple scales, integrating local actions with national priorities and global biodiversity commitments such as the Convention on Biological Diversity (CBD) and the Sustainable Development Goals (SDGs). Strengthening the operational capacity of the Forest Department was also highlighted as a key prerequisite for conservation success (20.5%) (**Figure 9.10**).

Other lessons included the importance of local government engagement (6.8%), the critical role of Co-Management Committees in securing community legitimacy (6.8%), and the need to enhance stakeholders' scientific knowledge (9.1%) (**Figure 9.10**). These reflections align with observations from Latin America (Oliva & Montiel, 2016), emphasizing that successful conservation outcomes depend as much on inclusive governance and stakeholder legitimacy as on ecological management.

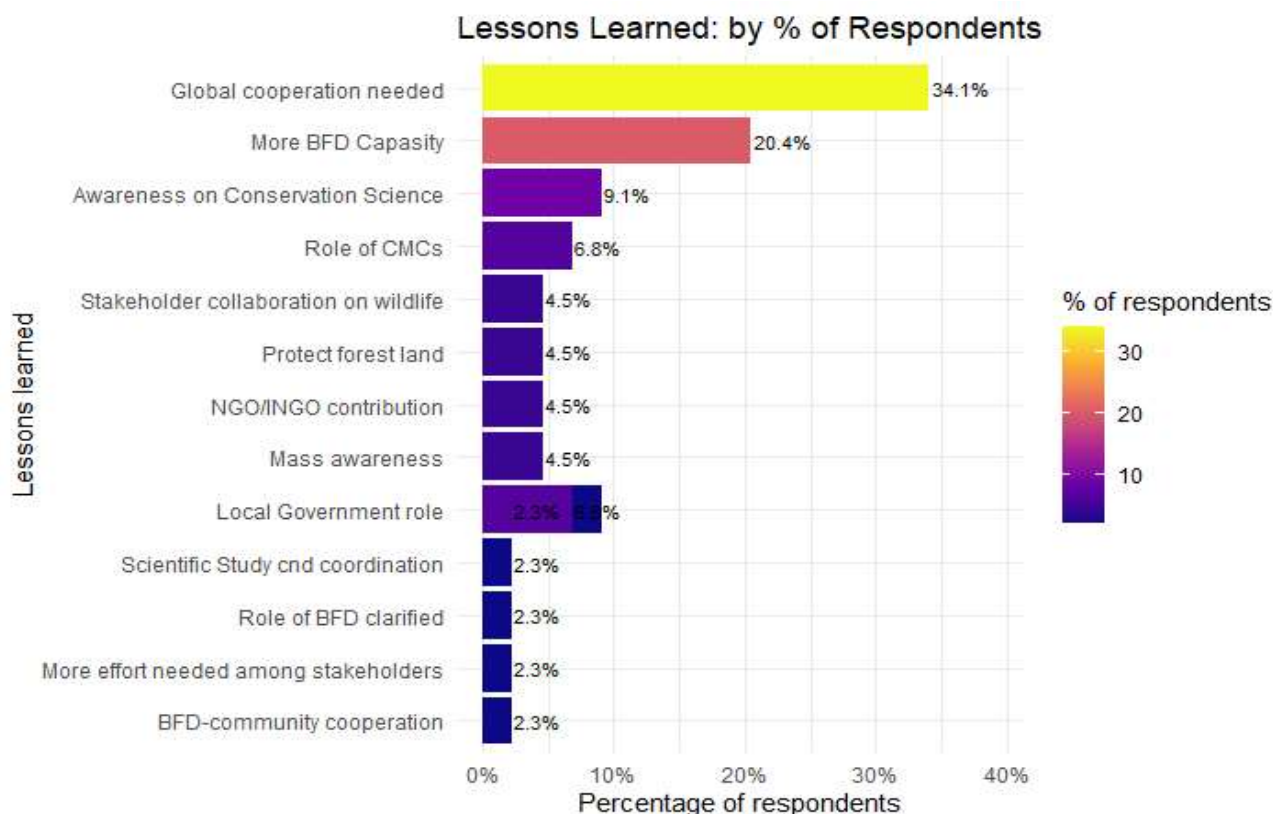


Figure 9.10. Stakeholder responses: Lessons learned

9.4. Discussion

This study reveals several critical governance and management challenges affecting biodiversity conservation in Inani National Park, one of Bangladesh's newly designated protected areas. The most frequently cited issue, reported by over half of respondents, was the acute shortage of logistical

support and trained personnel. While many stakeholders expressed strong interest in capacity-building initiatives—such as training opportunities and access to resources—this enthusiasm does not necessarily equate to full support for co-management. Demand for capacity building primarily reflects aspirations for enhanced skills, assets, and livelihood security. In contrast, effective co-management requires a more profound commitment to shared authority, collective responsibility, and participatory decision-making.

Targeted livelihood interventions have supported alternative income-generating activities among approximately 1,800 households, helping reduce dependence on forest resources for subsistence and fuelwood collection. Community groups have also established savings-and-loan mechanisms, combining self-financing with project support to enhance access to capital and strengthen local economic resilience (Annual Report on GREEN LIFE, Year 3, May 2022–April 2023). These findings are consistent with other contexts in the Global South, where insufficient infrastructure and understaffing remain persistent barriers to conservation effectiveness (Berkes, 2004; Watson et al., 2014).

The PA Co-Management Committee and associated committees as per the Protected Area Management Rules, 2017 have successfully protected about 7000 hectares of forest within INP through Community Patrol Groups (CPG) and minimized human-elephant conflicts via the Elephant Response Team (ERT). Sustained funding for these bodies is critical, and ongoing capacity-building initiatives—such as quarterly training for Union Parishad Standing Committees on environmental protection—have strengthened stakeholder participation (Annual Report on GREEN LIFE, Year 3, May 2022–April 2023). Nonetheless, field staff face the dual challenge of enforcing regulations while maintaining positive relations with local communities (Lockwood, 2010), emphasizing the need to align resources with legal designations to move beyond “paper parks” (DeFries et al., 2005).

While group-based livelihood initiatives have been more challenging to implement than individual projects, some efforts—such as a commercial drinking water project—have succeeded. Community interest in participatory conservation is high; however, local Forest Department personnel have concentrated primarily on the CPG and ERT, with limited engagement in the CMC. Political interference in committee membership has also been observed. Despite the traditionally male-dominated governance structure, women’s participation in economic and social development initiatives has increased, largely due to development interventions under the GREEN LIFE project (Annual Report on GREEN LIFE, Year 3, May 2022–April 2023).

Respondents highlighted governance and policy-related constraints—including weak accountability, unclear mandates, and limited enforcement capacity—which mirror broader critiques of institutional fragmentation and policy-practice gaps in conservation governance (Agrawal & Ribot, 1999; Ostrom, 2009). Despite progressive policies for protected area management in Bangladesh, their site-level implementation remains limited, reflecting the so-called “implementation deficit” (Bennett & Dearden, 2014). Similar challenges have been documented in Africa and Latin America, where national conservation commitments often falter due to weak institutions and competing land-use priorities (Hill et al., 2020).

Inter-agency coordination also emerged as a recurring concern, with nearly one-fifth of respondents noting institutional silos. Overlapping mandates among forestry, wildlife, and local government agencies can generate inefficiencies and conflict (Young et al., 2006; Borrini-Feyerabend et al., 2013). Strengthening cross-sectoral collaboration is widely recognized as a cornerstone of effective protected area governance (Lockwood et al., 2010), and the INP experience aligns with international calls for polycentric governance systems to reduce fragmentation (Ostrom, 2010; Wyborn & Bixler, 2013).

Despite these challenges, stakeholders proposed a range of actionable solutions, including capacity strengthening of the Forest Department, enhanced law enforcement, and community-based awareness programs. These recommendations resonate with global best practices advocating co-management and integrated conservation-development approaches (Berkes, 2009; Oldekop et al., 2016). The success of co management depends on a myriad of factors that are closely related to governance issue (Mohanty & Sahu, 2012; Secco et al., 2014,). The CMC of INP has actively worked to halt forest degradation by preventing encroachment, illegal extraction, and land-use conversion, emphasizing community participation in monitoring and management (Annual Report on GREEN LIFE, Year 3, May 2022–April 2023).

Alternative income-generating activities (AIGAs) have emerged as an essential component of sustainable conservation, providing livelihood security while reducing pressure on forest resources (Roe et al., 2012). The project has promoted conservation-friendly, gender-sensitive AIGAs through training, demonstrations, and access to finance via revolving loan funds and participatory savings programs (Annual Report on GREEN LIFE, Year 3, May 2022–April 2023). Similarly, stakeholders emphasized the importance of international cooperation, transboundary partnerships, and long-term funding for resilient conservation institutions (Brooks et al., 2012).

Active participation of key stakeholders—including the Bangladesh Forest Department, local government officers, and community members—has been critical to the success of these interventions. Engagement from Upazila and district-level technical experts and administrative leaders has further supported law enforcement, monitoring, and community involvement.

Overall, the lessons articulated by respondents underscore the importance of combining top-down institutional frameworks with bottom-up community engagement for effective conservation governance (Chhatre & Agrawal, 2009). Local actors in INP play roles comparable to those observed elsewhere in Asia and Africa, where empowered communities are often more adaptive and responsive to conservation challenges than centralized authorities (Fabricius & Collins, 2007). This reflects a broader shift in global conservation discourse from state-centric approaches toward participatory and deliberative governance (Armitage et al., 2008; Lockwood, 2010).

While financial and coordination issues were less frequently cited, they remain critical to long-term sustainability. Without predictable funding and institutionalized mechanisms for collaboration, conservation initiatives are unlikely to endure (Emerton et al., 2006; Balmford & Whitten, 2003). The INP experience illustrates the need for sustained institutional and financial commitments in addition to short-term project interventions.

Taken together, these findings suggest that improving biodiversity governance in Inani National Park requires a comprehensive, participatory, and context-sensitive approach. By situating the challenges of INP within the wider international scholarship, this study highlights how local experiences echo global patterns of institutional weakness, coordination deficits, and the need for greater community engagement. Importantly, the INP case provides an opportunity to test and refine global governance frameworks in a South Asian context, advancing comparative understanding of how conservation governance can be adapted to diverse socio-political landscapes.

9.5. Conclusion

This study adds to a growing body of international scholarship demonstrating that conservation outcomes depend as much on governance quality as on ecological planning. Evidence from Inani National Park (INP) shows that legal designation and progressive policy frameworks alone are insufficient to ensure biodiversity protection in the absence of adequate institutional capacity, effective inter-agency coordination, and meaningful local participation. By drawing on the perspectives of frontline stakeholders, this research reveals the persistence of governance challenges widely reported across protected areas globally—such as resource constraints, fragmented authority, and implementation gaps—while also identifying context-specific opportunities for reform.

The findings lend empirical support to international calls for polycentric, participatory, and adaptive governance systems (Ostrom, 2010; Lockwood et al., 2010). Stakeholder-driven recommendations—emphasizing strengthened staffing, improved enforcement, integrated livelihood support, and inclusive decision-making—demonstrate how these governance principles can be operationalized in a Bangladeshi protected area context. As such, INP functions not only as a site of governance challenge but also as an instructive case that enriches broader debates on managing institutional complexity in conservation practice across the Global South.

Overall, this study underscores the importance of bridging global conservation frameworks with local socio-political realities. By centering stakeholder experiences and situating them within international scholarship, the INP case highlights the potential of adaptive governance approaches to improve conservation effectiveness. In doing so, it offers valuable insights for other newly designated protected areas facing similar governance constraints, contributing to a more context-sensitive and practice-oriented understanding of conservation governance worldwide.

Chapter 10

GENERAL DISCUSSION

This study illustrates that Inani National Park preserves disproportionate conservation importance despite its minuscule size, fragmented condition, and existed anthropogenic pressures. The persistence of 23 wild mammal species—containing globally threatened taxa such as the Asian elephant (*Elephas maximus*), Western hoolock gibbon (*Hoolock hoolock*), Bengal slow loris (*Nycticebus bengalensis*), and the first rigorously verified photographic confirmation of the clouded leopard (*Neofelis nebulosa*) within INP. These findings confirmed that structurally heterogeneous residue forests can act as ecologically significant refugia in human-dominated forest landscapes. This studies copes with island biogeography theory (MacArthur & Wilson, 1967) and metapopulation dynamics (Hanski, 1999), which anticipate that small habitat patches can possess species richness when connectivity and habitat quality persist affluent. Comparable persistence of diverse mammalian assemblages has been documented in Baraiyadhala National Park, where high species richness has been identified in spite of fire, logging, and encroachment pressures (Hasan et al., 2025), and in Pittachhara Forest, where medium and small mammals occupy fragmented hill forests under immense disturbance (Shawon et al., 2024). These parallels strong evidence that small protected areas in Bangladesh can retain biodiversity when residual habitat complexity exists.

Nevertheless, mammalian assemblages in INP exhibit strong dominance by adaptable species and low detection rates of specialist or low-density carnivores, indicating ecological filtering under disturbance. Similar patterns of restricted occupancy and skewed community composition have been reported across Bangladesh's tropical hill forests and broader South Asian landscapes, where habitat loss and fragmentation disproportionately affect carnivores and arboreal specialists (Akash & Zakir, 2019). The predominantly nocturnal activity observed for cryptic carnivores in INP likely represents behavioral adaptation to avoid human activity—a phenomenon widely documented in disturbed forests. Studies from Eastern Himalayan protected areas further demonstrate that fine-scale habitat structure and anthropogenic intensity, rather than broad climatic gradients, are the primary determinants of mammal distribution at local scales (Frontiers in Ecology and Evolution, 2023). This behavioral shift underscores the adaptive responses of wildlife to anthropogenic landscapes but also signals ecological stress and altered predator–prey dynamics.

At broader scales, the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES, 2019) identifies land-use change as the primary driver of global biodiversity loss, with tropical forest ecosystems experiencing particularly acute pressures. The patterns observed in INP—restricted occupancy of large carnivores, community simplification, and habitat-mediated filtering—are therefore consistent with global trajectories of faunal decline under fragmentation and edge effects (Haddad et al., 2015). The congruence between local findings in INP and global syntheses suggests that the park exemplifies broader structural pressures acting across tropical forest biomes.

Vegetation analyses further revealed moderate floristic diversity but pronounced structural alteration, characterized by dominance of disturbance-tolerant and anthropogenically favored taxa, alongside regeneration bottlenecks in advanced growth stages. These findings mirror patterns described in degraded tropical forests worldwide (FAO, 2020; Chazdon, 2014), where anthropogenic disturbance promotes pioneer species and nitrogen-fixing families while constraining recruitment of late-successional canopy species. The relatively higher regeneration diversity observed in semi-open shrub and hill strata within INP is consistent with the intermediate disturbance hypothesis (Connell, 1978), which posits that moderate disturbance enhances species coexistence by preventing competitive exclusion. However, limited transition from seedling to sapling and mature strata indicates recruitment constraints, potentially driven by soil compaction, grazing, fuelwood extraction, and altered microclimatic regimes. These parallels indicate that INP's regeneration trajectory reflects broader successional constraints observed in anthropogenically modified tropical forests.

The strong association between vegetation structure and mammalian habitat suitability reinforces foundational principles of landscape ecology (Forman, 1995). Species distribution modelling in this study identified land cover heterogeneity and proximity to water bodies as more influential predictors of mammalian occurrence than broad-scale bioclimatic variables. Similar findings have been reported in Eastern Himalayan and Southeast Asian landscapes, where riparian corridors and fine-scale habitat mosaics play critical roles in sustaining mammalian assemblages (Joshi et al., 2021). These results emphasize that in fragmented tropical landscapes, microhabitat complexity and connectivity may buffer species persistence more effectively than regional climatic stability alone.

At the landscape level, INP functions as a connectivity node linking Teknaf Wildlife Sanctuary and Himchari National Park. Connectivity is widely recognized as a central determinant of gene flow, demographic rescue, and long-term population viability (Crooks & Sanjayan, 2006). For wide-ranging species such as elephants and potentially large carnivores, intermediary forest patches can serve as stepping-stone habitats that reduce isolation effects. The importance of small intermediary forest patches and corridors for maintaining gene flow has been consistently demonstrated across South and Southeast Asia. Puyravaud, J.-P., Cushman, S. A., Reddy, P. A., et al. (2022) demonstrated that landscape features and functional connectivity, including terrain and forest corridors in the Western Ghats and Nilgiri Biosphere Reserve, influence gene flow and dispersal patterns of Asian elephants. Connectivity across such corridors mitigates the genetic isolation created by habitat fragmentation and barriers like protected area fencing. However, escalating pressures—including encroachment, plantation expansion, infrastructure development, and fuelwood extraction—reflect patterns of land-use intensification documented across Bangladesh and other rapidly developing tropical nations (IUCN Bangladesh, 2015). These pressures highlight systemic governance and socio-economic drivers rather than isolated ecological degradation.

Stakeholder perceptions documented in INP align with broader human–wildlife coexistence research across the Global South. Human–elephant conflict, particularly crop raiding, has been identified as a primary determinant of negative conservation attitudes in agrarian communities in India, Nepal, and Sri Lanka (Fernando et al., 2005). The coexistence of ecological appreciation and livelihood-based resentment observed in INP reflects a globally recognized conservation paradox: communities may

value biodiversity conceptually while resisting conservation measures that impose economic costs. Although respondents emphasized habitat loss and encroachment as primary drivers of wildlife decline—consistent with IPBES global assessments—the comparatively lower emphasis on illegal hunting contrasts with global meta-analyses identifying overexploitation as a significant threat (Maxwell et al., 2016). This discrepancy may indicate underreporting or differential threat visibility rather than actual ecological insignificance.

Governance challenges identified in INP—including understaffing, inter-agency fragmentation, and resource limitations—mirror systemic critiques of protected area effectiveness in developing countries (Leverington et al., 2010). While enforcement-based strategies are often prioritized, empirical research demonstrates that long-term conservation success requires institutional legitimacy, participatory governance, predictable funding, and equitable benefit-sharing (Oldekop et al., 2016). Co-management initiatives in Bangladesh have demonstrated localized successes but often face challenges including limited power-sharing, elite influence, and resource constraints—issues widely documented across protected areas in the Global South. Chronic understaffing and inter-agency fragmentation observed in INP reinforce concerns regarding implementation gaps between policy intent and field-level outcomes.

Collectively, the INP case underscores a broader conservation paradox: small and degraded protected areas can retain significant biodiversity when structural heterogeneity and connectivity remain intact, yet their resilience is highly conditional. The convergence of ecological degradation, regeneration constraints, human–wildlife conflict, and governance limitations suggests increasing vulnerability under sustained anthropogenic pressure. These findings align with regional and global research demonstrating that long-term persistence of biodiversity in fragmented tropical landscapes requires integrated strategies that combine habitat restoration with native species, protection of semi-natural forest mosaics, maintenance of ecological corridors, conflict mitigation, inclusive governance, and institutionalized ecological monitoring.

By situating INP within both regional and global conservation discourse, this study contributes to the growing recognition that adaptive, connectivity-centered conservation approaches are essential for biodiversity persistence in densely populated tropical regions. The integration of floristic regeneration assessment, mammalian ecology, spatial modelling, and stakeholder analysis offers a replicable interdisciplinary framework for evaluating resilience and vulnerability in fragmented protected areas across South Asia and comparable tropical landscapes worldwide.

Chapter 11

GENERAL CONCLUSION

This study represents the first integrated ecological and governance-based evaluation of biodiversity persistence, habitat structure, regeneration dynamics, and management efficiency in a tropical protected area, Inani National Park (INP). Irrespective of its comparatively small size and vulnerable to acute anthropogenic disturbance, INP preserves disproportionately high conservation value.

INP persists to act as a refuge habitat of some important mega fauna reported by this study and supporting movement corridor within the Cox's Bazar–Chattogram forest region. The persistence of these interruption-sensitive species assists hypothetical projections that even tiny, structurally heterogeneous protected areas may possess significant biodiversity when entrenched within partially connected landscapes.

Combined field surveys and spatial modeling demonstrated significant correlation between mammalian diversity and habitat complexity. Hill forests, riparian corridors, and shrub–scattered tree mosaics showed the highest species richness which predicted habitat suitability, structural heterogeneity and predator existence. While structural degradation and governance constraints pose serious risks, evidence from vegetation regeneration, mammal occupancy, and spatial modeling indicates that ecological recovery remains achievable.

Notably, the study illustrates biodiversity persistence in INP which confined as much by governance limitations as by ecological degradation. Stakeholder evaluation recognizes encroachment, illegal extraction, grazing, and human–wildlife conflict as principal threats—challenges generally perceived in small protected areas. Thus, long-term conservation outcomes rely on incorporating ecological restoration with reinforced institutional capacity and participatory co-management frameworks.

On the whole, this research confirms that INP preserves high ecological significance in spite of degradation, however, its resilience is conditional and reversible. Without strategic restoration, connectivity planning, and governance reforms, biodiversity erosion of the park may be continued. In contrast, science-based management interventions, strengthened enforcement, corridor protection, and participatory governance could secure and elevate its conservation value within the regional forest networks.

Evidence-Based Recommendations

1. Long-Term Ecological Monitoring;

- 1) Required to establish standardized, permanent monitoring grids using camera traps and line transects to generate occupancy and population trend data for focal carnivores and large mammals.
- 2) Implementation of adaptive monitoring frameworks which can be aligned with IUCN protected area management effectiveness standards.

2. Habitat Restoration and Structural Recovery;

- 1) Prioritize natural regeneration as the primary restoration pathway, given demonstrated resilience potential,
- 2) apply assisted natural regeneration only in severely degraded patches, using native late-successional species to restore vertical structure,
- 3) phase out exotic monoculture plantations and gradually remove invasive species to enhance structural heterogeneity and
- 4) Restore riparian buffers to stabilize microclimatic conditions and improve connectivity for arboreal and terrestrial mammals.

3. Landscape Connectivity and Corridor Security

- 1) Conduct landscape-scale corridor mapping across the Cox's Bazar–Chattogram forest complex using resistance-based connectivity modeling.
- 2) Legally designate and protect ecological corridors linking INP to adjacent forest patches to maintain gene flow for wide-ranging species.
- 3) Prioritize riparian and hill-ridge corridors for strict protection, given their demonstrated role in mammal movement.

4. Species-Specific Conservation Interventions

- 1) Develop recovery and monitoring plans for the Clouded leopard, Asian elephant, and Western hoolock gibbon aligned with IUCN Species Action Planning frameworks.
- 2) Implement spatially targeted human–elephant conflict mitigation measures (e.g., early warning systems, community response teams), consistent with global best practices.
- 3) Strengthen anti-poaching patrols in carnivore core zones using SMART-based enforcement systems.

5. Governance Strengthening and Institutional Reform

- 1) Increase patrol density and enforcement frequency in identified disturbance hotspots.
- 2) Expand training in ecological monitoring, GIS, and conflict mitigation for protected area staff.
- 3) Secure sustained financial allocation for management operations, recognizing that protected area effectiveness strongly correlates with adequate resourcing.

6. Community-Based Co-Management

- 1) Expand participatory forest management frameworks to improve compliance and stewardship.
- 2) Introduce conservation-linked livelihood diversification programs to reduce extraction pressure.
- 3) Establish structured environmental education programs in fringe communities to build long-term conservation support.
- 4) A co-management framework should clearly define the roles, responsibilities, and benefits of both local communities and conservation agencies. Communities should be involved in decisions concerning wildlife and natural-resource management, while mechanisms such as community conservation agreements, livelihood-support initiatives, and benefit-sharing schemes should provide tangible incentives for continued participation.

7. Policy Integration and Adaptive Planning

- 1) Incorporate empirical findings into updated management plans for INP.
- 2) Develop buffer zone restoration strategies to reduce edge effects.
- 3) Align biodiversity planning with regional development and refugee settlement management to reduce cumulative landscape pressure.

APPENDICES

Appendix-1

Table: Camera ID, location, setup–recovery period, number of operational days, and number of events recorded in Inani National Park

Camera Station Label	Camera ID	Setup		Recovery		Number of Days Operational	Number of Events of Mammal Species
		Date	Time	Date	Time		
C01L1	Cam01L1	27-Nov-22	12:17	25-Nov-23	14:53	363	28
C02L1	Cam02L1	27-Nov-22	12:44	17-Feb-23	11:08	82	11
C02L2	Cam02L2	08-Mar-23	11:38	29-Nov-23	9:35	266	42
C03L1	Cam03L1	27-Nov-22	14:09	23-Dec-22	11:40	26	2
C03L2	Cam03L2	23-Dec-22	12:14	22-Jun-23	13:38	181	66
C04L1	Cam04L1	27-Nov-22	13:36	26-Jan-23	15:03	60	17
C04L2	Cam04L2	26-Jan-23	15:23	28-Nov-23	10:05	306	188
C05L1	Cam05L1	27-Nov-22	8:45	11-Feb-23	10:20	76	6
C05L2	Cam05L2	11-Feb-23	12:08	28-Nov-23	12:52	290	45
C06L1	Cam06L1	27-Nov-22	9:07	24-Jan-23	11:12	58	7
C06L2	Cam06L2	03-Feb-23	16:38	02-Jul-23	10:03	149	33
C06L3	Cam06L3	17-Jul-23	15:16	29-Nov-23	9:01	135	33
C07L1	Cam07L1	27-Nov-22	9:42	14-Mar-23	8:45	107	19
C07L2	Cam07L2	14-Mar-23	15:50	23-Jun-23	11:54	101	14
C08L1	Cam08L1	28-Nov-22	9:18	12-Feb-23	11:49	76	11
C08L2	Cam08L2	12-Feb-23	13:22	17-Feb-23	11:30	5	4
C08L3	Cam08L3	19-Feb-23	13:05	29-Aug-23	10:30	191	40
C09L1	Cam09L1	29-Nov-22	11:36	24-Dec-22	8:12	25	14
C09L2	Cam09L2	24-Dec-22	8:39	11-Jun-23	14:54	169	70
C09L3	Cam09L3	12-Jun-23	7:20	25-Nov-23	9:05	166	47
C10L1	Cam10L1	28-Nov-22	10:48	31-Dec-22	10:51	33	3
C10L2	Cam10L2	31-Dec-22	12:05	14-Jun-23	16:22	165	16
C10L3	Cam10L3	22-Jun-23	14:53	28-Nov-23	9:12	159	32
C11L1	Cam11L1	30-Nov-22	9:34	20-Nov-23	11:10	355	209
C12L1	Cam12L1	02-Dec-22	9:12	15-Jun-23	7:55	195	76
C12L2	Cam12L2	27-Jun-23	10:07	01-Dec-23	10:27	157	55
C13L1	Cam13L1	30-Nov-22	16:32	28-Dec-22	16:56	28	3
C13L2	Cam13L2	08-Jan-23	10:03	30-Oct-23	9:43	295	29
C13L3	Cam13L3	30-Oct-23	10:41	12-Nov-23	8:39	13	7
C14L1	Cam14L1	01-Dec-22	12:59	11-Jul-23	14:43	222	92
C14L2	Cam14L2	11-Jul-23	14:52	20-Nov-23	11:35	132	26
C15L1	Cam15L1	28-May-23	11:25	29-Nov-23	8:57	185	21
				TOTAL		4771	1266

Appendix-2

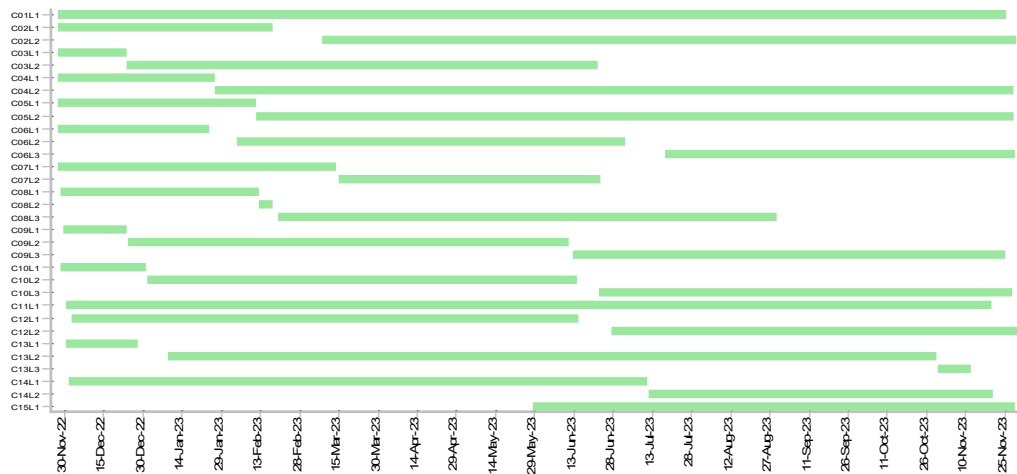


Figure. Sampling history of camera traps at each camera station during the whole study period.

Appendix-3

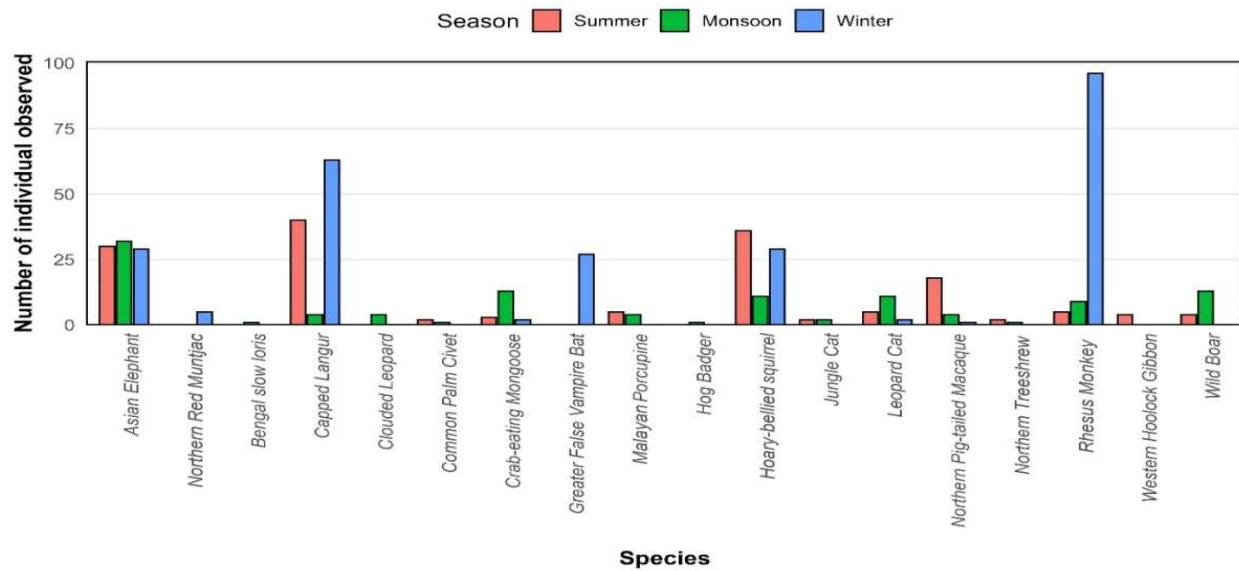


Figure. Seasonal variation in species composition and abundance of mammals in Inani National Park.

Appendix-4

Table: Calculation of the strata area.

SL No.	Strata/Class	Number of Polygon	Minimum Polygon Area (ha)	Maximum Polygon Area (ha)	Average Polygon Area (ha)	Total Area (ha)
1	Hill Forest	391	0.50	49.80	2.60	1015.89
2	Forest Plantation	38	0.51	55.05	7.61	289.37
3	Shrub with Scattered Trees	85	0.51	3325.29	44.54	3785.73
4	Orchard and Other Plantations (Trees)	11	0.53	3.12	1.21	13.29
5	Rural Settlement	84	0.54	165.79	9.42	790.90
6	Rivers and Khals	7	0.59	22.04	6.29	44.04
7	Lake	1	0.94	0.94	0.94	0.94
8	Fresh Water Aquaculture	1	1.17	1.17	1.17	1.17
9	Multiple Crop	58	0.51	34.32	3.31	192.23
10	Single Crop	131	0.51	250.81	5.53	724.78
Total		807				6858.34

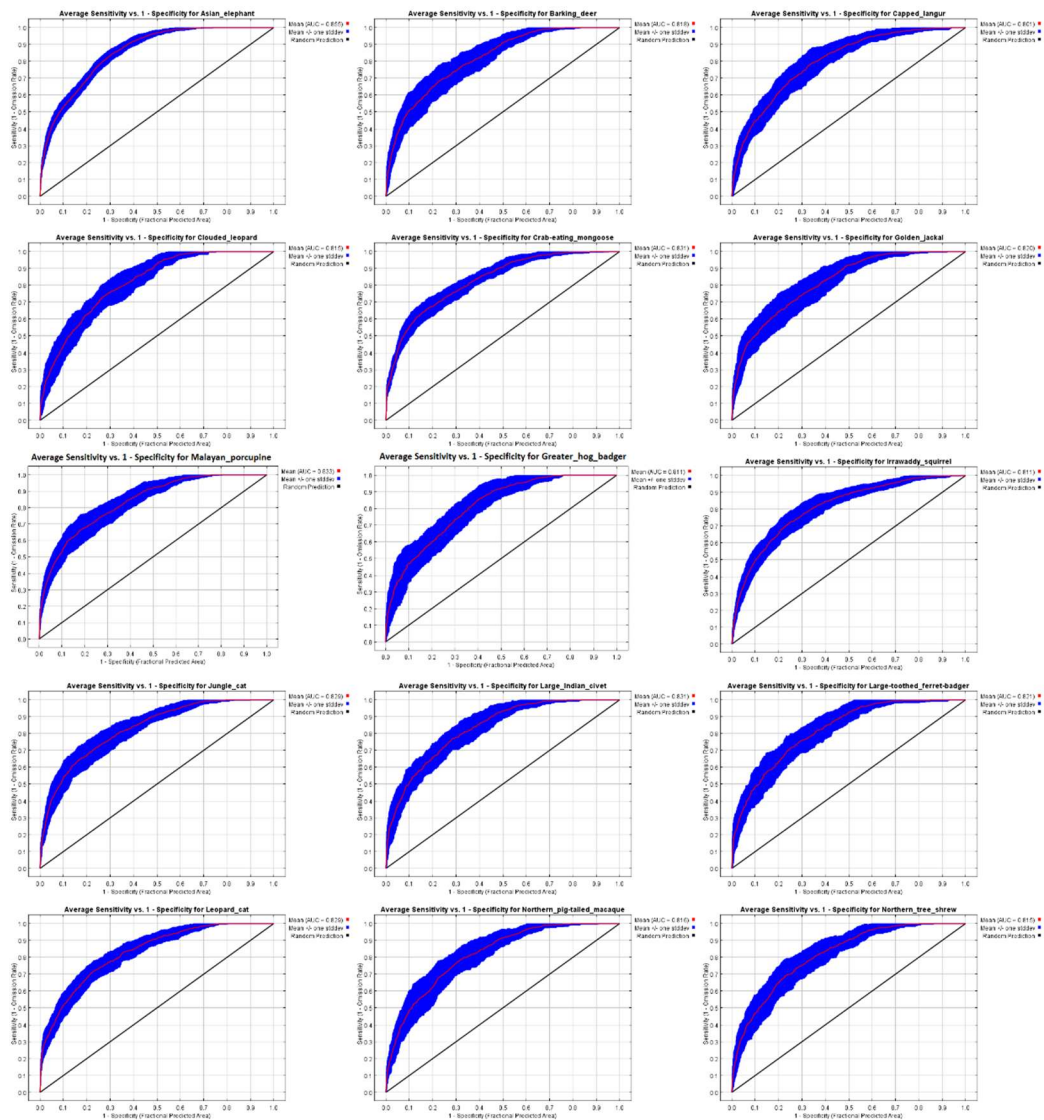
Appendix-5

Table: Environmental variables considered for the model

Sl. No.	Variables
1.	Annual mean temperature
2.	Mean diurnal range
3.	Isothermality
4.	Temperature seasonality
5.	Maximum temperature of the warmest month
6.	Minimum temperature of the coldest month
7.	Temperature annual range
8.	Mean temperature of the wettest quarter
9.	Mean temperature of the driest quarter
10.	Mean temperature of the warmest quarter
11.	Mean temperature of the coldest quarter
12.	Annual precipitation
13.	Precipitation of the wettest month
14.	Precipitation of the driest month
15.	Precipitation seasonality
16.	Precipitation of the wettest quarter
17.	Precipitation of the driest quarter

18.	Precipitation of the warmest quarter
19.	Precipitation of the coldest quarter
20.	Elevation
21.	Slope
22.	Normalized Difference Vegetation Index (NDVI)
23.	Normalized Difference Water Index (NDWI)
24.	Bare Soil Index (BSI)
25.	Normalized Difference Built-up Index (NDBI)
26.	Land cover
27.	Proximity to Rivers and Lakes

Appendix-6



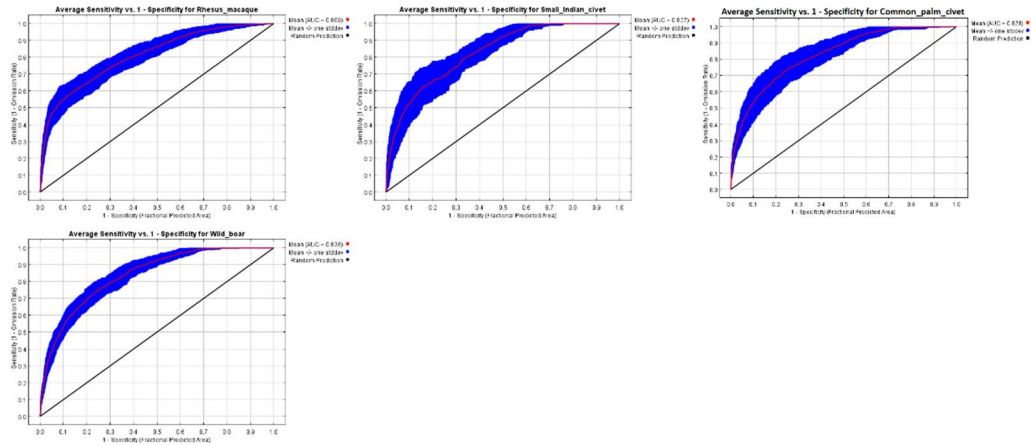


Figure: The Area under the curve (AUC) for different species

Appendix 7:

Table: Specification of phytosociological parameters and biodiversity indices for tree species in the INP

Phytological attributes	Formula	Note and References
Density	$x = \frac{a}{b}$	Where, x is the density (Shukla & Chandel, 1994), a is the total number of individuals of a species in all the plots, b is the total number of plots.
Frequency	$y = \frac{c}{b}$	Where, y is the frequency (Shukla & Chandel, 1994), c is the total number of plots in which the species occurs, b is the total number of plots.
Abundance	$z = \frac{a}{c}$	Where, z is the abundance (Shukla & Chandel, 1994), a is the total number of individuals of a species in all the plots, c is the total number of plots in which the species occurs.
Basal Area	$d = \frac{22}{7} * (\frac{dbh}{2})^2$	Where, d is the basal area (Ulfah et al., 2019).
Basal Area/ha	$BA = \frac{\sum \frac{22}{7} * \frac{dbh^2}{4}}{\sum \text{Area of all quadrate}} * 10000$	
No. of Trees/ha	$\text{No. of Trees/ha} = \frac{\text{No. of individuals of a species}}{\sum \text{Area of all quadrate}} * 10000$	

	$RD = \frac{n}{N} * 100$	Where, RD is relative density (Dallmeier, 1992; Misra, 1968), n is the number of individuals of a species, N is the total number of individuals of all the species.
Relative Frequency	$RF = \frac{y_i}{\sum_{i=1}^k y_i} * 100$	Where, RF is relative frequency (Dallmeier, 1992; Misra, 1968), y_i is the frequency of i species.
Relative Dominance	$RDo = \frac{d_i}{\sum_{i=1}^k d_i} * 100$	Where, RDo is relative dominance (Dallmeier, 1992; Misra, 1968), d_i is the basal area of i species.
Important Value Index	IVI $= RD + RF + RDo$	Where, IVI is the important value index (Dallmeier, 1992; Krebs, 1989; Misra, 1968; Shukla & Chandel, 1994).
Species Diversity Index	$S_{DI} = \frac{S}{N}$	where, S_{DI} is the species diversity index (Odum & Barrett, 1971), S the total number of species, N the total number of individuals of all the species.
Shannon-Wiener Diversity Index	$H = - \sum_{i=1}^s P_i \ln P_i$	where, H is the Shannon-Wiener diversity index (Michael, 1984), $P_i = \frac{n_i}{N}$, n_i = Number of individuals of i species, N = Total number of individuals of all species.
Shannon's Maximum Diversity Index	$H_{max} = \ln S$	where, H_{max} is Shannon's maximum diversity index (Kent, 2011), S is the total number of species.
Shannon's Equitability Index	$E_H = \frac{H}{H_{max}}$	where, E_H is Shannon's equitability index (Kent, 2011), H the Shannon-Wiener diversity index, H_{max} the Shannon's maximum diversity index.
Simpson's Diversity Index	$D = \sum_{i=1}^n P_i^2$	where, D is the Simpson's diversity index (Magurran & McGill, 2010), $P_i = \frac{n_i}{N}$, n_i = Number of individuals of i species, N = Total number of individuals of all species. As biodiversity increases, the Simpson index decreases.
Dominance of Simpson's Index	$D' = 1 - D$	where, D' is dominance of Simpson index (Magurran & McGill, 2010).
Simpson's Reciprocal Index	$D_r = \frac{1}{D}$	where, D_r is Simpson's reciprocal index (Keller, 2000).
Margalef's Diversity Index / Species Richness Index	$R = \frac{(S - 1)}{\ln(N)}$	where, R is the Margalef's diversity index or species richness index (Margalef, 1958),

		S the total number of species, N the total number of individuals of all the species.
Species Evenness Index	$E = \frac{H}{\log(S)}$	where E is the species evenness index (Pielou, 1966), H the Shannon-Winner diversity index, S the total number of species.

Appendix- 8

Table: Distribution of phytosociological attributes of recorded saplings and seedlings in Inani National Park.

Saplings			Seedlings		
Family	Scientific Name	Density (individuals ha ⁻¹)	Family	Scientific Name	Density (individuals ha ⁻¹)
1. Acanthaceae	1. <i>Avicennia alba</i> Blume	3.886	1. Anacardiaceae	1. <i>Mangifera indica</i>	19.431
2. Achariaceae	2. <i>Hydnocarpus kurzii</i>	7.772		2. <i>Swintonia floribunda</i>	3.886
3. Anacardiaceae	3. <i>Mangifera indica</i>	19.431	2. Apocynaceae	3. <i>Alstonia scholaris</i>	3.886
	4. <i>Swintonia floribunda</i>	3.886	3. Arecaceae	4. <i>Areca catechu</i>	11.659
4. Apocynaceae	5. <i>Holarrhena antidysenterica</i> (L.) Wall. ex Decne	3.886	4. Bignoniaceae	5. <i>Stereospermum colais</i> (Buch. - Ham. ex Dillw.)	3.886
5. Arecaceae	6. <i>Areca catechu</i>	50.520	5. Bixaceae	6. <i>Bixa orellana</i> L.	7.772
6. Bignoniaceae	7. <i>Oroxylum indicum</i> (L.) Benth. ex Kurz	3.886	6. Boraginaceae	7. <i>Cordia grandis</i> Roxb.	31.090
7. Burseraceae	8. <i>Protium serratum</i> (Wall. ex DC.) Engler	23.317	7. Burseraceae	8. <i>Garuga pinnata</i>	3.886
8. Cannabaceae	9. <i>Trema orientalis</i> (L.) Blume	19.431		9. <i>Protium serratum</i> (Wall. Ex DC.) Engler	31.090
9. Clusiaceae	10. <i>Garcinia cowa</i> Roxb. ex DC.	7.772	8. Cannabaceae	10. <i>Trema orientalis</i>	15.545
10. Combretaceae	11. <i>Terminalia chebula</i>	3.886	9. Clusiaceae	11. <i>Garcinia cowa</i> Roxb. ex DC.	15.545
11. Crypteroniaceae	12. <i>Crypteronia paniculata</i>	3.886	10. Combretaceae	12. <i>Anogeissus acuminata</i>	3.886

				(Roxb. ex DC.) Guill. et Perr.	
12. Dichapetalaceae	13. <i>Dichapetalum gelonioides.</i> (Roxb.)	3.886		13. <i>Terminalia chebula</i>	7.772
13. Dipterocarpaceae	14. <i>Anisoptera scaphula</i>	3.886	11. Dichapetalaceae	14. <i>Dichapetalum gelonioides.</i> (Roxb.)	15.545
	15. <i>Dipterocarpus turbinatus</i>	11.659	12. Dipterocarpaceae	15. <i>Anisoptera scaphula</i>	3.886
14. Ebenaceae	16. <i>Diospyros pilosula</i>	23.317	e	16. <i>Dipterocarpus turbinatus</i>	69.951
	17. <i>Diospyros toposia</i>	3.886	13. Ebenaceae	17. <i>Diospyros nigricans</i> Wall. ex Hiern	15.545
15. Euphorbiaceae	18. <i>Macaranga denticulata</i> (Blume.) Muell.-Arg.	46.634		18. <i>Diospyros pilosula</i> (A.DC.) Wall. ex Hiern	143.789
	19. <i>Mallotus nudiflorus</i>	3.886		19. <i>Diospyros toposia</i>	11.659
	20. <i>Mallotus roxburghianus</i>	3.886	14. Elaeocarpaceae	20. <i>Elaeocarpus floribundus</i>	3.886
	21. <i>Sapium baccatum</i> Roxb.	7.772	15. Euphorbiaceae	21. <i>Macaranga denticulata</i> (Blume.) Muell.-Arg.	124.358
16. Fabaceae	22. <i>Acacia auriculiformis</i>	69.951		22. <i>Shirakiopsis indica</i>	11.659
	23. <i>Caesalpinia sappan</i> L.	23.317	16. Fabaceae	23. <i>Acacia auriculiformis</i>	233.171
	24. <i>Cajanus cajan</i>	15.545		24. <i>Archidendron clypearia</i> (Jack) I. C. Nielsen	11.659
	25. <i>Cassia fistula</i> L.	3.886		25. <i>Caesalpinia sappan</i> L.	15.545
	26. <i>Derris robusta</i> (Roxb. ex DC.) Benth.	3.886		26. <i>Dalbergia ovata</i> Graham ex Benth.	11.659
	27. <i>Ormosia robusta</i> (Roxb.) Baker	11.659		27. <i>Derris robusta</i> (Roxb. ex DC.) Benth.	34.976

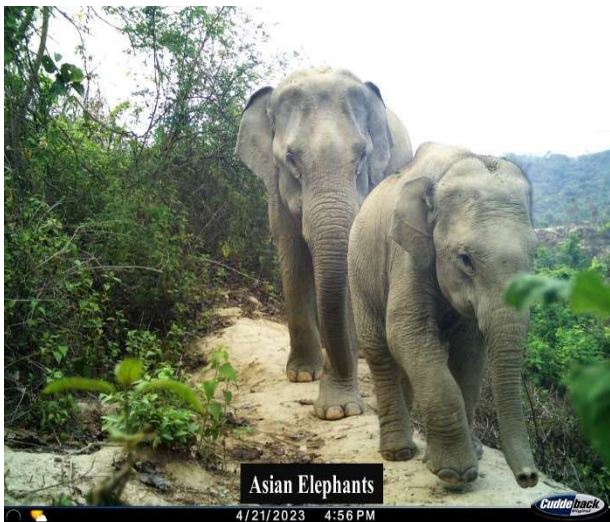
	28. <i>Pithecellobium angulatum</i> Benth.	3.886		28. <i>Ormosia robusta</i> (Roxb.) Baker	50.520
	29. <i>Senna siamea</i> (Lamk.) Irwin & Barneby	3.886		29. <i>Sesbania grandiflora</i> Pers	58.293
	30. <i>Sesbania grandiflora</i> Pers	42.748	17. Fagaceae	30. <i>Castanopsis indica</i>	81.610
17. Fagaceae	31. <i>Castanopsis indica</i>	19.431	18. Flacourtiaceae	31. <i>Hydnocarpus laurifolia</i> (Dennst.)	3.886
18. Lamiaceae	32. <i>Callicarpa macrophylla</i> Vahl	11.659	19. Gentianaceae	32. <i>Fagraea ceilanica</i>	7.772
	33. <i>Gmelina arborea</i>	7.772	20. Lamiaceae	33. <i>Callicarpa macrophylla</i> Vahl	34.976
	34. <i>Tectona grandis</i>	3.886		34. <i>Vitex glabrata</i> R.Br.	66.065
	35. <i>Vitex glabrata</i> R.Br.	3.886	21. Lauraceae	35. <i>Actinodaphne angustifolia</i> Ness	7.772
19. Lythraceae	36. <i>Lagerstroemia parviflora</i>	7.772		36. <i>Cinnamomum glaucescens</i> (Nees) Hand.-Mazz	23.317
	37. <i>Lagerstroemia speciosa</i>	31.090		37. <i>Cinnamomum iners</i> Reinw. ex Blume	7.772
20. Malvaceae	38. <i>Brownlowia elata</i> Roxb.	34.976		38. <i>Litsea monopetala</i>	3.886
	39. <i>Grewia abutilifolia</i> W. Vent ex Juss.	27.203	22. Lythraceae	39. <i>Lagerstroemia parviflora</i>	19.431
	40. <i>Grewia nervosa</i> (Lour.) Panigr.	31.090		40. <i>Lagerstroemia speciosa</i>	85.496
21. Meliaceae	41. <i>Aphanamixis polystachya</i>	15.545	23. Malvaceae	41. <i>Brownlowia elata</i> Roxb.	69.951
22. Moraceae	42. <i>Ficus racemosa</i> L.	19.431		42. <i>Grewia abutilifolia</i> W. Vent ex Juss.	73.838

	43. <i>Ficus semicordata</i> Buch.-Ham. ex Smith	27.203		43. <i>Grewia nervosa</i> (Lour.) Panigr.	291.464
23. Myristicaceae	44. <i>Knema bengalensis</i>	15.545		44. <i>Pterospermum semisagittatum</i>	3.886
	45. <i>Myristica linifolia</i> Roxb.	3.886	24. Meliaceae	45. <i>Aphanamixis polystachya</i>	34.976
24. Myrsinaceae	46. <i>Maesa indica</i> (Roxb.) A. DC.	38.862		46. <i>Swietenia mahagoni</i>	3.886
25. Myrtaceae	47. <i>Syzygium cumini</i> (L.) Skeels	15.545		47. <i>Walsura robusta</i> Roxb.	11.659
	48. <i>Syzygium grande</i> (Wit.) Walp.	15.545	25. Moraceae	48. <i>Artocarpus chama</i>	3.886
	49. <i>Syzygium oblatum</i>	3.886		49. <i>Broussonetia papyrifera</i>	11.659
	50. <i>Syzygium syzgioides</i>	3.886		50. <i>Ficus racemosa</i> L.	256.489
26. Phyllanthaceae	51. <i>Antidesma ghaesambilla</i> Gaertn.	46.634		51. <i>Ficus semicordata</i> Buch.-Ham. ex Smith	58.293
	52. <i>Glochidion arborescens</i> Blume	31.090	26. Myristicaceae	52. <i>Knema bengalensis</i>	38.862
27. Proteaceae	53. <i>Grevillea robusta</i>	3.886		53. <i>Knema linifolia</i>	3.886
28. Putranjivaceae	54. <i>Drypetes eglandulosa</i> (Roxb.) Pax & K.Hoffm.	3.886	27. Myrsinaceae	54. <i>Maesa indica</i> (Roxb.) A. DC.	66.065
29. Rubiaceae	55. <i>Mitragyna rotundifolia</i>	15.545	28. Myrtaceae	55. <i>Syzygium cumini</i> (L.) Skeels	128.244
	56. <i>Morinda citrifolia</i>	7.772		56. <i>Syzygium grande</i> (Wit.) Walp.	50.520
	57. <i>Neolamarckia cadamba</i>	7.772		57. <i>Syzygium syzgioides</i>	31.090
	58. <i>Pavetta indica</i>	3.886		58. <i>Syzygium nervosum</i> DC.	31.090

30. Salicaceae	59. <i>Flacourtia indica</i> (Burm.f.) Merr.	27.203	29. Phyllanthaceae	59. <i>Antidesma ghaesambilla</i> Gaertn.	120.472
31. Sapindaceae	60. <i>Lepisanthes rubiginosa</i>	3.886		60. <i>Glochidion arborescens</i> Blume	174.879
32. Sapotaceae	61. <i>Palaquium polyanthum</i>	3.886	30. Putranjivaceae	61. <i>Drypetes eglandulosa</i> (R oxb.) Pax & K.Hoffm.	11.659
33. Tamaricaceae	62. <i>Tamarix gallica</i>	3.886	31. Rubiaceae	62. <i>Mitragyna rotundifolia</i>	97.155
34. Vitaceae	63. <i>Leea indica</i> (Burm. f.) Merr.	3.886		63. <i>Morinda citrifolia</i>	7.772
Total		940.452		64. <i>Neolamarckia cadamba</i>	11.659
				65. <i>Pavetta indica</i>	54.407
			32. Rutaceae	66. <i>Acronychia pedunculata</i>	3.886
			33. Salicaceae	67. <i>Flacourtia indica</i> (Burm.f.) Merr.	23.317
			34. Sapindaceae	68. <i>Litchi chinensis</i> Sonn.	7.772
			35. Sapotaceae	69. <i>Palaquium polyanthum</i>	7.772
			36. Tamaricaceae	70. <i>Tamarix gallica</i>	58.293
			37. Verbenaceae	71. <i>Phyla nodiflora</i> (L.) Greene	7.772
			Total		3073.977

GLIMPSES OF FIELD ACTIVITIES





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