

**STUDY ON DISTRIBUTION AND RELATIVE ABUNDANCE OF LARGE MAMMALS  
AND IMPACTS OF HUMAN DISTURBANCE IN AND AROUND MEHAO WILDLIFE  
SANCTUARY, ARUNACHAL PRADESH**

**A THESIS**

**Submitted by**

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Registration No: 17247

For the award of the Degree of  
**DOCTOR OF PHILOSOPHY**  
**IN**  
**WILDLIFE SCIENCE**

**Under the guidance of**  
**(Dr. Gopi G.V.)**

**WILDLIFE INSTITUTE OF INDIA**



**Thesis submitted to the**  
**Saurashtra University,**  
**Rajkot (Gujarat)**





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## DECLARATION

I hereby declare that the work conducted under the thesis titled “**Study on distribution and relative abundance of large mammals and impacts of human disturbance in and around Mehao Wildlife Sanctuary, Arunachal Pradesh**”, is a record of original research work, done by me and subsequently submitted for the award of the degree of Doctor of Philosophy in Wildlife Science to Saurashtra University, Rajkot. This research work has been carried out under the guidance and supervision of Dr. Gopi G.V., Scientist-F, Wildlife Institute of India. The work has not formed the basis for the award of any other degree, diploma or any other qualification. I also declare that the thesis embodies my own work, analysis, observation and understanding and the particulars given in it are true to the best of my knowledge.

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This is to certify that the thesis by **Mr. Arif Ahmad** titled “**Study on distribution and relative abundance of large mammals and impacts of human disturbance in and around Mehao Wildlife Sanctuary, Arunachal Pradesh**” is an original and independent research work submitted to the **Saurashtra University, Rajkot (Gujarat)**, for the award of the degree of **Doctor of Philosophy in Wildlife Science**.

**Mr. Arif Ahmad** has put more than six semesters of research work embodied in this thesis under my guidance and supervision. The work presented in this thesis has not been submitted to any other University or Institute for the award of any degree, diploma or distinction.

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I certify that the research work was appreciated by all who were present, and the comments made by the faculty and researchers have been appropriately included in the thesis.

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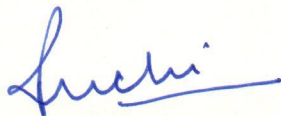
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*To be an ecologist is to live  
"alone in a world of wounds."  
- Aldo Leopold (1953)*

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*Leopold, A. (1953) Round River: from the journals of Aldo Leopold. L. B. Leopold, editor. Oxford University Press, New York, New York.*

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*I dedicate this thesis to my Family.*

**ARIF AHMAD**

## Executive Summary

Northeast India comprises Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, and Tripura. The remoteness of the territory, challenging terrain, and the high hunting pressures exerted by people in many regions of the area make it extremely difficult to document the region's biodiversity. With around 250 species, Northeast India has the most considerable mammalian diversity in India. Many of these are in jeopardy. Seven of India's 11 'Critically Endangered' mammal species have been identified in this region.

Arunachal Pradesh is one of the "seven sister states" of India's northeast. It is India's easternmost state, bordering three neighbouring countries. China connects the north, while Myanmar and Bhutan border east and west. The state's broad geographical area is 83,743 km<sup>2</sup>. The elevation varies from 50 m to 7000 m, resulting in a wide range of forest types, including tropical, subtropical, temperate, and alpine. There are 154 different species of mammals in Arunachal Pradesh, making it the only state having the tiger (*Panthera tigris*), leopard (*Panthera pardus*), clouded leopard (*Neofelis nebulosa*), and snow leopard (*Panthera uncia*). With a wide range of religious and cultural practices and numerous languages and dialects, the state is home to 26 tribes and 110 subtribes. According to the most recent assessment, the state's forest cover covers 66,688 km<sup>2</sup>, or 79.6% of its total area (FSI 2019). Global Forest Watch (2020) reports that the forest cover has been decreasing and is now 74%.

Terrestrial mammals are an essential component of tropical forest ecosystems because they are a diverse and rich component of this biome. Regrettably, they face severe global risks, such as hunting, habitat degradation, and habitat fragmentation. To develop effective conservation strategies, it is crucial to comprehend how human-altered landscapes in the tropics affect mammal communities. Northeast India's tropical forest is a hotspot for biodiversity and is home to many mammalian species. The main issue they are dealing with is the shrinking and fragmentation of forests and wildlife habitats caused by human activities. Agriculture and forest resources are expanding quickly in the tropics to keep up with the increased human need for food, fiber and timber. Understanding how human-modified environments in the tropics affect mammal communities is becoming increasingly crucial in reconciling conservation and development. The biodiversity conservation in tropical rainforests remains at risk due to habitat loss, hunting, land-use change, and deforestation.

The current study focuses on Mehao Wildlife Sanctuary (Mehao WLS), Lower Dibang Valley district, Arunachal Pradesh. We performed the first systematic camera trapping study to assess the diversity of terrestrial mammals in the Mehao WLS. A deliberate attempt was made to place camera trap units near stream beds, animal pathways, and other locations where the preliminary sign survey indicated the presence of animals. A camera trap survey was used to record the sanctuary's occurrence and relative abundance of mammals.

We evaluate and quantify land use/land cover (LULC) change to highlight spatial characteristics and identify drivers of LULC change. Nevertheless, we also study the consequences of human-induced LULC change on protected areas in this area. We utilise landscape metrics to quantify changes in the pattern and extent of cover types. LULC change in and around Mehao WLS between 1998 and 2020 is identified and quantified by the study using geospatial technology. To gain an ecological understanding of the climatic, topographic, landscape composition, vegetation, and human influence variables, a multiscale distribution modelling approach was carried out for a few mammalian species using the GAM method. We are recognising the relevant scales that influence species distribution and determining the regions in the human-dominated landscape of Arunachal Pradesh where these species can coexist.

We employed single-season occupancy models to identify the variables influencing the probability of mammalian species detection and their use of space in the landscape. We identified 27 mammalian species in our study. On the IUCN Red List, twelve of these species are "threatened." We detected clouded leopard (*Neofelis nebulosa*), marbled cat (*Pardofelis marmorata*), Gongshan muntjac (*Muntiacus gongshanensis*), red goral (*Naemorhedus baileyi*), Mishmi takin (*Budorcas taxicolor*), and sambar (*Rusa unicolor*). Still, they were found to be rare in the landscape. We also report the presence record of the Asian brush-tailed porcupine in Mehao for the first time. The occupancy results revealed that all species preferred undisturbed forest habitats, with mainland serow (*Capricornis sumatraensis*) occupying most of the sanctuary's area, followed by northern red muntjac (*Muntiacus vaginalis*), yellow-throated marten (*Martes flavigula*), and masked palm civet (*Paguma larvata*). The mammals showed diverse responses to various ecological and anthropogenic variables, indicating the necessity for species-specific management measures in addition to a landscape-scale conservation approach. The outcomes of this study demonstrate the

significance of maintaining and protecting elusive and rare mammalian species in and around Mehao WLS.

The Maximum Likelihood Classifier (MLC) was used to build LULC maps through supervised classification. We chose to map eight primary LULC categories, including grassland, riverbed, built-up land, mixed forest, barren land, and riverine forest. These maps are the baseline for landscape metrics and change detection studies. Furthermore, this investigation also included the perceptions of local communities regarding biodiversity conservation. The results demonstrated that Mehao WLS experienced significant land use and land cover changes during the research period, including a substantial decrease in riverine and mixed forest cover. Agricultural and barren land categories increased at the expense of riverine and mixed forests. The landscape metrics analysis found that whereas other classes showed fragmentation and disaggregation trends, built-up areas and agricultural land underwent an aggregation pattern. Subsequent research found that local dependence on the forest and settlement expansion substantially impacted the process of land use/land cover change in the protected area.

Reconnaissance, camera-trap surveys, and previous systematic studies were used to collect spatial occurrence data. After accounting for spatial bias, we retained a total of 55, 135, 48, 153, 147, and 80 spatially rarified occurrence records of an Asiatic golden cat, leopard cat, Himalayan palm civet, Indian red muntjac, Mainland serow, and Wild pig, respectively, for further analysis. We predetermined 38 variables to predict the relationship between the species and their habitat. Five broad categories were used to classify the predictor variables: climatic, topography, landscape composition, vegetation, and human influence. We calculated the focal mean of each variable for each presence and pseudo-absence site across seven geographic scales: 50, 100, 200, 400, 800, 1600, and 3200m radii, based on the average dispersal distance recorded for all selected species. We utilised GAM to build multivariate models to predict the occurrence of mammalian species. In Asiatic golden cats, the scale at fine (50 m) and large scale (1600 and 3200 m) spatial extents occurred more frequently. Mainland serow and wild pigs perceive habitat variables more consistently at the fine and broadest scales. Leopard cat and Himalayan palm civet showed a strong relationship for predictor variables at the broadest scale (1600m and 3200m). The northern red muntjac preferred medium-to-large scale variables more frequently. Mainland serow and wild pigs perceive habitat variables more consistently at the fine and broadest scales. The target mammalian

species considered in this study had a significant difference between the smallest and largest spatial scales, which suggests that processes influence how the species are dispersed across various spatial scales. Our results agree with studies that explicitly observe several variables at spatial scales essential for determining the species-habitat associations in multiscale habitat modelling. All six mammal species selected different predictor variables at various spatial scales. This study's predictor variables were essential for determining the species' occurrence at various spatial scales. Our study will inspire forest management and provide them with a set of conceptual tools that they can use to manage a range of species and environments efficiently. In the interim, our findings will act as a preliminary step for conservation efforts focused on specific regions that aim to protect biodiversity from the effects of climatic and land-use changes.

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# **Chapter 1**

## General Introduction

### General Overview

Globally, biodiversity is decreasing at an alarming rate because of habitat loss, deforestation, and habitat fragmentation, which endangers the terrestrial ecosystem (Bradshaw et al., 2009a), threatens ecosystem services and human well-being (Diaz et al., 2006) and exacerbates hazardous climate change (Gullison et al., 2007). Humans have significantly impacted animal populations globally, rapidly falling in geographical distribution and extinction. (Butler, 2006; Ceballos & Ehrlich, 2002). Biodiversity is quickly diminishing because of continuing and rising anthropogenic environmental consequences. Without proper governmental action, biodiversity is predicted to decline even further.

Loss and habitat degradation, which affect 40% of species, have been highlighted as the main threat to mammals worldwide (Schipper et al., 2008). Knowing how a species uses its resources on a smaller scale, as shown by information on space usage patterns within a landscape, can help to preserve critical habitats. Various ecosystems depend on mammals to function correctly (Bryant & Bailey, 1997). To be more precise, they are essential for the survival of plant species, a significant source of protein in the food supply, and a vital tool for pest control (Eldredge, 1998). Historical, cultural, and aesthetic considerations call for preserving mammalian biodiversity (Takacs, 1996).

### Mammals in Tropical Forests and their importance

Many national and international initiatives for conserving biodiversity have tropical forests as a fundamental tenet (CBD, 2015; Panfil & Harvey, 2015). Despite occupying less than 10% of the area of the Earth, tropical forests support at least two-thirds of the world's biodiversity (Raven, 1988). Economic commodities and ecosystem services significantly improve local, regional, and global human well-being. Sadly, the future of tropical forests and the biodiversity contained within them is looking bleaker and bleaker due to unchecked deforestation and forest alteration brought on by human activities like logging, hunting, invasive species, agricultural expansion, and human settlement that make tropical forests the epicentre of current and future extinctions (Wilcove et al., 2013; Davalos et al., 2016).

Deforestation and fragmentation are frequently associated with wildlife habitat loss or decline, particularly in tropical ecosystems (Canale et al., 2012; Cardillo et al., 2005). Due to their higher species variety than other places, tropical forests are particularly susceptible to negative consequences (Rosenzweig, 1992). Numerous tropical forests are cut down yearly for agriculture (Achard et al., 2002; Etter et al., 2006). Geographically, the features that make a species sensitive to land-use change differ (Fritz et al., 2009; Newbold et al., 2012), with a high number of species in tropical forests possessing these traits (Newbold et al., 2012; Newbold et al., 2014). According to Smith (2010), tropical forests will soon face some of the highest rates of natural vegetation loss.

Since the initial research demonstrating mammals' effects on tropical (Phillips, 1931) forest regeneration, the involvement of mammals in forest dynamics has been a subject of attention. Because they comprise a diverse and abundant portion of this biome, mammals in tropical forests are particularly concerned (Ceballos et al., 2005; Schipper et al., 2008; Ahumada et al., 2011). Despite being universally threatened, these animals are constantly threatened by hunting and habitat loss.

The removal or decrease in abundance of tropical mammals will likely have an impact on forest dynamics because of their direct involvement in seed predation, seed dispersal, herbivore control, nutrient cycling, and other ecosystem functions (Hooper et al., 2005; Asquith & Meji'a-Chang, 2005; Struhsaker, 1997). According to Estes et al. (2011), mammals play a unique role in ensuring that terrestrial ecosystems continue to function correctly. If they were to disappear, the ecosystem would suffer cascade trophic impacts.

In tropical forests, mammals are crucial for seed dispersal, maintaining the forest community and structure (Stoner et al., 2007). Rodents, bushpigs, primates, and particularly elephants, which are regarded as ecosystem engineers, have all been shown to be significant agents of seed dispersal in African forest systems (Nyiramana et al., 2011; Beaune et al., 2012; Campos-Arceiz & Blake, 2011; Chapman, 1995).

### [Impacts on Mammals in Tropical Southeast Asia](#)

Northeast India, Indochina, Sundaland, and the Philippines are Southeast Asia's tropical forests and are experiencing a biological catastrophe (Wilcove et al., 2013). According to Sodhi et al.

(2004), among the principal tropical forest regions, tropical Asia has the lowest percentage of remaining natural forest cover and the highest rates of modern deforestation, primarily because of expanding Acacia, Rubber, and Oil Palm plantations (Hansen et al., 2013).

Even though numerous Southeast Asian nations have demonstrated relatively low concentrations of large mammals, including ungulates, carnivores, and primates (Desai & Vuthy, 1996; Duckworth et al., 1999; Steinmetz, 2004), commercial poaching to serve local and global markets is the leading cause of the low animal numbers that are typical of the interior of many Southeast Asian protected areas (Srikosamatara & Suteethorn, 1994; Nooren & Claridge, 2001; Sodhi et al., 2004). Although it typically has a negligible impact, subsistence hunting can be unsustainable, especially for food species that are already the targets of commercial hunting. New and committed partnerships between biologists, governments, conservation groups, and locals will be necessary to tackle the complex problems of conserving Southeast Asia's great mammals in the face of this worsening crisis.

### [Mammals of Northeast India](#)

A variety of physiography and ecoclimatic conditions can be found in Northeast India. The region's forests are highly diversified in their structure and composition, with a mix of tropical and temperate forest types, alpine meadows, and frigid deserts. With 64% of its total land area covered by forests, northeast India is frequently referred to be a region with a surplus of forests. However, the area's whole forest cover is quickly vanishing. Between 1991 and 1999, the area covered by forests fell by around 1800 square kilometres (F.S.I., 2000).

Significant amounts of Northeast India's primary vegetation have been disrupted, changed, and in some cases, destroyed by seismic activity, regular landslides, and subsequent soil erosion. While these natural factors have only slightly influenced the change in vegetation type, human activity has irrevocably altered the landscapes and caused massive biodiversity loss throughout the entire region. Numerous species have been exterminated due to human activities, severely damaging fragile natural environments. There are many places where natural ecosystems are being destroyed, which is a severe cause for concern.

The region's vast array of altitude changes and the intense rainfall and humidity that encourage lush plant growth, especially in the lower elevations, are likely responsible for the North-eastern States' wealth. It should be emphasised that all of these endangered species dwell in the hills and area's hills and valleys in constrained forest areas and are highly vulnerable to habitat loss and hunting pressures since they are found in small groups. Since lowland forests were the first to be inhabited, changed, and degraded by humans, many of their species are already in danger of going extinct.

Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, and Tripura are the states that make up northeastern India. It is challenging to record the area's fauna due to its isolation, rocky terrain, and the significant hunting impacts that people in many areas have on wildlife. With almost 250 species, NE India has the most considerable mammalian diversity in the country. Numerous of these are in danger. Seven of the 11 mammal species categorized as "Critically Endangered" have been found in NE India.

### [Mammals of Arunachal Pradesh](#)

One of the seven sibling states of northeast India is Arunachal Pradesh. It is the most eastern state in India and borders three other nations. Bhutan and Myanmar border the eastern and western portions, respectively, and China borders the north. The area of the state is 83,743 km<sup>2</sup>. The vast diversity of the woods, including tropical, sub-tropical, temperate, and alpine types, is due to the height range of 50 m to 7000 m (Behera et al., 2000). The state's five physiographic zones are the Greater Himalayan Mountains, the Lesser Himalayan Ranges, the Shiwalik Ranges, Purvanchal Ranges, and the Brahmaputra plains. Arunachal Pradesh, there are more than 100 different tribal groups, 20 of which are combined tribes with strong linguistic, cultural, and traditional ties. Territorial isolation has, nevertheless, led to different tribal identities and notable variances in language and social development (Choudhury, 2009). Two national parks and 11 animal sanctuaries are part of a network of protected areas that cover 9527.99 km<sup>2</sup>, or roughly 11.68% of the state's total land area (Sinha, 2008).

Arunachal Pradesh has 154 types of mammals (Chandra et al., 2018). The tiger *Panthera tigris*, leopard *Panthera pardus*, clouded leopard *Neofelis nebulosa*, and snow leopard *Panthera uncia* are the four most giant cats, and they are exclusively found in this one state.

## Extinction Risk in Mammals and factor Affecting the Distribution and Abundance

Understanding extinction processes is a critical concern for conservation ecology since human actions endanger the diversity of life on Earth and cause the mass extinction of non-human species (IUCN, 2010; Ceballos & Ehrlich, 2002). Mammals are imperiled globally; 27% of mammalian species are in danger of going extinct, and habitat loss and climate change have been identified as the main dangers (Isaac, 2009; Schipper et al., 2008).

According to Cardillo et al. (2005), there are "multiple ecological pathways" to extinction, with significant heterogeneity in these pathways for different mammal taxa. Mammal species are at a higher risk of extinction than other taxa. Models aiming to synthesise predictors of extinction risk across many species have likely produced low explanatory power because of this variance (Cardillo et al., 2008).

Larger animals are more susceptible, according to multiple studies looking at correlates of extinction risk in mammals, and these studies have shown that body size is a crucial determinant (Cardillo et al., 2003). Small geographic ranges, low population densities, small group sizes, slow reproduction rates, extensive home ranges, habitat modes, contractions and expansions of geographic coverage, and activity periods are other critical indicators of extinction risk in mammals globally (Purvis et al., 2000; Isaac, 2009; Davidson et al., 2009). Overall, these comparison studies show increased animal extinction danger. They have also demonstrated that a species' susceptibility to local extinctions can vary greatly (Isaac & Cowlishaw, 2004). These findings emphasise the need to study large mammals in varied locations and habitats, particularly in biodiverse and vulnerable landscapes, including rare and endemic species. This is important from the perspective of biodiversity conservation.

To determine the 25 Indian mammals' local extinction susceptibility, compare their historical and present distributions. These species and their habitats are thought to have been seriously damaged by widespread hunting, land-use changes (agricultural expansion, deforestation), and rapid economic and demographic growth during the past 100 years (Forest Survey of India, 2005; Das et al., 2006).

The consequences of humans on mammal species and their habitats have increased over the past 100 years because of rapid economic development and population rise (Forest Survey of India, 2000; Das et al., 2006). The survival of 20% of large Indian animals is reportedly in jeopardy, and others have disappeared from more than 90% of their native habitat, according to cautious estimations (Madhusudan & Mishra, 2003).

Understanding the factors that most affect the occupancy (or presence or persistence) and abundance (or density) of distinct mammal species in various forests of concern, as well as looking for similar patterns across sites, are top priorities in the science of conservation biology. This assumes that we aim to avoid the local extirpation of animal populations to prevent the further extinction of large mammals. A small number of studies have discovered strong correlations between variables and significant mammal presence or abundance in tropical forests, even though it is rare to be able to prove that a specific variable, whether natural or anthropogenic, is or has been a direct cause of a mammal species' or population's decline. In other words, these analyses have found a few 'predictors' of variation in animal persistence and abundance.

#### [Status of Knowledge on Mammals in Arunachal Pradesh](#)

Arunachal Pradesh has had several surveys and documentation on large and small mammals (Athreya, 1997; Chowdhury, 1997; Datta, 1999; Datta, 2003; Datta et al., 2008; Datta & Naniwadekar, 2008; Mishra et al., 2006; Chauhan et al., 2006; Gopi et al., 2009, 2013, 2014; Most wildlife surveys in Arunachal Pradesh have been restricted to low and mid-elevation forests and include surveys of rare species (Kaul & Ahmed, 1993; Athreya Jhonsingh, 1995; Katti et al., 1992, 1990; Kumar & Singh, 1999; Selvan et al., 2013; Roy et al., 2015). There have not been many surveys and ecological studies done in the state that have produced significant findings and information (Kumar & Singh, 1999; Datta & Goyal, 1997; Datta, 2000, 2001, Selvan et al., 2014) about new species like Leaf deer (Datta et al., 2003), Chinese goral (Mishra et al., 2004), Arunachal macaque (Mishra & Sinha, 2008; Kumar et al., 2008; Chakraborty & Ramakrishnan, 2007; Sinha et al., 2006; Sinha et al., 2005), Tibetan macaque (Kumar, 2005). Some studies on the status and distribution of Non-human primates (Ghosh et al., 2020; Das et al., 2015 and 2016; Sarma et al., 2015; Roy et al., 2015; Kumar et al., 2013 and 2014; Chakraborty, 2014; Chetry et al., 2010; Kumar et al., 2009; Mendiratta et al., 2009; Solanki et al., 2007 and 2008; Kumar & Solanki, 2008;

Alfred et al., 2004; Chetry et al., 2003; Chaudhury, 2002; Das & Srivastava, 2001; Singh, 2001; Borang & Thapliyal, 1993), squirrels (Krishna et al., 2016; Krishna & Kumar, 2017).

Aiyadurai (2010, 2011, and 2015), Chutia (2010), Selvan et al. (2013), Velho and Laurance (2013), Singh et al. (2014) conducted studies on indigenous hunting practices, as well as interactions between ethnic communities, livestock, and dhole (Lyndogh et al., 2014; Varma & Subba, 2001; Varma, 2010); conservation using traditional knowledge (Dollo et al., 2010); and conservation in communities.

In Dibang Valley, a study on the status and distribution of Gongshang Muntjac (Aiyadurai & Meme, 2015), Tiger (Adhikarimayum & Gopi, 2018), Asiatic golden cat (Nijhawan et al., 2019) was recently done. There are few studies done on mammals in the Mehao Wildlife Sanctuary (Dilip et al., 2010; Chetry et al., 2010 and 2008; Sarma et al., 2015; Sarma & Kumar, 2016; Roy et al., 2015; Chakraborty & Sen, 1991; Katti et al., 1992; Krishna & Kumar, 2017), and a report on the Mehao Wildlife Sanctuary that is unpublished by Sinha (1984).

#### Information gap and genesis of the present study

Despite such rich biodiversity, the megafauna of Mehao WLS still needs to be thoroughly explored. Apart from a few rapid surveys carried out on mammals, some studies were done using satellite imagery to understand biodiversity (Prasad et al., 1996; Areendran et al., 2018), and a few studies were done on plant species (Ahmad et al., 2020; Das, 2009; Das and Singh, 2009 and 2007; Rawat and Sahu. 2009; Rawat, 2012; Rawat & Satyanarayana, 2015), herpetofauna (Saikia et al., 2019; Das et al., 2009), lichens (Pinokyo et al., 2008). Besides these, there have not been any in-depth investigations on issues like the status, distribution, or ecology of animals in the Mehao WLS. As a result, there is a knowledge deficit about the local mammalian flora, which is crucial for the efficient management and protection of the ecosystem. This has generated a strong need and scope for research on understanding the essential ecological aspects of mammalian fauna inhabiting Mehao WLS. The study's outcome would benefit the Sanctuary conservation and management administration.

The current study was started to gather baseline data on a few ecological factors (diversity, distribution, relative abundance, activity patterns, and habitat preference) of selected large animals

in Mehao W.L.S. Additionally; an effort was made to assess the degree of wildlife-human conflict in the Mehao W.L.S. area and model the suitable habitat of a few selected large mammals there. A long-term monitoring protocol for the area could be developed by comparing the new data to the old. The management plans and legislation could be created to address any substantial changes in their state.

### Study Objectives

To estimate the relative abundance and occupancy of selected large mammals in and around Mehao wildlife sanctuary.

To analyse the land use/land cover change patterns and to identify the main driving factors.

To develop a habitat suitability model for selected large mammals in and around Mehao wildlife sanctuary.

To quantify the nature and extent of human-wildlife negative interaction in and around Mehao wildlife sanctuary.

### Research Question

1. What is the relative abundance and occupancy of selected large mammals in and around the mehao wildlife sanctuary?
2. What are the major factors responsible for land use/land cover change in the landscape of mehao wildlife sanctuary?
3. How do the distribution patterns of selected mammalian fauna change concerning different elevation gradients and habitats in and around Mehao wildlife sanctuary?
4. What are the attitudes and perceptions about the importance of large mammals and their conservation among the local communities?

### Study Period

The study period was extended from November 2017 to May 2018 and December 2019 to April 2020. The Wildlife Institute of India, Dehradun, in collaboration with the Science and Engineering

Research Board (SERB), Department of Science and Technology (DST), Government of India, initiated the research project titled "An Investigation of species occupancy patterns and niche differentiation among sympatric carnivores across varying land use and disturbance regimes in and around Mehao Wildlife Sanctuary, Arunachal Pradesh." This study was a component of that project. The Wildlife Institute of India, Dehradun, provided all the field tools and logistical assistance needed for this investigation.

#### Instruments/Equipment Used

GARMIN Etrex 30x Handheld G.P.S. for geographic position

Binoculars - 8 × 42 for field identification

Slope and canopy cover by ocular estimation

Canon 60D DSLR Camera with 70 - 300 mm lens for photo documentation

Camera traps- Cuddeback C1 and Cuddeback G model was I.R. (infrared) model.

#### Challenges and Limitations

The species' secretive or elusive nature and nocturnal habits resulted in few observations. For several animal species found in the study area, including mountain ungulates, standard photographic capture-recapture estimation techniques cannot be used since individuals are not uniquely identifiable. The undulating terrain of the sanctuary was confined by foot alone. Washing away bridges and frequent landslides during monsoons impeded field research. Many camera traps could not be tested as the trails were inaccessible during winter and pre-monsoon season due to heavy snowfall and rainfall in the study area. The sensitivity of the camera due to the low moving clouds, movement of vegetation due to wind, and movement of tourists, local people, and semi-domesticated Mithun affect camera trapping days. Malfunction of camera traps because of extremely low temperatures in the Mayodia area was also a limitation. Eight units of camera traps have been stolen from the field and could not be recovered. Pellet groups were often found in a degraded state due to incessant rain in monsoon. This scenario presents a severe limitation of conventional techniques to monitor abundances for mammals that are ecologically little studied in

the eastern Himalayan context and, in some cases, seriously threatened. Extensive fieldwork could not be conducted in the Northern part of Mehao W.L.S. due to inaccessibility.

### Organization of Thesis

The thesis is organized into six chapters, with Chapter 1 dealing with the General Introduction. Chapter 2 describes the Study Area. Chapter 3 deals with General Methodology. Chapter 4 deals with the relative abundance and occupancy of selected large mammals in and around Mehao W.L.S. Chapter 5 deals with analysing the land use/land cover change patterns and identifies the main driving factors. Chapter 6 deals with a habitat suitability model for selected large mammals in and around Mehao wildlife sanctuary.

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## **Chapter 2**

## Study Area

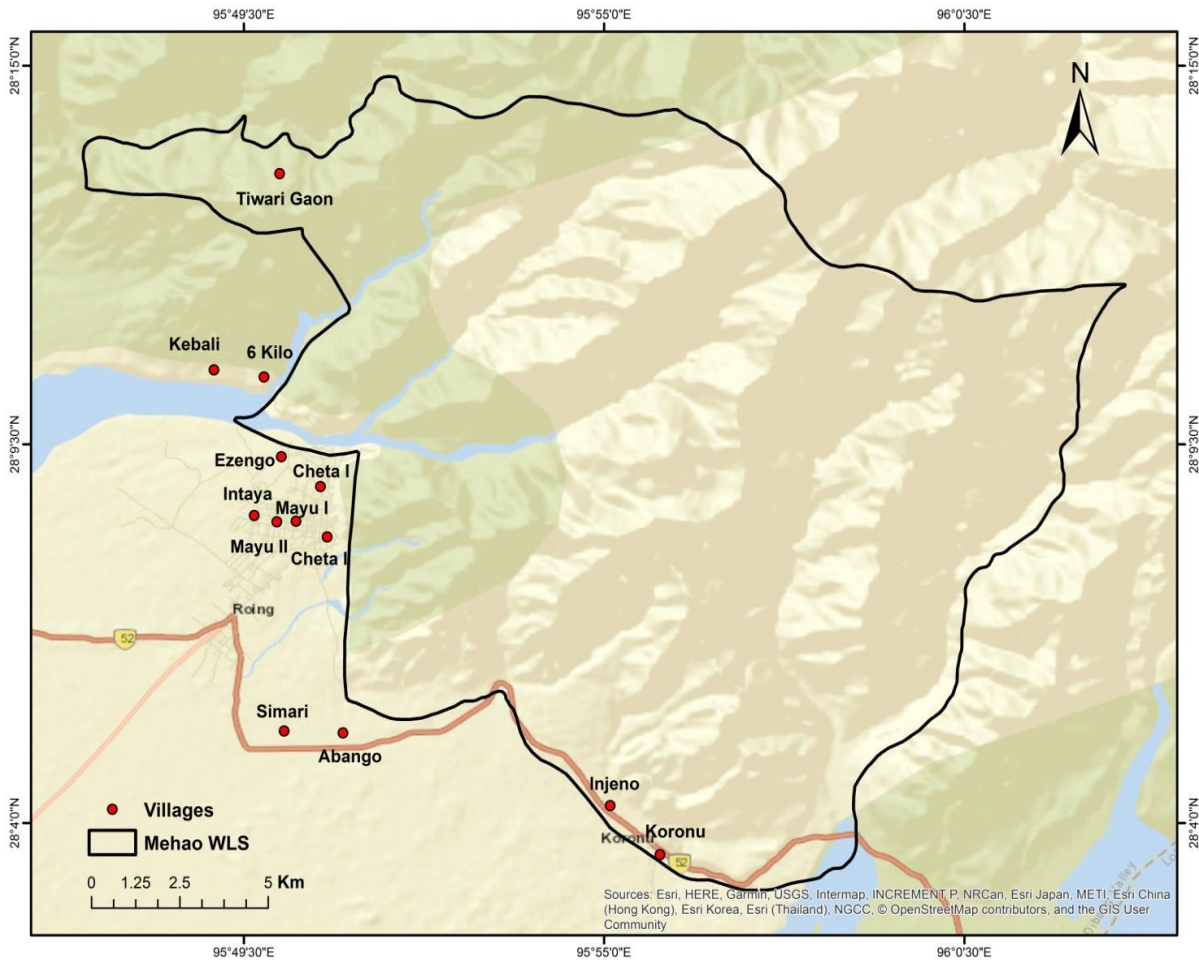
In the Lower Dibang Valley district of Arunachal Pradesh's Mehao Wildlife Sanctuary (Mehao WLS), the current study will be carried out (Fig. 2.1). Numerous wild creatures, including the Bengal tiger, hoolock gibbon, leopard, tree shrew, wild dog, and clouded leopard, call the sanctuary home. It was established in 1980. The Mehao WLS has an area of 281.5 Km<sup>2</sup> and is located between 93 30' and 95 45' east longitudes and 28 05' and 28 15' north latitude. The landscape of Mehao WLS range from the plain in the south to mountainous in the north, with an altitude between 400m and 3568m asl. Along the rivers and streams, the valleys are constrained. At various reliefs around the sanctuary, little patches of flat terrain provide habitat for species. The sanctuary's primary perennial streams are the Ashupani, Deopani, Jowe, Enjopani, and Diphu. All the streams merge to form the Lohit River, one of the major tributaries of the Brahmaputra River, which the Dibang River feeds. In between these rivers, several seasonal streams run vigorously when it rains. Mehao Lake, tiny Mehao Lake, and Sally Lake are three natural bodies of water. The sanctuary's centre is where Mehao Lake is located.

The type of forest in Mehao WLS varies with elevation. Tropical evergreen forests (900m), subtropical and temperate forests (900m-1800m), temperate broad leaf forests (1800m-2800m), and temperate conifer forests (2800m-3500m) are the different types of forests found in Mehao WLS. The area's main shrub and herb species are *Clerodendrum viscosum*, *Maesa indica*, *Tephrosia candida*, and *Solanum khaslanum*. The forest is dominated by *Terminalia myriocarpa*, *Abizzia lucida*, *Messua ferra*, *Dillenia indica*, and *Castanopsis indica*. There are many other types of bamboos, including *Dendrocalamus giganteus*, *Dendrocalamus hamitonii*, *Phyllostchy bambusoides*, *Bambussa pallida*, and *Pseudo taehiyum*. Additionally known to exist in Mehao WLS is the highly prized medicinal herb Mishmi Teeta (*Coptis teeta*).

## Climate

The sanctuary is in a subtropical climate zone. From November through February, it has distinctly chilly weather. In addition, this is the time of year with the lowest humidity. The monsoon season begins in May, and humidity begins to rise fast as temperatures climb during June, July, and August. The region is in a monsoon zone and receives precipitation from both the southwest and northeast monsoons. The southwest monsoon has an impact from May to October and is responsible for more than 80% of the annual rainfall. In February, there are frequently pre-monsoon showers.

From November to January, the northeast monsoon barely contributes 20% of the total rainfall during the winter season. The Sanctuary is warmer in the lower altitudes, whereas it is cooler in the higher altitudes. The summertime temperature in the low altitude is roughly 38°C. It ranges in the winter from 4°C to 12°C. In higher altitudes, the summertime temperature is about 12°C, and the wintertime temperature drops to -3°C when snow begins to fall on the high hills. The temperature distribution, however, fluctuates from year to year (Sha, 2010).



**Figure 2. 1: Study map of Mehao Wildlife Sanctuary**

### Demography

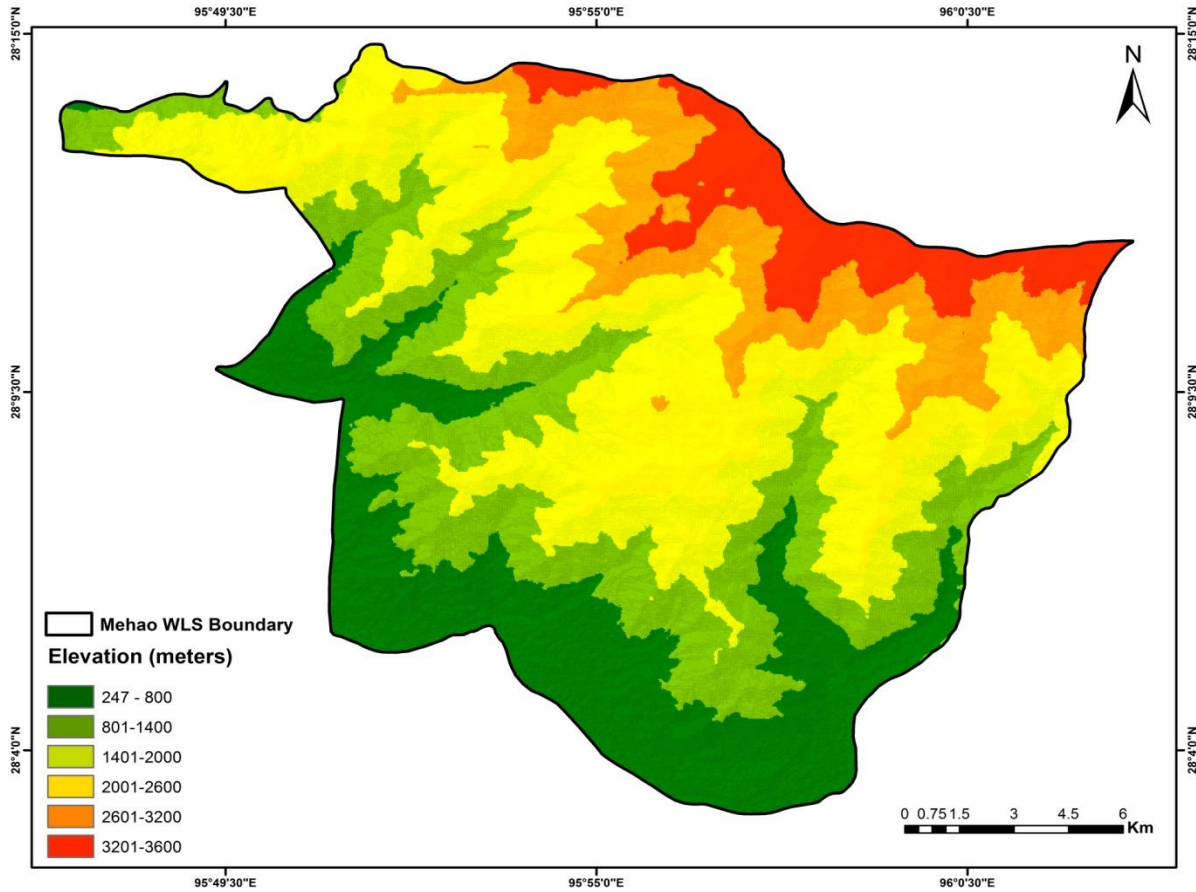
The two largest populations surrounding the Mehao WLS are the Idu Mishmi and the Adi. Although they are of Tibeto-Burman descent and practice animism, the Idu Mishmi also include some Buddhist practices in their beliefs because of Buddhism's influence. While the Idu Mishmis

traditionally rule the region from the foothills onward, Adis typically live in the lowlands from Shantipur to Roing. The area has sizable populations of Assami, Bihari, and Nepalis. Most work as workers who share in the harvest while cultivating land for the Idu Mishmis. Along the park's perimeter are many Idu Mishmi villages, including Koronu, Injuno, Abango, Balek, Kanu, and Tiwarigaon. Gibbon hunting is strictly forbidden by the Idu Mishmi, which may be why the species is so prevalent there.

### Elevation

Downloaded from USGS-Earth Explore, the DEM created from the SRTM 90m DEM file was used to analyse the topographic changes caused by altitude. According to the derived DEM, the elevation varies from a minimum of 240 metres to 3600 metres. The sanctuary was divided into six groups (Fig. 2.2). The park's southern region is where you will find the lowest elevation (240 m to 800 m). The northern region of the WLS has the highest height (2601 m to 3600 m). In the sanctuary's centre, you may view more elevation ranges.

Most of the park is between 820 and 1400 metres above sea level (22%), whereas just 7% of its total area is between 3200 and 3600 metres above sea level. Between 1401 m and 2500 m, around 37% of the area is located. (Table 2.1).



**Figure 2. 2: Elevation distribution map of Mehao WLS**

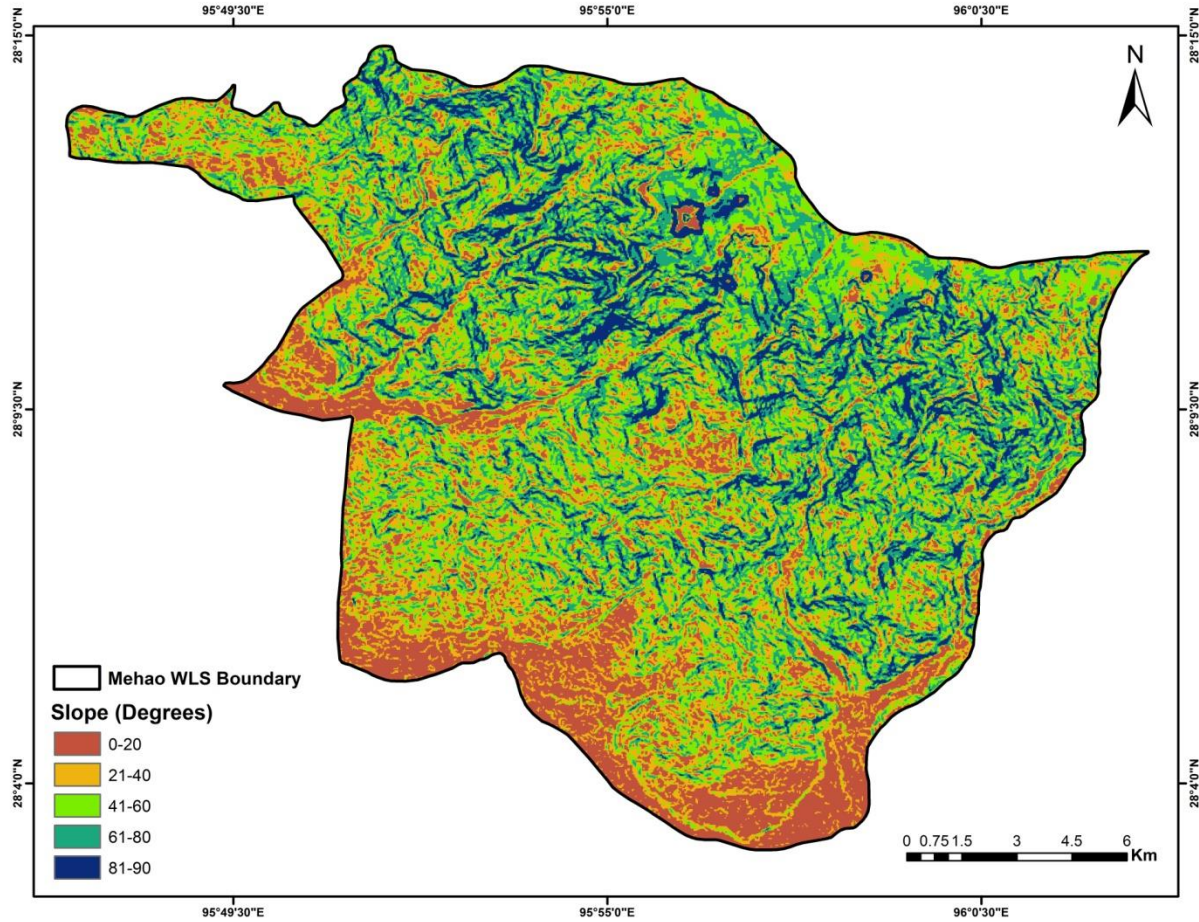
**Table 2. 1: Area (sq km) within different elevation zones in Mehao WLS**

Elevation(m)	Area (sq km)
<b>247-800</b>	<b>64.18</b>
<b>801-1400</b>	<b>66.29</b>
<b>1401-2000</b>	<b>60.90</b>
<b>2001-2600</b>	<b>49.84</b>
<b>2601-3200</b>	<b>33.52</b>
<b>3201-3600</b>	<b>23.04</b>

### Slope

Based on the calculated slope, the region was classified into five categories (Fig. 2.3). The slope varies from completely flat regions of 0° to steepest gradients of 89°. The southern region of the WLS has the most low-lying areas with the slightest slope. The northern and central portions of

the sanctuary also have a few low-lying minimum slope zones. Most of the area lies within 41° - 60°, which is 27%. About 23% area lies within 61°-80°. Slope ranging from 81°-90° covers 10% of the area (Table 2.2).



**Figure 2. 3: Distribution of slope in Mehao Wildlife Sanctuary**

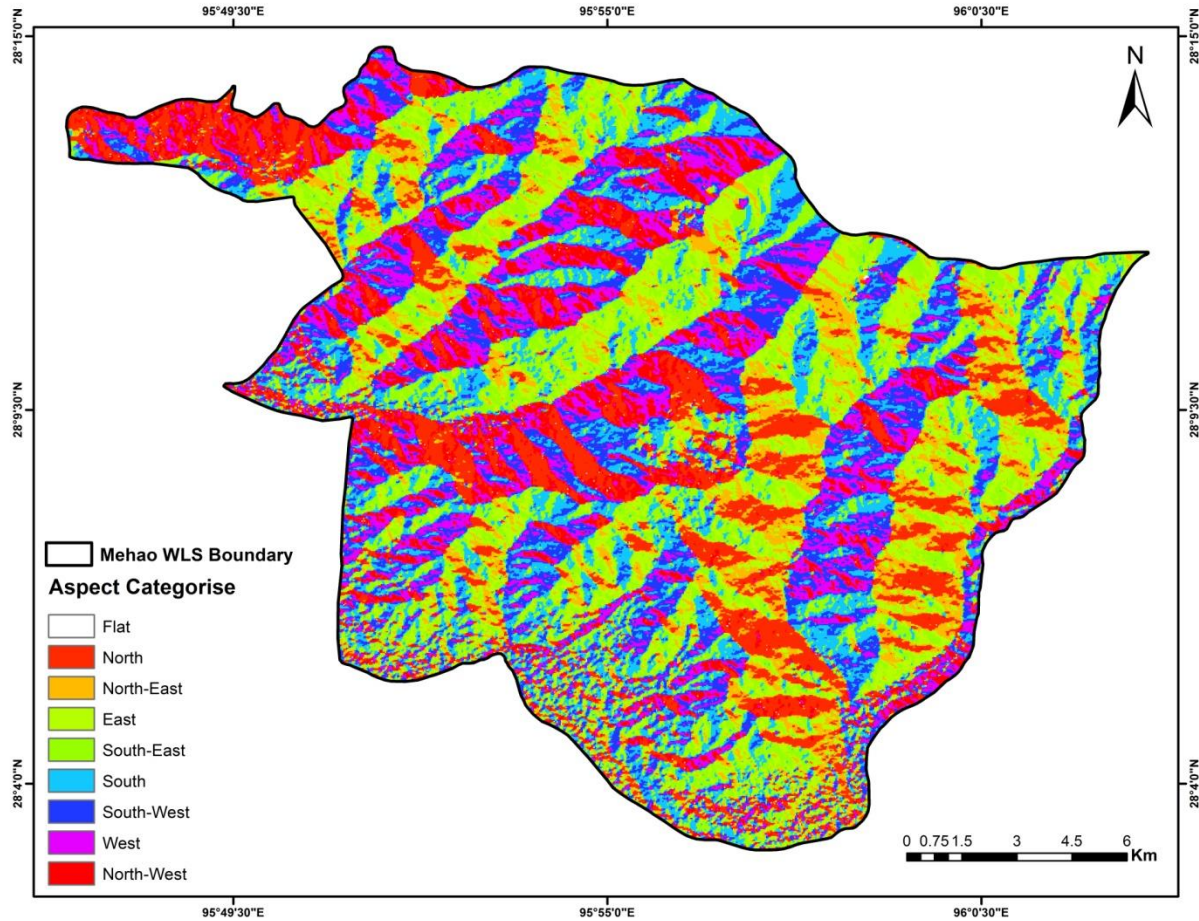
**Table 2. 2: Area and percentage distribution within slope categories in Mehao WLS**

<b>Slope (Degrees)</b>	<b>Area (sq km)</b>	<b>Percentage</b>
<b>0-20</b>	<b>49.73</b>	<b>16.70</b>
<b>21-40</b>	<b>67.62</b>	<b>22.71</b>
<b>41-60</b>	<b>80.58</b>	<b>27.06</b>
<b>61-80</b>	<b>69.11</b>	<b>23.21</b>
<b>81-90</b>	<b>30.70</b>	<b>10.31</b>

Most of the area lies within 41° - 60°, which is 27%. About 23% area lies within 61°-80°. Slope ranging from 81°-90° covers 10% of the area (Table 2.2).

### Aspect

The slope's Aspect is the direction it faces. It can identify the spot on a surface with the steepest downslope. It can be compared to the compass direction a hill faces or the slope direction (Fig. 2.4). Aspect is measured in degrees, anticlockwise, from 0 (true north) to 360 (true north once more, making a full circle). The direction that each cell's slope faces is indicated by its value in an aspect grid. Flat slopes are given a rating of -1 since they have no guide. Flat (0.14%), North (12.52%), North-east (9.1%), East (13.8%), South-east (14.35%), South (14.88%), South-west (13.33%), West (12.1%), and North-west (9.78%) were the eight categories that were retrieved (Table 2.3).



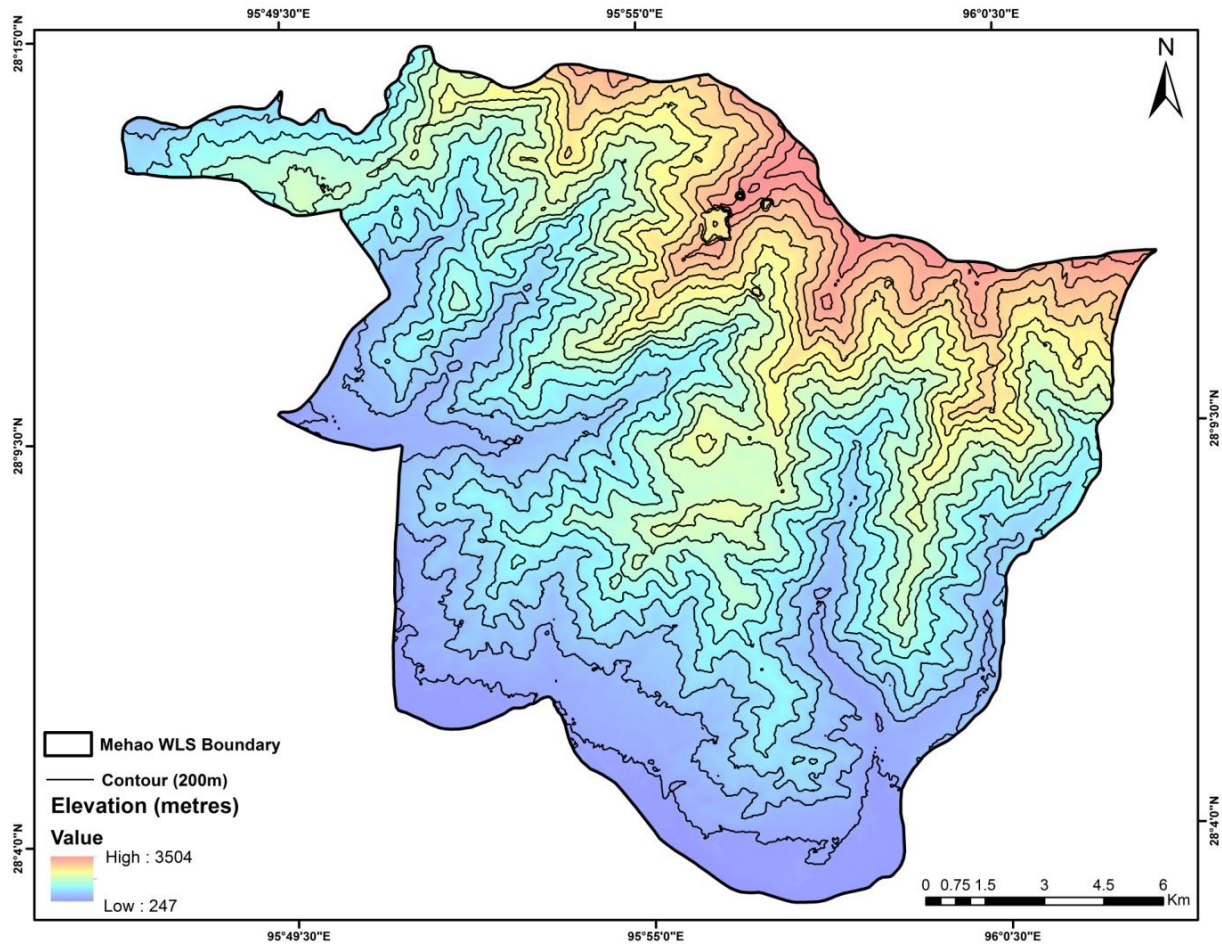
**Figure 2. 4: Map depicting aspect distribution within the Wildlife Sanctuary**

**Table 2. 3: Area and percentage distribution within aspect categories in Mehao WLS**

Aspect Categorise	Area (sq km)	Percent
Flat	0.42	0.14
North	37.28	12.52
North-East	27.10	9.10
East	41.08	13.80
South-East	42.73	14.35
South	44.32	14.88
South-West	39.69	13.33
West	36.04	12.10
North-West	29.11	9.78

## Contour

Contours are lines that connect locations with the same elevation. The elevation distribution inside the Mehao WLS is shown on the contour map. In this instance, the contour interval is 200m. The contour map makes it simple to see the altitudinal changes inside the Mehao WLS. Additionally, the digitised contour lines were used to create the "Digital Elevation Model" (DEM) (Fig. 2.5).



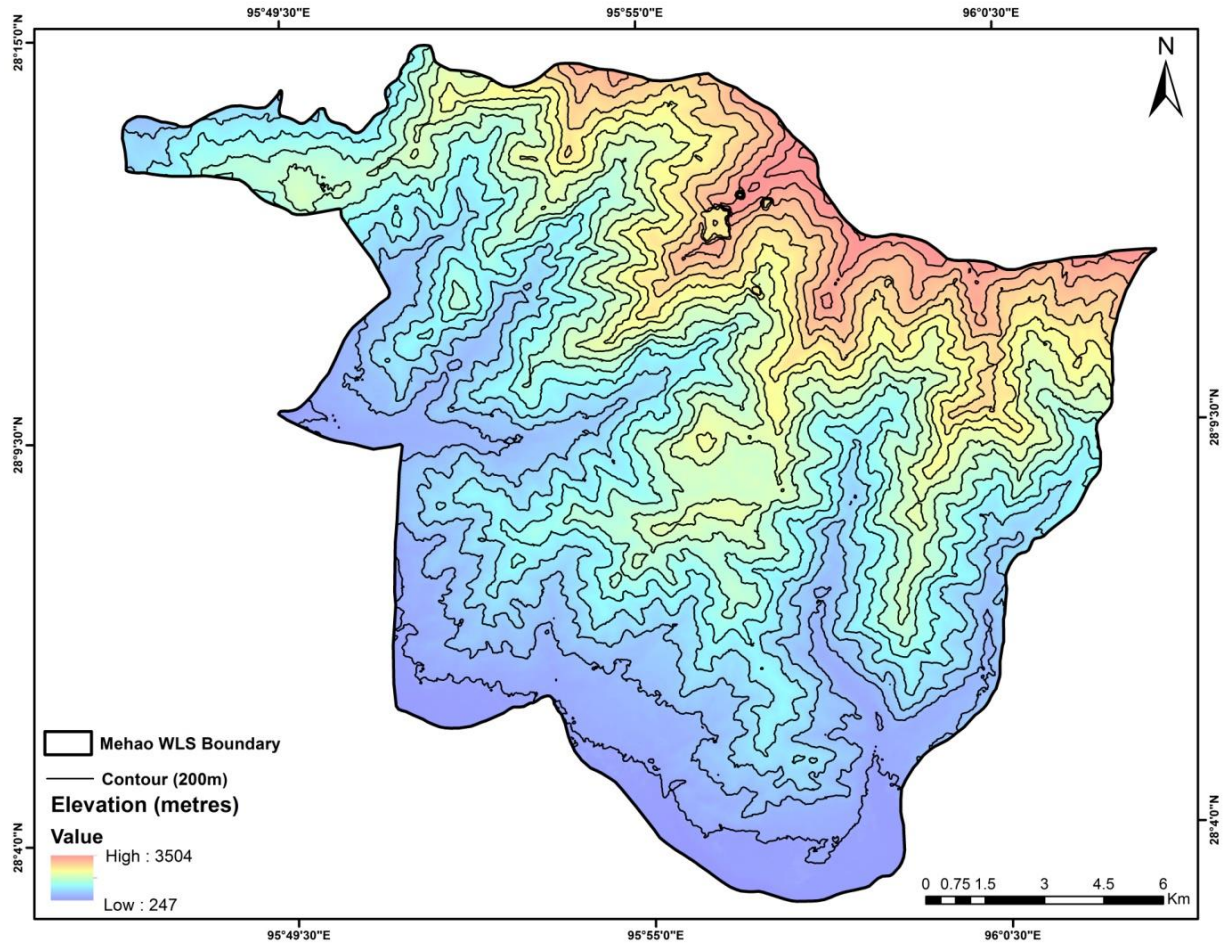


Figure 2. 5: Contour line at 200 m interval is depicted in the map

## **Chapter 3**

## **General Methodology**

### **Introduction**

All field activities were carried out as field expeditions - camping in different areas of the intensive study area. One field survey was usually 3 to 4 days during both seasons (winter and summer). Other conventional field methods, such as trail monitoring, sign surveys, camera trapping, and vegetation sampling, were used to achieve the objectives. For regular and systematic monitoring, the base camp was located near Roing Town (Mayu village), where sampling in Mehao WLS was conducted.

### **Reconnaissance**

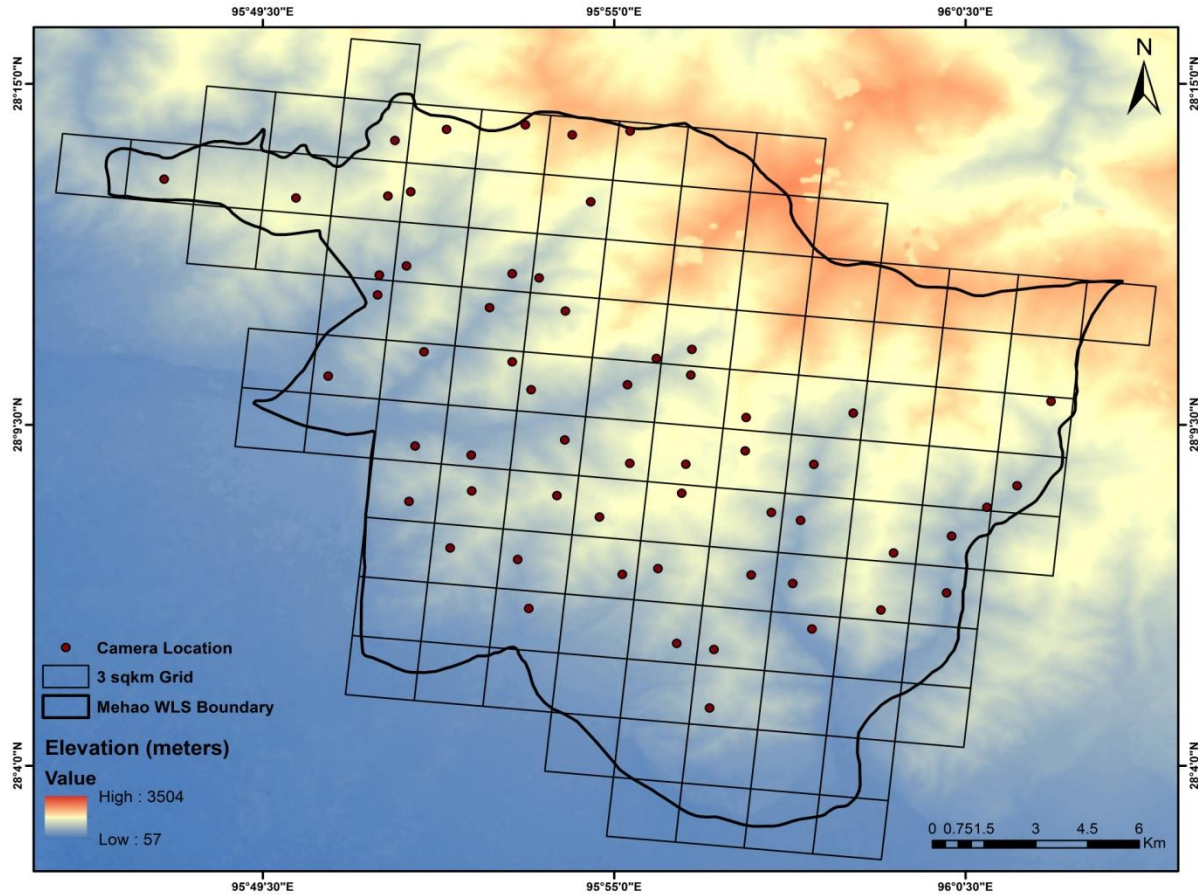
The field survey was conducted between November 2017 to May 2018. Reconnaissance was carried out during the initial months of the study to develop adequate knowledge and understanding of the area and a baseline for further intensive sampling. Because of the intricate topography and remoteness of the site, all field activities were carried out as expeditions, i.e., camping in different areas of the sanctuary. The direct sightings and indirect evidence (scats, tracks, pugmarks, scrapes, scratch marks) of mammals, information on geographic location, elevation, and habitat characteristics (primary vegetation type) were also recorded.

### **Camera Trapping**

The effort was made to deploy the camera trap units along the stream beds, animal trails, and locations with evidence of animal presence as identified during the preliminary sign survey. One hundred twenty camera traps were deployed seasonally (winter and summer) in a three km<sup>2</sup> grid covering an area of 183 km<sup>2</sup> (Fig 3.1). Camera traps deployed were Cuddeback C1 models, a white flash model with a range of detection about 100ft, with a ¼ sec of trigger speed and set to as FAP (Fast as possible) for recovery fast after being triggered once.

Cameras were set for 24-hour monitoring, including changing batteries and memory cards. Head-on, oblique, and side-view camera configurations obtained photographs at varying body orientations (Jackson et al., 2006). Due to difficult field conditions in summer (monsoon), no camera trapping was carried out in the northern part of the study area. However, this portion was

covered intensively during winter when the water flow was low. Among the 120 camera locations, camera units at 7 locations stopped working within a few days due to malfunctioning or human interference.

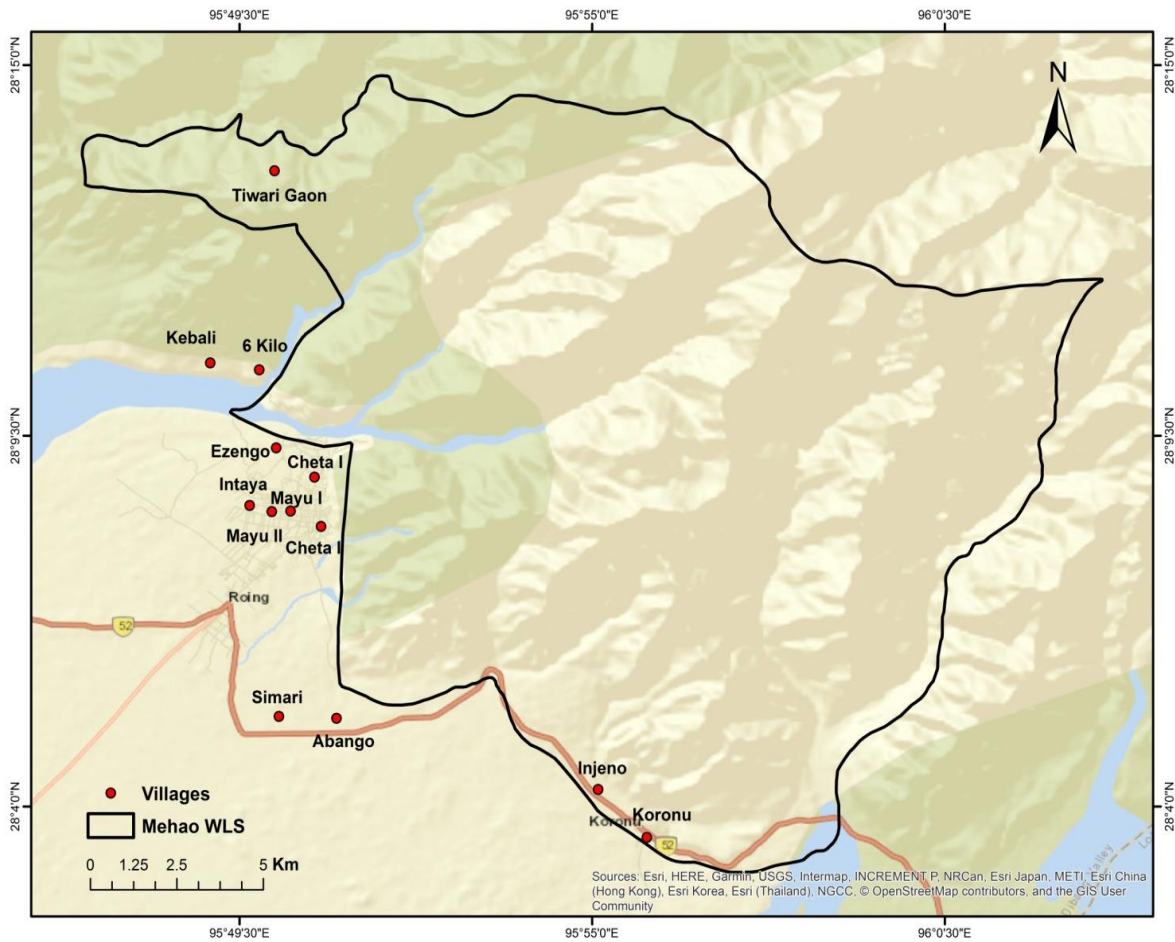


**Figure 3. 1: Map showing the location of camera trap and grids covered during the survey in Mehao Wildlife Sanctuary**

### Local Interviews

To assess local people's awareness of the area's mammalian diversity and compare it with camera trapping results (Can and Togan 2009), interviews and informal discussions (Mishra et al., 2006) were conducted in 13 villages to the sanctuary. In total, interviews and informal discussions were conducted with the family heads, and a focal group discussion of 40 households was done in 13 villages in and around the study area (Fig 3.2). Which included farmers, Mithun owners, former hunters, and trekking guides, during which they were also asked to identify photographs of

mammalian species from field guides (Prater, 1971; Menon, 2003) if ever sighted in the area. The *Idu Mishmi* and the *Adi* are significant communities living along the Mehao WLS.



**Figure 3. 2: Village location map around Mehao Wildlife Sanctuary**

### Challenges and limitations

There were few observations due to the species' secretive or elusive nature and nocturnal habits. For several animal species found in the study area, including mountain ungulates, standard photographic capture-recapture estimation techniques cannot be used since individuals are not uniquely identifiable. The undulating terrain of the sanctuary was confined by foot alone. Washing away bridges and frequent landslides during monsoons impeded field research. Many camera traps could not be tested as the trails were inaccessible during winter and pre-monsoon season due to heavy snowfall and rainfall in the study area. The sensitivity of the camera due to the low moving

clouds, movement of vegetation due to wind, and movement of tourists, local people, and semi-domesticated Mithun affect camera trapping days. Malfunction of camera traps because of extremely low temperatures in the Mayodia area was also a limitation. Eight units of camera traps have been stolen from the field and could not be recovered. Pellet groups were often found in a degraded state due to incessant rain in monsoon. This scenario presents a severe limitation of conventional techniques to monitor abundances for mammals that are ecologically little studied in the eastern Himalayan context and in some cases, seriously threatened. Extensive fieldwork could not be carried out in the Northern part of Mehao WLS due to the area's inaccessibility.

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## Chapter 4

Objective: To estimate the relative abundance and occupancy of selected large mammals in and around Mehao wildlife sanctuary.

## Introduction

Globally, biodiversity is decreasing at an alarming rate as a result of habitat loss, deforestation, and habitat fragmentation, which jeopardise the terrestrial ecosystem (Bradshaw et al., 2009), undermine ecosystem services and human well-being (Diaz et al., 2006; Dobson et al., 2006) and exacerbate climate change (Gullison et al., 2007). Along with climate change, humans have significantly impacted animal populations worldwide, reducing the geographic range and driving many to extinction (Thomas, 1956; Butler, 2006; Ceballos & Ehrlich, 2002). Without adequate policy action, biodiversity is anticipated to continue to decline (Rands et al., 2010).

Tropical forests support at least two-thirds of the world's biodiversity, although they comprise less than 10% of the planet's land area (Bradshaw et al., 2009). Soon, it is anticipated that tropical forests will have one of the highest rates of natural vegetation loss (Smith, 2010). Protecting tropical forests is a cornerstone of numerous national and international biodiversity conservation strategies (CBD, 2015; Panfil & Harvey, 2015). Supplying commercial goods and ecosystem services significantly improves local, regional, and global human well-being. Due to their greater species diversity than other regions, tropical forests are especially susceptible to detrimental effects (Rosenzweig, 1992). Priority should be given to saving tropical forest mammals because they are a vital and functionally diverse part of this biome but are also universally endangered by habitat loss, hunting, and poaching (Ceballos et al., 2005; Visconti et al., 2011; Ahumada et al., 2011). Tropical mammals are among the most endangered species, yet few people are familiar with them because it is typically challenging to study them (Linkie et al., 2007). However, data on habitat use, distribution, and responses to hazardous processes are essential for directing conservation measures (Espartosa et al., 2011).

In ecosystem functions, mammals play a crucial role in maintaining forest structure, trophic management, nutrient cycling, carbon storage, and seed dispersal (Sobral et al., 2017; Estes et al., 2011; Jansen et al., 2010; Brodie et al., 2009). However, the cryptic nature of forest-dwelling mammals hinders the development of conservation measures. Applying statistical techniques, such as occupancy modeling, that consider and correct imperfect detection is essential to produce evidence for environmental policies (Guillera-Arroita, 2017; Brodie et al., 2015; MacKenzie et al., 2002). Track and sign surveys, direct observations, camera trapping, and interviews with local communities and hunters currently detect mammalian fauna (Ramesh & Down, 2014; Bondi et al.,

2010; Aiyudurai et al., 2010). Numerous studies indicate that camera traps are effective for surveying mammals, particularly rare, elusive, or nocturnal species (Espartosa et al., 2011; O'Connell, Nichols, and Karanth, 2011; Harmsen et al., 2010; Tobler et al., 2008; Silveira, Jacomo, and Diniz, 2003). Sign surveys (Norris et al., 2008; Bali et al., 2007; Parry et al., 2007; Harvey et al., 2006; Naughton-Treves et al., 2003; Carrillo et al., 2000) are being increasingly used to survey tropical forest mammals. In tropical forests, a suitable substrate for footprint impression is not always present, and weather conditions make sign surveys biased for further study (Norris et al., 2008; Dirzo & Miranda, 1990).

To reconcile conservation and development, it is increasingly essential to comprehend how human-modified landscapes in the tropics affect mammal communities (Boron et al., 2019). In tropical rainforests, habitat loss, hunting, land-use change, and deforestation threaten biodiversity conservation (Barlow et al., 2016; Visconti et al., 2011; Schipper et al., 2008; Hansen et al., 2008; Laurance, 1999). Agriculture and tree plantations are rapidly increasing across the tropics to fulfill rising human demands for food, wood, and fibre (Riitters et al., 2016; Abood et al., 2015; Haddad et al., 2015; Hansen et al., 2013). These developments are lowering the area of forests and fragmenting or reducing wildlife habitat (Laurance et al., 2011; Fischer & Lindenmayer, 2007; Laurance et al., 2002). The problem of hunting has gotten worse due to expanding human populations, more accessible access to isolated areas, and modern hunting techniques and weapons. According to recent estimates, hunting pressure and land-use change have caused mammal populations to decline by more than 80% and 30%, respectively (Almeida-Rocha et al., 2017; Benitez-L'opez et al., 2017). India has a history of conserving wildlife (Rangarajan, 2001); the native populations of northeast India are more like Southeast Asian cultures than those of peninsular India. Hence hunting practices are prevalent (Datta, 2007). Hunting has decreased the abundance of wildlife in Arunachal Pradesh because it is culturally and widely practiced there (Mishra et al., 2006; Hilaluddin et al., 2005; Datta, 2002).

In Arunachal Pradesh, several surveys and documentation have been done on large and small mammals (Athreya, 1997; Chowdhury, 1997; Datta, 1998; Datta et al., 2008; Mishra et al., 2006; Gopi et al., 2010, 2012; Selvan, 2013, 2014; Dasgupta et al., 2014, 2015; Adhikarimayum & Gopi, 2018), Malayan sun bear (Sethy & Chauhan, 2011) and red panda (Kakati, 1996). Most wildlife surveys in Arunachal have been restricted to low and mid-elevation forests and have focused on

rare species (Athreya & Jhonsingh, 1995; Katti et al., 1990; Selvan et al., 2013; Roy et al., 2015). In the state, only a few surveys and ecological research has produced significant discoveries and information (Datta & Goyal, 1997; Selvan et al., 2014) of new species like Leaf deer (Datta et al., 2003), Chinese goral (Mishra et al., 2004) Arunachal Macaque (Sinha et al., 2005).

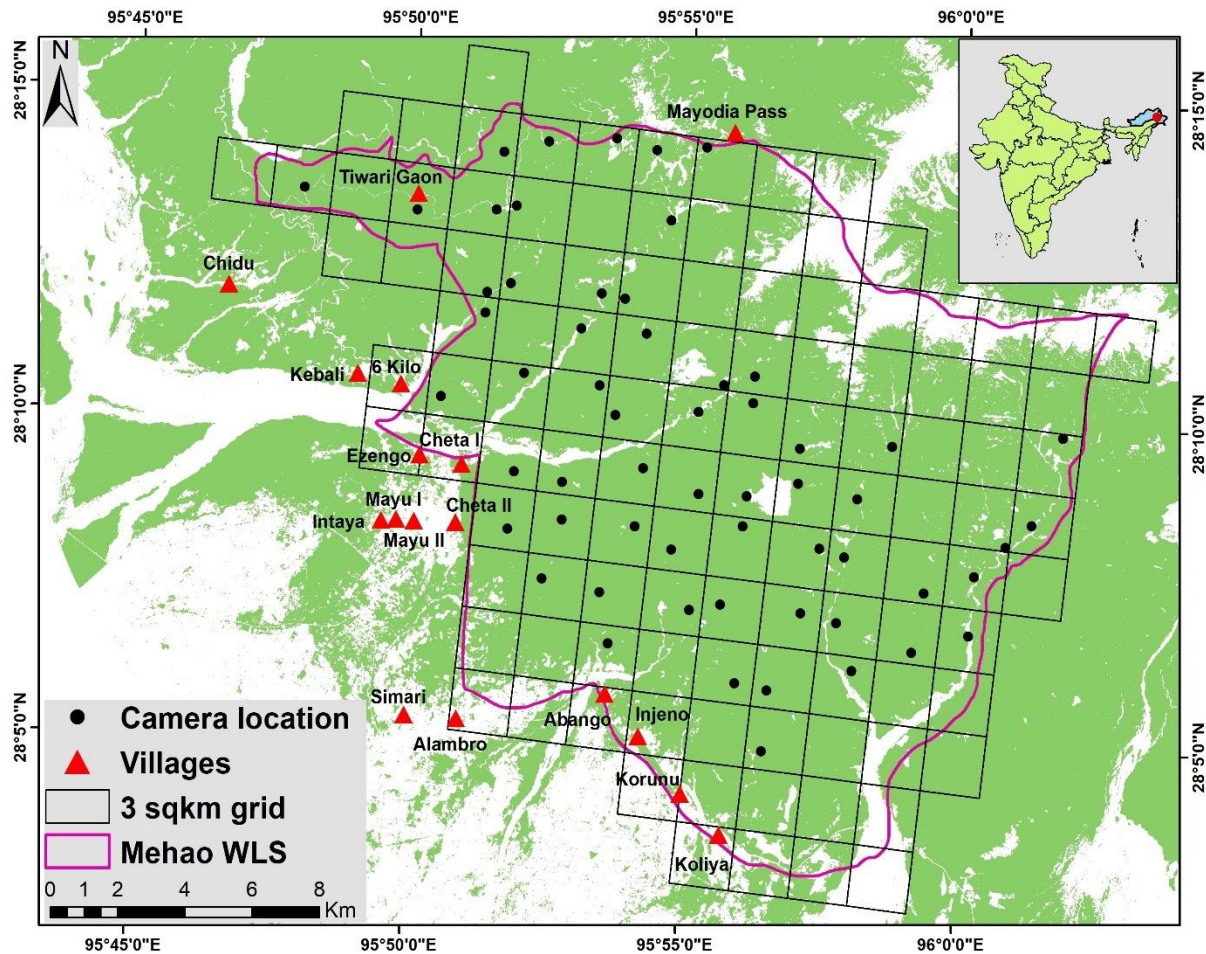
This is the first systematic camera trapping study to evaluate the assemblage of terrestrial mammals in Mehao WLS and factors affecting detection probability and occupancy. Mehao WLS located in Arunachal Pradesh within the Eastern Himalayas global biodiversity hotspot (Myers et al., 2000). The rugged terrain and dense forest cover of Mehao WLS harbor sixty species of mammals (Chakaraborty & Sen, 1991). However, Idu Mishmi and Adi are the principal communities residing in the vicinity of Mehao WLS which showed that taboos in the Idu Mishmi community restricting hunting and forest use might be contributed to biodiversity protection (Nijhawan & Mihu, 2020). There are few studies done in the Mehao Wildlife sanctuary on mammals (Sarma et al., 2015; Chakaraborty & Sen, 1991; Katti et al., 1992), mainly on hoolock gibbon (Chetry et al., 2010; Roy et al., 2015) and a write-up on the Mehao wildlife sanctuary was unpublished by Sinha (1984).

Our specific objectives were (1) to determine the species richness and relative abundance of mammals in and around Mehao WLS and (2) an investigate the factor influencing the detection probability and occupancy of mammalian fauna. The outcome of this study would be crucial and beneficial for rare and elusive mammals for managing and conserving mammalian species in and around Mehao WLS.

## **Study Area**

The current study is conducted in the Mehao Wildlife Sanctuary (Mehao WLS), Lower Dibang Valley district of Arunachal Pradesh (Fig 4.1). The sanctuary was founded in 1980 and is home to numerous species of wild creatures, including Bengal tigers, leopards, hoolock gibbons, tree shrews, wild dogs, and clouded leopards. The Mehao WLS lies between 93° 30' and 95° 45' east longitudes and 28° 05' and 28° 15' north latitude, with an area of 281.5 Km<sup>2</sup>. The terrain in Mehao WLS plain in the southern part and hilly in the northern region with an elevation range between 400m to 3568m asl. Along the rivers and streams, the valleys are narrow. The sanctuary is interspersed with small flat land at various elevations that provide habitat for various wildlife.

Deopani, Ashupani, Jowe, Diphu, and Enjopani are the primary perennial rivers that flow through the sanctuary. All the streams flow into the Dibang River into the Lohit River, one of the Brahmaputra River's main tributaries. Several seasonal streams connect to these rivers, which flow rapidly during rainy seasons. Mehao Lake, Mini Mehao Lake, and Sally Lake are the three natural water bodies; Mehao Lake is in the sanctuary's heart.



**Figure 4. 1: Map showing the location of the camera trap, grids, and the forest cover (green) in Mehao Wildlife Sanctuary.**

Champion and Seth (1968) state that the study area falls within 8B/CI East Himalayan Sub-tropical Wet Hill Forests. The forest type changes with altitude in Mehao WLS and contains the following forest types: tropical evergreen forest (900m), subtropical and temperate forest (900m-1,800m), temperate broad leaf forest (1,800m-2,800m), and temperate conifer forest (2,800m-3,500m) The forest are dominated by *Terminalia myriocarpa*, *Messua ferra*, *Dillenia indica* *Castanopsis indica*,

and *Abizzia lucida* while primary shrub and herb species include *Clerodendrum viscosum*, *Tephrosia candida*, *Maesa indica*, and *Solanum khaslanum*. Bamboos such as *Dendrocalamus giganteus*, *Phyllostachy bambusoides*, *Bambusa pallida*, *Dendrocalamu hamitonii*, and *Pseudo taehiyum* are also present. Mehao WLS is also known to contain Mishmi Teeta (*Coptis teeta*), a precious medicinal herb and threatened holoparasitic plant *Sapria himalayana* (Ahmad et al., 2020). The Sanctuary is warmer at lower altitudes and colder at higher altitudes. In the summer, the temperature at a low altitude is around 38°C and 4°C to 12°C in the winter. In higher altitudes, the summer temperature is nearly 12°C, and in the winter, snowfall begins on the mountainsides, and the temperature drops to -3°C.

The Idu Mishmi are of Tibeto-Burmese ancestry and practice animism, while Buddhism's influence has resulted in adopting some Buddhist practices into their beliefs. The *Adi* inhabits the lowlands between Shantipur and Roing, while the *Idu Mishmi* inhabit the region from the foothills onward. The region has a sizeable Bihari, Nepali, and Assami population; most laborers cultivate the land for *Idu Mishmi* and share the yield. Along the sanctuary's periphery are numerous *Idu Mishmi* villages, including Koronu, Injuno, Abango, Balek, Kanu, and Tiwarigaon. Strong taboos exist among the Idu Mishmi against hunting gibbons or other wild animals, which may explain their regional abundance.

There were low numbers of sightings to study the species' shy or elusive nature and nocturnal habits. For several animal species found in the study area, including mountain ungulates, standard photographic capture-recapture estimation techniques cannot be used since individuals are not uniquely identifiable. The terrain of the study region was steep and rugged to allow a reconnaissance by foot alone. Washing away bridges and frequent landslides during monsoons impeded field research. Few camera units could not be inspected during the winter and pre-monsoon seasons due to inaccessible routes caused by severe snowfall and rainfall at high elevations. Temporary camera failure due to extremely low temperatures in the Mayodia area was also a limitation. Eight units of camera traps have been stolen from the field and could not be recovered. Pellets were often found in a degraded state due to incessant rain in monsoon. This scenario presents a severe limitation of conventional techniques to monitor the abundance of mammals that are ecologically less studied in the eastern Himalayan context and some cases,

seriously threatened. Extensive fieldwork could not be conducted in the Northern part of Mehao WLS due to inaccessibility.

### **Methodology and Data Analysis**

The field survey was conducted between November 2017 to Feb 2018. Reconnaissance was conducted during the initial months of the study period to develop adequate knowledge and understanding of the area and a baseline for further intensive sampling. The effort was made to deploy the camera trap units along the stream beds, animal trails, and locations with evidence of animal presence as identified during the preliminary sign survey. A total of 58 camera traps were deployed in a 3 km<sup>2</sup> grid covering 183 km<sup>2</sup>. Cuddeback C1 camera traps were used; they had a trigger speed of 14 seconds, a detection range of 100 feet, and were programmed to recover as quickly as possible (FAP) after being triggered. Along animal trails, cameras were placed 20 centimetres above the ground and left 24 hours a day to capture images of all mammalian species encountered.

### **Relative abundance index**

The relative abundance index (RAI) was obtained by dividing the total number of independent photographs for each species by the total number of trap nights and multiplying by 100 (Carbone et al., 2001). Multiple photographs of single individuals within a 20-min period were recorded as one effective photograph (O'Brien et al., 2003).

### **Species Accumulation Curve**

The species accumulation curve of mammals in Mehao WLS was calculated using rarefaction. It estimates the species richness or the assemblage if a particular level of camera effort is made (Magurran, 2004). After repeated re-sampling is accomplished by taking the mean of all pooled individuals or samples (Gotelli & Colwell, 2001). Thus, the sample-based rarefaction curves can account for natural sampling heterogeneity in data. Therefore, the rarefaction curve of the mammalian species found in Mehao WLS was calculated using the vegan package of R software 3.4.0.

## Occupancy Modelling

The effort was made to deploy the camera trap units along the stream beds, animal trails, and locations with evidence of animal presence as identified during the preliminary sign survey. We conducted a camera trapping survey between November 2017 and February 2018, documenting the sanctuary's occupancy and relative abundance of mammals. A total of 58 camera traps were deployed in a 3 km<sup>2</sup> grid covering 183 km<sup>2</sup>.

Each grid contained at least one camera trap site, with an average distance of 1 km between traps. Each camera was installed for fifty days, resulting in 3329 trap nights. Throughout the sampling areas, trap stations were placed. Using camera traps to collect data on the distribution and abundance of mammals, photographs can unveil much information. (Ramesh et al. 2013; Kinnaird and O'Brien 2012; Ramesh et al. 2012; Pettorelli et al. 2010; Tobler et al. 2009; Rowcliffe & Carbone 2008).

As it is difficult to estimate the abundance or density of many species, the relative abundance index (RAI) is the primary alternative for abundance. Mammalian occupancy can be determined by the presence or absence of species at camera trap sites during a sampling session. For each camera location, we created a mammalian species detection history (1100100), with '1' indicating species detection during the sampling event and '0' indicating non-detection (Otis et al., 1978). Site occupancy is the proportion of an area or sites occupied by a species (MacKenzie et al., 2006). Naive occupancy is an estimate of occupancy that disregards detection, i.e., the site where the species was detected at least once is included in the estimation. (MacKenzie et al., 2006). The detection probability is detecting a species through repeated site surveys, which permits unbiased estimation of site occupancy (MacKenzie et al., 2006). The occupancy and detection probabilities of species with low capture rates were not calculated.

The main benefit of occupancy models is that they explicitly account for imperfect detection or the probability of missing a present species. In wildlife research and camera trapping research, imperfect detection is unavoidable. A failure to account for imperfect detection can substantially affect model results and bias inferences (Sollmann et al., 2013; MacKenzie et al., 2005b; Gu & Swihart, 2004).

The camera traps were placed randomly in all possible grids of the sanctuary. Each camera site estimated an independent photographic capture rate of Mithun (semi-domesticated animal) and human (hunter and woodcutter) per 100 trap nights. For large-scale monitoring of several species, site occupancy gives an impartial measure of species status and is cost-effective (Kinnaird & O'Brien, 2012; Sarmiento et al., 2011). The camera trapping period was limited to 50 days to reduce the probability of changes in occupancy. The single-season occupancy model (MacKenzie et al., 2018) was used to predict the likelihood of a species occupying a specified site and the detection probability  $p$ . However, it identifies ecological and anthropological factors underlying mammal distributions. For each camera-trap location, detection records of target species were created using a standard "X-matrix format" for 50 sampling instances (Otis et al., 1978).

To improve model convergence, we z-standardized all continuous covariates using the formula  $z = (x-x')/SD$ , where  $x$  is the individual value,  $x'$  is the factor mean, and  $SD$  is the standard deviation (Sunarto et al., 2012). Correlations between independent variables were evaluated to eliminate multicollinearity issues (Graham, 2003). First, a variance inflation factor (VIF) was calculated for each covariate to assess multicollinearity among variables; those with a  $VIF < 3$  were included in the model. Then, Pearson correlation tests were conducted, and correlated variables (Pearson correlation coefficient  $> 0.70$ ) were excluded from the same model. Using the CamtrapR package, we created species-specific detection matrices for several mammal species (version 1.2.3, Niedballa et al., 2016). We used the "Unmarked package" to model occupancy (version 0.13-2, Fiske & Chandler, 2017).

## Covariates

We investigated several natural and anthropogenic covariates that could influence the space utilisation of mammals in this region (Table 4.1). Based on previous research (Wang et al., 2019; Yang et al., 2019; Wang et al., 2018; Xiao et al., 2018; Li et al., 2017; Hebblewhite et al., 2014), we investigated variables such as vegetation, ruggedness, elevation, Mithun encounter rates, and distance to a water body, as well as settlements and roads, may influence species occupancy. We calculated the distances from each camera to settlements, roads, and rivers using ArcToolbox in ArcGIS 10.3 (ESRI Inc.).

**Table 4. 1: Factors hypothesized to influence patterns of occupancy ( $\psi$ ) and detection probability in Mehao WLS.**

Covariates	Description	Justification of the selection of covariate	A prior hypothesis	
			p	$\psi$
Distance to water sources (WB)	Generated a surface by calculating the Euclidean distance from rivers, streams (both permanent and seasonal), and stagnant water bodies	The presence of water bodies is expected to impact the abundance positively and hence the site use by mammalian species.		+
Elevation (DEM)	Computed using the SRTM digital elevation model-30m	Elevation can both positively and negatively influence the habitat use of the studied species (Thapa & Kelly, 2017; Phumanee et al., 2020)		+/-
Distance to nearest human settlement (DHS)	Generated a surface by calculating the Euclidean distance from agriculture, settlements, built-up areas, and roads	DHS is a surrogate measure of prolonged disturbance in the study site associated with human activity such as grazing, hunting, and resource extraction. (Vinitpornsawan 2013, Thapa and Kelly 2017).		-
Human Detection rate (HD)	Relative abundance of humans in camera trap	The anthropogenic activities could negatively impact habitat use and the population of mammals in		-

		the study area (Thapa & Kelly, 2017; Jornburom et al., 2020; Phumanee et al., 2020)	
Mithun Detection Rate (Mdet)	Relative abundance of Mithun in the camera trap	Mithun's presence inside the study area and their presence were likely to impact the ungulate populations through competition negatively for forage.	-
Terrain Ruggedness Index (TRI)	TRI is derived from the DEM using the terrain analysis function.	It is an essential ecological component affecting the distribution of mammals and vegetation.	+/-
Terrain Wetness Index (TWI)	Terrain Wetness Index is defined as $\ln(a/\tan\beta)$ where 'a' is the local upslope area draining through a certain cell per unit contour length in a DEM, and ' $\tan\beta$ ' is the local slope.	It is a geomorphometric parameter used to describe the distribution of mammals.	+/-
Canopy cover (CC)	Canopy cover was estimated for each plot based on visual observations in a 10m circular plot centred on each trap station.	Canopy cover affects the occupancy of mammals (Li et al., 2018).	+/-

Topographical Position Index (TPI)	The topographic Position Index is the mean difference between a cell and a neighborhood (3*3 cell) of surrounding cells. in a digital elevation model (DEM)	It indicates areas accumulating water flow, often with seasonally and permanently waterlogged ground influences the occupancy of mammals and vegetation structure.	+/-
Bamboo-mixed Forest (BMF)	The proportion of bamboo and mixed forest extracted from the LULC map prepared for the study.		+/-
Mixed forest (MF)	mixed forest extracted from LULC map prepare for the study	Different vegetation structures associated with forest types could influence the occupancy of studied mammalian species.	+/-
Shrub cover (SC)	Shrub cover was estimated for each plot based on visual observations in a 5m circular plot centred on each trap station.		+/-

We used portable GPS receivers to determine the elevation at each location. Ruggedness was determined using a one-kilometer radius and a topographic position index derived from the Shuttle Radar Topography Mission (SRTM) 30-m digital elevation model. The WorldClim database (<http://www.worldclim.org/bioclim>) was used to obtain the annual mean temperature and annual precipitation. Mithun and human presence may influence an animal's detection rate. Using a 30-min period of independence for each record, Mithun and human encounter rates at each camera station were calculated as the number of detections per 100 camera trap days over the entire sampling period (O'Brien et al., 2003). By laying a 10m-by-10m plot around each camera location

and recording covariates like elevation, habitat type, forest type, and the percentage of tree/vegetation cover, the habitat characteristics at each camera location were assessed (including ground cover as well as shrub cover and canopy cover visual estimation).

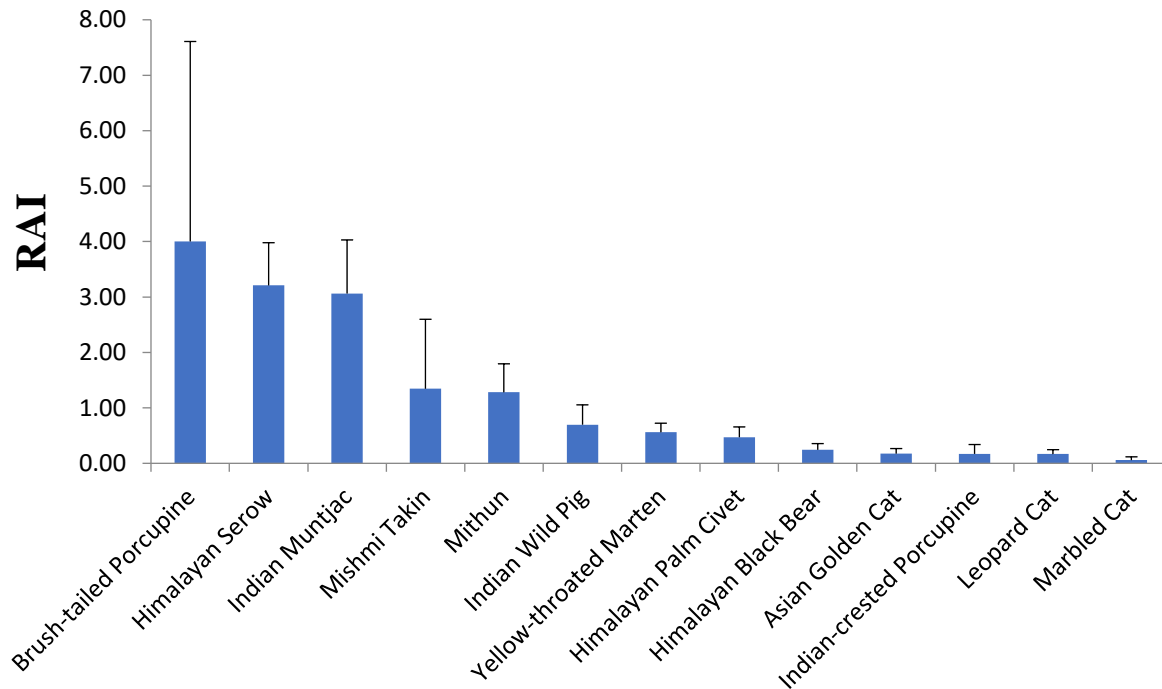
## **Result**

### **Relative abundance, Species accumulation, sampling effort, and trap nights**

During 50 days of camera trapping at 58 sites,  $n = 2900$  trap nights, 27 species of wild mammals, Mithun (semi-domesticated), and humans were recorded. We focused our on-site occupancy analyses on 10 of the 27 species for which we had sufficient data. We analysed the abundance of all terrestrial mammals.

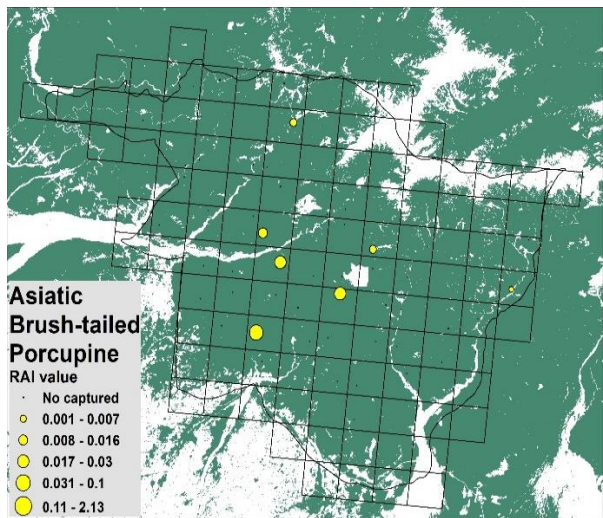
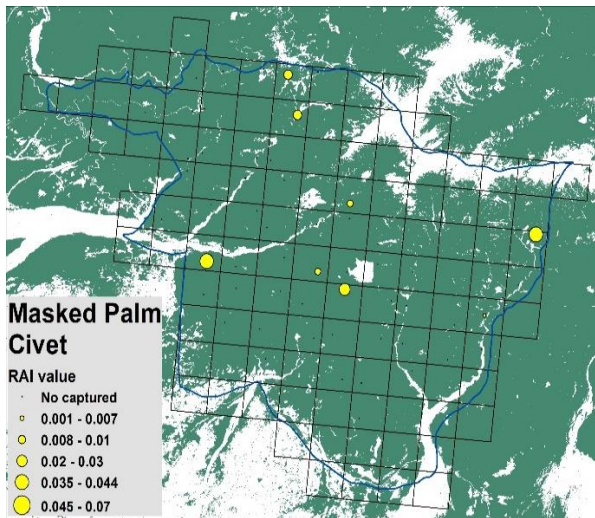
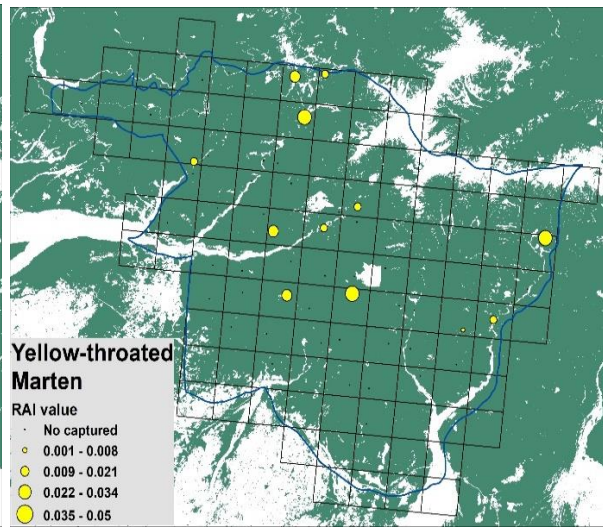
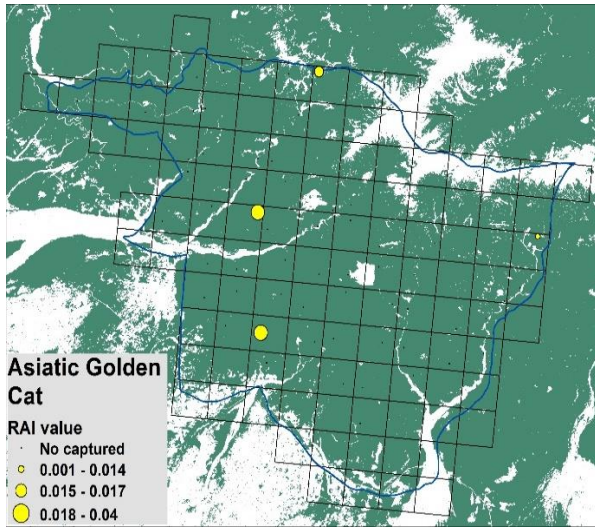
In the present study, we recorded 27 species of mammals, which include 12 carnivores (four felids, three viverrids, two mustelidae, two canids, and each from the Ursidae, Prionodontidae family), seven herbivores (four Bovidae, two Cervidae, one Suidae) species. In the carnivore guild, we got Indo-Chinese Clouded Leopard, Marbled Cat, Leopard Cat, Asiatic Golden Cat, Masked Palm Civet, Common Palm Civet, Large Indian Civet, Wild Dog, Spotted Linsang, Asiatic Black Bear, Golden Jackal, Yellow-throated Martin. In the herbivore guild, Mishmi Takin, Red Goral, Mainland serow, Mithun, Indian Muntjac, Sambar, and Indian Wild Pig. 7 Others (two Hystricidae, three Sicuridae, and each from Hylobatidae, Herpestidae, and Cercopithecidae) in which Indian Crested Porcupine, Asiatic Brush-tailed Porcupine, Black Giant Squirrel, Himalayan striped Squirrel, Palla's Squirrel, Crab-eating Mongoose, Eastern Hoolock Gibbon, Northern Pig-tailed Macaque. Through sign survey, direct sighting, questionnaire survey, and camera-trapping, a total of 27 species were identified in Mehao WLS. On the IUCN Red List, 12 of the 27 species identified are of high global conservation importance and are listed as Endangered (2), Vulnerable (9), and Near Threatened (3) Least Concern (11) (IUCN 2010) (Table 1).

Recent scientific work stated that habitat fragmentation and loss of habitat due to anthropogenic pressure (like an expansion of agricultural land, build-up area, construction of highways, presence of humans inside the sanctuary, and excessive cutting of cane and timber) results in local species extinction. Such anthropogenic pressures may affect the species distribution and abundance in the landscape.



**Figure 4. 2: Graph showing Relative Abundance Index (RAI) of photo-captured mammals in the Sanctuary**

The relative abundance index (Fig 4.2) was noted for Asiatic Brush-tailed Porcupine (RAI=  $4 \pm 3.61$ ), followed by Mainland serow (RAI=  $3.21 \pm 0.77$ ), Northern Red Muntjac (RAI=  $3.06 \pm 0.97$ ), Mishmi Takin (RAI=  $1.34 \pm 1.25$ ), Mithun (RAI=  $1.28 \pm 0.51$ ), Indian Wild Pig (RAI=  $0.70 \pm 0.36$ ), Yellow-throated Marten (RAI=  $0.56 \pm 0.16$ ), Masked Palm Civet (RAI=  $0.47 \pm 0.18$ ), Himalayan Black Bear (RAI=  $0.24 \pm 0.11$ ), Asian Golden Cat ( $0.17 \pm 0.09$ ) and Leopard Cat (RAI=  $0.17 \pm 0.08$ ). According to the 'relative abundance index,' the most abundant mammalian species were the Asiatic Brush-tailed Porcupine (*Atherurus macrourus*). Among carnivores, Yellow-throated marten (*Martes flavigula*) was the most abundant carnivore. According to the relative abundance index Yellow-throated Marten, Masked Palm Civet, Large Indian Civet, Leopard Cat, Marbled Cat, Asiatic Golden Cat, Indo-Chinese clouded Leopard, Dhole, and Himalayan Balck Bear are the primary predator in Mehao WLS. Fig 4.3 represents the Mainland serow, Northern red muntjac, and Yellow-throated marten spatially distributed across the study area. Asiatic brush-tailed porcupine was present in the southern part of the sanctuary.



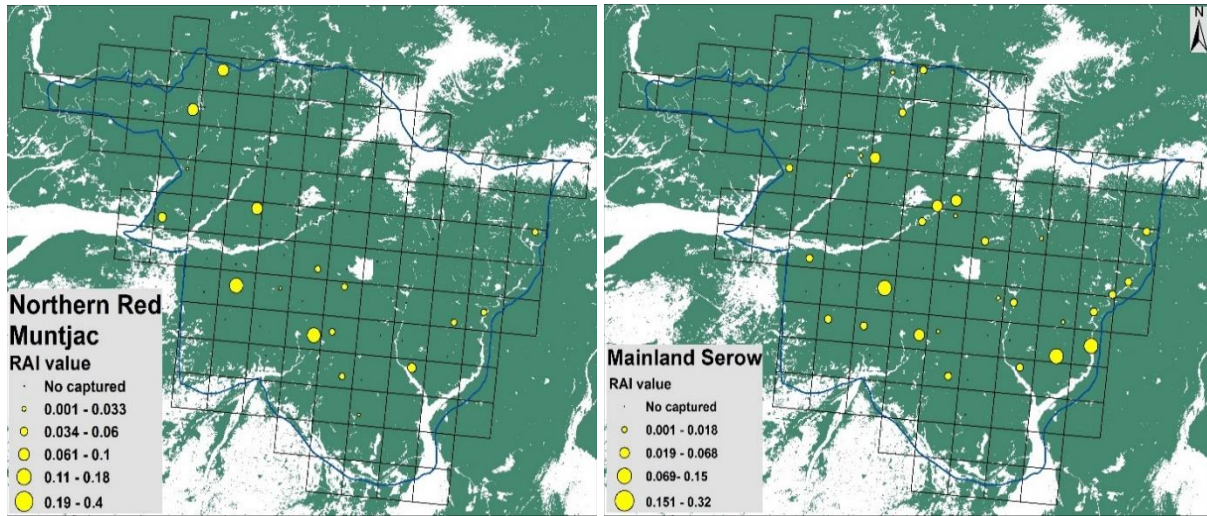
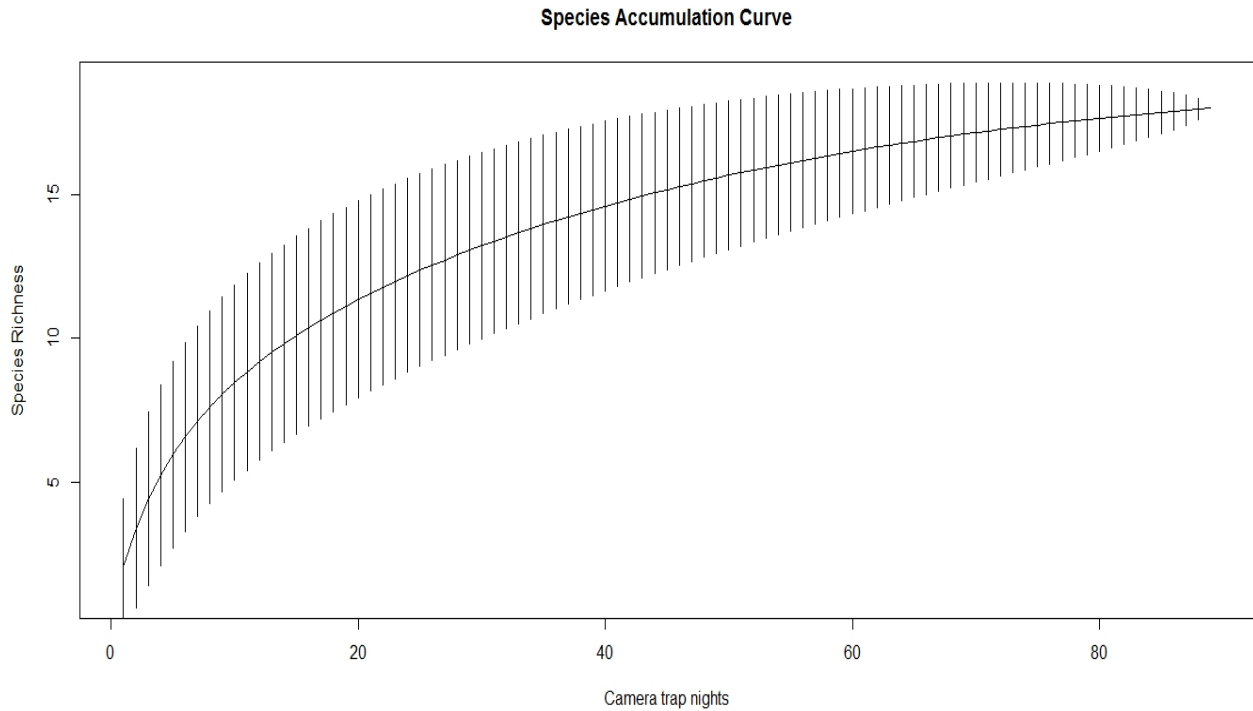


Figure 4. 3: Spatial distribution maps of Asian golden cat, yellow-throated marten, Masked palm civet, Asiatic brush-tailed porcupine, Northern red muntjac, and Mainland serow in Mehao WLS.

## Species accumulation curve

The species accumulation curve shows that the species richness in camera trap nights in Mehao WLS reached an asymptote after 60 trap nights. (Fig 4.4).



**Figure 4. 4: Species rarefaction curve of mammals in Mehao Wildlife Sanctuary**

## Occupancy

In well-supported models, the number of variables influences occupancy patterns and detection probability. Table 4.2 displays the site occupancy and detection probability of selected mammalian species. Naive occupancy was highest for Mainland serow (0.48), followed by Northern Red Muntjac (0.28), Yellow-throated marten (0.16), Masked Palm Civet (0.107), and lowest in Leopard cat (0.07), and Mishmi Takin (0.05).

## Estimates of occupancy

Across all species, estimates of site occupancy with standard errors ranged from  $0.0651 \pm 0.0379$  to  $0.576 \pm 0.083$ . Mainland serow has the highest probability of occupancy [ $\psi(\cdot)$ SE  $\psi(\cdot)$ ]:  $0.576 \pm$

0.083], followed by Northern Red Muntjac [ $\psi(\cdot)$  SE  $\psi(\cdot)$ :  $0.297 \pm 0.0629$ ], Yellow-throated marten [ $\psi(\cdot)$  SE  $\psi(\cdot)$ :  $0.228 \pm 0.0793$ ] and leopard cat [ $\psi(\cdot)$  SE  $\psi(\cdot)$ :  $0.184 \pm 0.161$ ]. Mishmi takin [ $\psi(\cdot)$  SE  $\psi(\cdot)$ :  $0.0651 \pm 0.0379$ ] and Asian golden cat [ $\psi(\cdot)$  SE  $\psi(\cdot)$ :  $0.095 \pm 0.04$ ] has the lowest occupancy probability (Table 4.2). The estimated occupancy probability for all these species is lower than the naïve estimates.

### Detection Probability

Estimates of the probability of detection with standard error range from  $0.027 \pm 0.026$  to  $0.304 \pm 0.042$ . The probability of detection was highest for Brush-tailed Porcupine ( $\rho = 0.304 \pm 0.042$ ), followed by Northern Red Muntjac ( $\rho = 0.184 \pm 0.024$ ) and Asian golden cat ( $\rho = 0.169 \pm 0.039$ ). Leopard cat, Wild boar, Asiatic black bear, Yellow-throated marten, and Masked Palm Civet has the lowest ( $< 0.1$ ) probability of detection. The occupancy model was performed with the combinations of different ecological and anthropogenic covariates that influence the probability of habitat use by mammals (Table 4.3). As a result, we examined the effect of Mithun presence on detection probability in all analysed species, including Northern Red Muntjac, Brush-tailed porcupine, Yellow-throated marten, and Mainland serow. When doing site occupancy models for species such as the Asian golden cat and the Masked Palm Civet, we used a constant detection  $p(\cdot)$  probability. In the case of Northern Red Muntjac, the presence of Mithun positively impacted the detection (Mdet,  $\rho = 0.25 \pm 0.09$ ) (Table 4.4). Figure 4.5 shows the influence of Mithun on the Northern Red Muntjac detection probability.

### Influence of covariates on Occupancy probability

The site use probability was modelled using an information-theoretic approach and the detection probability model that best fit the data. Table 4.5 contains the best predictive models for species occupancy, including a complete set of models and regression coefficient estimates for each model. Figure 4.6 shows the influence of covariates on the studied species' occupancy probability. The best model for Northern Red Muntjac revealed that bamboo-mixed forest (BMF) ( $\beta$ estimate:  $1.08 \pm 0.48$ ) and distance from waterbody (WB) ( $\beta$ estimate:  $0.65 \pm 0.35$ ) had a positive influence on the occurrence probability. The strongest ecological correlate for Serow was a negative response to distance from the waterbody (WB) ( $\beta$ estimate:  $-1.85 \pm 0.78$ ). The Asiatic Brush-tailed porcupine is their best model, with 31% AIC weight. The response to distance from a water body (WB) was

the strongest ecological correlation ( $\beta$ estimate:  $0.6 \pm 0.32$ ). In the case of the Asiatic golden cat, elevation (DEM) was found to have a positive effect ( $0.97 \pm 0.43$ ) on the occurrence probability with 37% AIC weight. Masked Palm Civet, BMF, TWI, and HD positively affect the occurrence probability with 43% AIC weight. On the other hand, Yellow-throated marten had a positive (DEM), and terrain ruggedness index (TRI) had a negative response on the occurrence probability.

**Table 4. 2: Occupancy and probability of detection**

Species	(Naïve $\psi$ occupancy)	$\psi \pm SE$	$\rho \pm SE$
Northern Red Muntjac	0.28	$0.297 \pm 0.0629$	$0.184 \pm 0.0244$
Mainland serow	0.48	$0.576 \pm 0.083$	$0.107 \pm 0.0155$
Brush-tailed Porcupine	0.1	$0.109 \pm 0.0421$	$0.304 \pm 0.0426$
Asian Golden Cat	0.089	$0.0955 \pm 0.0409$	$0.169 \pm 0.0399$
Asiatic Black Bear	0.089	$0.152 \pm 0.0813$	$0.0508 \pm 0.0269$
Yellow-throated Marten	0.16	$0.228 \pm 0.0793$	$0.0695 \pm 0.0233$
Masked Palm Civet	0.107	$0.145 \pm 0.0615$	$0.0768 \pm 0.0301$
Mishmi Takin	0.05	$0.0651 \pm 0.0379$	$0.101 \pm 0.0436$
Wild Boar	0.089	$0.144 \pm 0.0756$	$0.055 \pm 0.0288$
Leopard Cat	0.07	$0.184 \pm 0.161$	$0.0277 \pm 0.0261$

**Table 4. 3: Results of model selection to determine ecological and anthropogenic covariates that influence the probability of habitat use by mammals in Mehao Wildlife Sanctuary, Arunachal Pradesh. Several parameters (K), Akaike information criterion (AIC), and Akaike weights ( $\omega_i$ )**

Northern Red Muntjac (*Muntiacus muntjak*)

Model	nPars	AIC	delta	AICwt	cumltvWt
p(Mdet)psi(BMF+DR)	5	323.5	0	0.45007	0.45
p(Mdet)psi(BMF+TR)	5	325.74	2.23	0.14747	0.6
p(Mdet)psi(BMF)	4	325.91	2.4	0.1354	0.73
p(Mdet)psi(TR+DR+BMF+HD+MF)	8	326.98	3.48	0.07912	0.81

p(Mdet)psi(BMF+HD)	5	327.88	4.38	0.05048	0.86
p(.)psi(BMF+DR+TR)	5	327.92	4.42	0.04944	0.91
p(Mdet)psi(DR+TR)	5	329.59	6.09	0.02146	0.93
p(Mdet)psi(DR)	4	330.07	6.57	0.01686	0.95
p(Mdet)psi(TR)	4	330.74	7.24	0.01208	0.96
p(Mdet)psi(HD)	4	332.14	8.63	0.00601	0.97
p(Mdet)psi(CC)	4	332.37	8.87	0.00533	0.97
p(Mdet)psi(TPI)	4	332.4	8.9	0.00525	0.98
p(Mdet)psi(SC)	4	332.67	9.16	0.00461	0.98
p(Mdet)psi(TWI)	4	332.8	9.3	0.00431	0.99
p(Mdet)psi(DEM)	4	332.82	9.32	0.00427	0.99
p(Mdet)psi(WB)	4	333.22	9.72	0.00349	1
p(Mdet)psi(MF)	4	333.23	9.72	0.00348	1
p(.)psi(.)	2	336.02	12.51	0.00086	1

Mainland serow (*Capricornis sumatraensis*)

<b>Model</b>	<b>nPars</b>	<b>AIC</b>	<b>delta</b>	<b>AICwt</b>	<b>cumltvWt</b>
p(.)psi(WB)	3	434.77	0	0.7216	0.72
p(.)psi(DEM+TR+MF)	5	437.84	3.06	0.1561	0.88
p(.)psi(DEM)	3	441.03	6.26	0.0316	0.91
p(.)psi(MF)	3	442	7.22	0.0195	0.93
p(.)psi(SC)	3	442.36	7.59	0.0162	0.95
p(.)psi(.)	2	442.74	7.96	0.0135	0.96
p(.)psi(TPI)	3	443.22	8.45	0.0106	0.97
p(.)psi(TWI)	3	443.96	9.19	0.0073	0.98
p(.)psi(TR)	3	444.06	9.28	0.007	0.98
p(.)psi(HD)	3	444.58	9.81	0.0054	0.99
p(.)psi(BMF)	3	444.7	9.93	0.005	0.99
p(.)psi(CC)	3	444.73	9.96	0.005	1

Asiatic Brush-tailed Porcupine (*Atherurus macrourus*)

Model	nPars	AIC	delta	AICwt	cumltvWt
p(.)psi(WB)	3	185.57	0	0.306	0.31
p(.)psi(.)	2	187.07	1.5	0.145	0.45
p(.)psi(TR+MF)	4	187.74	2.18	0.103	0.55
p(.)psi(TR)	3	187.8	2.24	0.1	0.65
p(.)psi(CC)	3	187.99	2.43	0.091	0.75
p(.)psi(TWI)	3	188.5	2.94	0.07	0.82
p(.)psi(TPI)	3	188.61	3.05	0.067	0.88
p(.)psi(BMF)	3	188.7	3.13	0.064	0.95
p(.)psi(HD)	3	189.06	3.5	0.053	1

Asiatic Golden Cat (*Catopuma temminckii*)

Model	nPars	AIC	delta	AICwt	cumltvWt
p(.)psi(DEM)	3	123.81	0	0.373	0.37
p(.)psi(DEM+BMF+BMF^2)	5	126.36	2.55	0.104	0.48
p(.)psi(HD)	3	127.07	3.26	0.073	0.55
p(.)psi(.)	2	127.09	3.27	0.073	0.62
p(.)psi(MF)	3	127.32	3.5	0.065	0.69
p(.)psi(TPI)	3	128.25	4.44	0.041	0.73
p(.)psi(BMF^2)	3	128.3	4.48	0.04	0.77
p(.)psi(TWI)	3	128.61	4.79	0.034	0.8
p(.)psi(CC)	3	128.77	4.95	0.031	0.83
p(.)psi(MF^2)	3	128.82	5	0.031	0.86
p(.)psi(SC)	3	128.87	5.05	0.03	0.89
p(.)psi(DR)	3	128.91	5.09	0.029	0.92
p(.)psi(BMF)	3	129	5.18	0.028	0.95
p(.)psi(TR)	3	129.09	5.27	0.027	0.98
p(.)psi(MF+SC+DR)	5	130.68	6.86	0.012	0.99
p(.)psi(DR+TR)	4	130.91	7.09	0.011	1

Yellow-throated Marten (*Martes flavigula*)

Model	nPars	AIC	delta	AICwt	cumltvWt
p(.)psi(DEM+TR)	4	146.14	0	0.6109	0.61
p(.)psi(DEM+TR+WB+MF)	6	149.3	3.16	0.1258	0.74
p(.)psi(DEM+TR+SC+MF)	6	149.39	3.25	0.1201	0.86
p(.)psi(DEM)	3	151.1	4.96	0.0512	0.91
p(.)psi(WB)	3	152.7	6.56	0.023	0.93
p(.)psi(TR)	3	153.63	7.49	0.0144	0.95
p(.)psi(TPI)	3	154.45	8.31	0.0096	0.95
p(.)psi(.)	2	154.54	8.4	0.0091	0.96
p(.)psi(TWI)	3	154.8	8.66	0.008	0.97
p(.)psi(MF)	3	154.89	8.75	0.0077	0.98
p(.)psi(CC)	3	155.4	9.26	0.006	0.99
p(.)psi(HD)	3	156.32	10.18	0.0038	0.99
p(.)psi(SC)	3	156.44	10.31	0.0035	0.99
p(.)psi(BMF)	3	156.46	10.33	0.0035	1
p(.)psi(WB)	3	156.49	10.36	0.0034	1

Masked Palm Civet (*Paguma larvata*)

Model	nPars	AIC	delta	AICwt	cumltvWt
p(.)psi(BMF+TWI+HD)	5	106.28	0	0.43	0.43
p(.)psi(BMF+HD^2)	4	109.52	3.24	0.0851	0.52
p(.)psi(BMF+HD)	4	109.73	3.46	0.0763	0.59
p(.)psi(BMF)	3	110.06	3.78	0.0649	0.66
p(.)psi(BMF+SC+HD)	5	110.6	4.32	0.0495	0.71
p(.)psi(SC+BMF)	4	110.69	4.41	0.0474	0.75
p(.)psi(.)	2	110.8	4.52	0.0448	0.8
p(.)psi(BMF^2)	3	111.34	5.07	0.0341	0.83
p(.)psi(BMF+HD+DEM)	5	111.41	5.13	0.033	0.87
p(.)psi(BMF+HD+WB)	5	111.58	5.3	0.0303	0.9

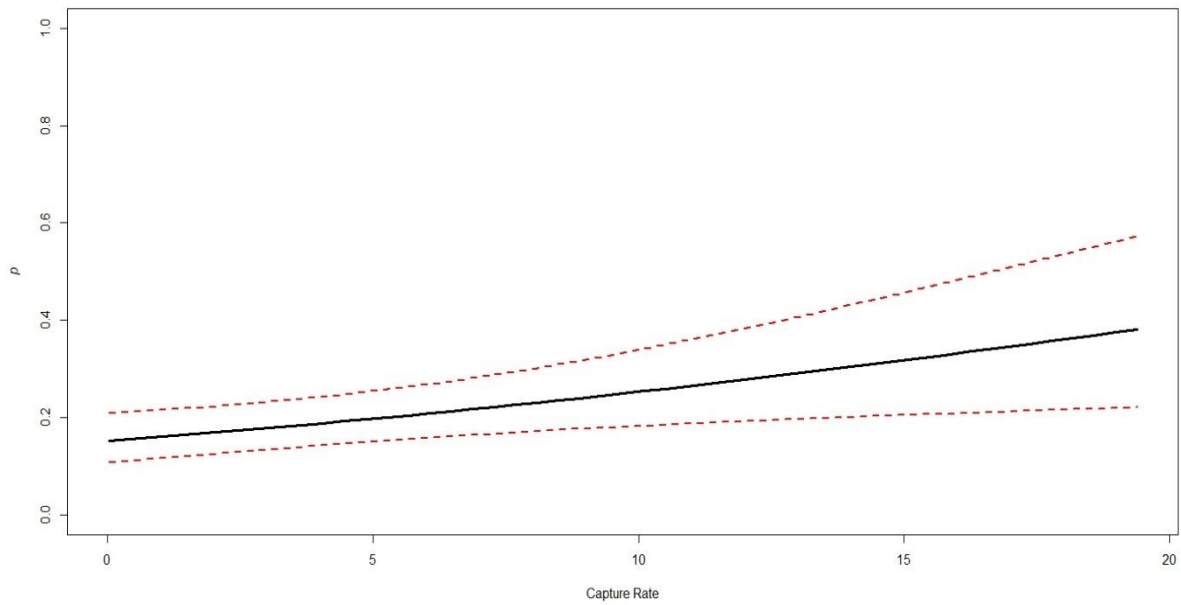
p(.)psi(BMF+DR+HD)	5	111.58	5.3	0.0303	0.93
p(.)psi(BMF+HD+MF)	5	111.67	5.4	0.0289	0.95
p(.)psi(BM+WB)	4	112	5.73	0.0245	0.98
p(.)psi(BMF+WB+HD+MF)	6	113.52	7.25	0.0115	0.99
p(.)psi(BMF+DR+MF)	5	113.97	7.7	0.0092	1

**Table 4. 4: Estimates of  $\beta$  coefficient values (standard errors, SE) of Northern Red Muntjac detection probability for different covariates based on the models  $\Delta AIC > 2$ . \*indicate statistical significance as defined by  $\beta \pm 1.96 \times SE$  not overlapping 0.**

Species	Covariate	Estimate	SE
Northern Red Muntjac	(Intercept)	-1.633	0.183
	Mdet*	0.257	0.097

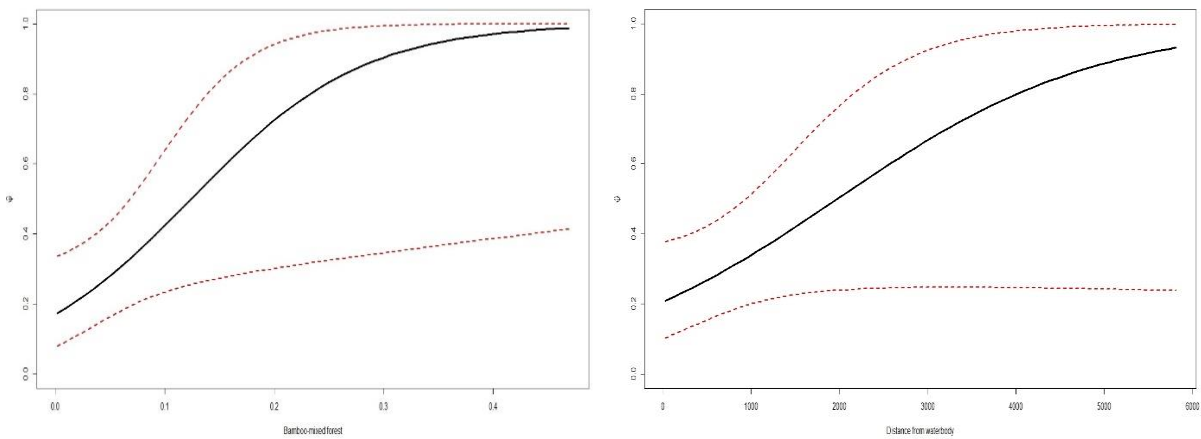
**Table 4. 5: Estimates of  $\beta$  coefficient values (standard errors, SE) of mammals' site-use probability for different individual covariates based on the models  $\Delta AIC > 2$ . \*indicate statistical significance as defined by  $\beta \pm 1.96 \times SE$  not overlapping 0.**

Species	Covariate	$\beta$ Estimate	SE
Northern Red Muntjac	(Intercept)	-0.943	0.349
	BMF*	1.082	0.487
	WB*	0.645	0.35
Mainland serow	(Intercept)	0.108	0.403
	WB*	-1.853	0.783
Brush-tailed Porcupine	(Intercept)	-2.248	0.475
	WB	0.599	0.32
Asian Golden Cat	(Intercept)	-2.677	0.625
	DEM*	0.966	0.437
Yellow-throated Marten	(Intercept)	-1.89	0.622
	DEM*	1.49	0.759
	TRI*	-1.66	0.807
Masked Palm Civet	(Intercept)	-2.14	0.832
	BMF*	2.53	1.111
	TWI	1.41	0.762
	HD	3.37	1.861

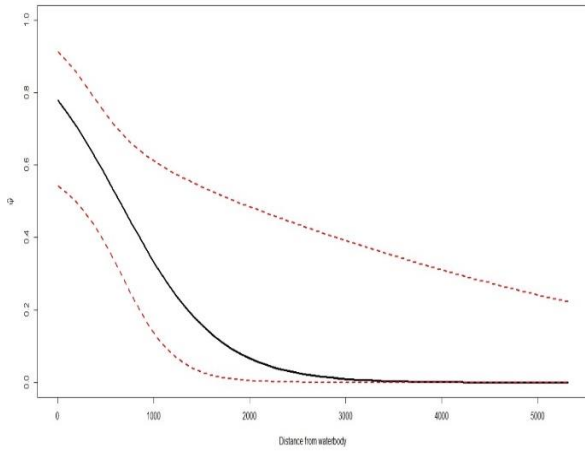


**Figure 4. 5: Association between the highly influential covariates (based on estimates of regression parameters ( $\beta$ ) and 95% CI from the best models) and the probability of Northern Red Muntjac occupancy in Mehao wildlife sanctuary, Arunachal Pradesh.**

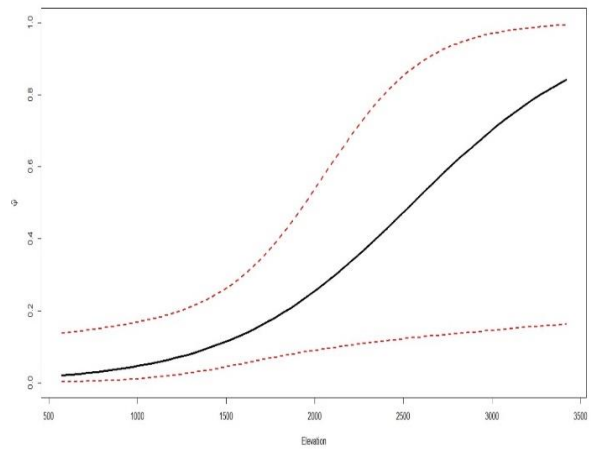
### Northern Red Muntjac



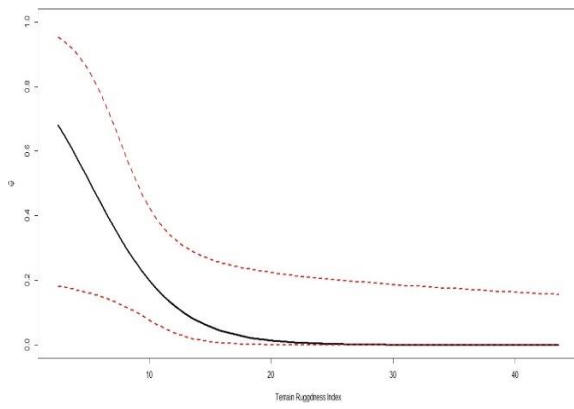
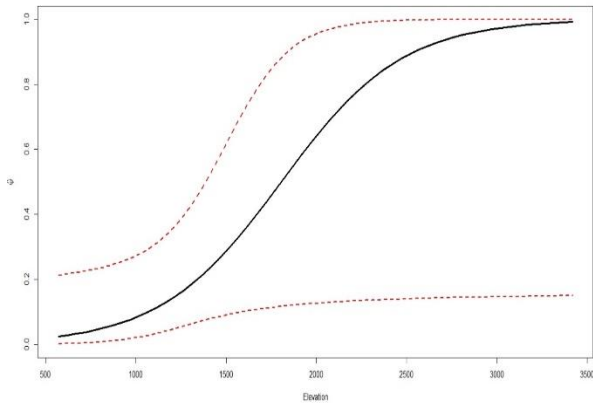
### Mainland serow



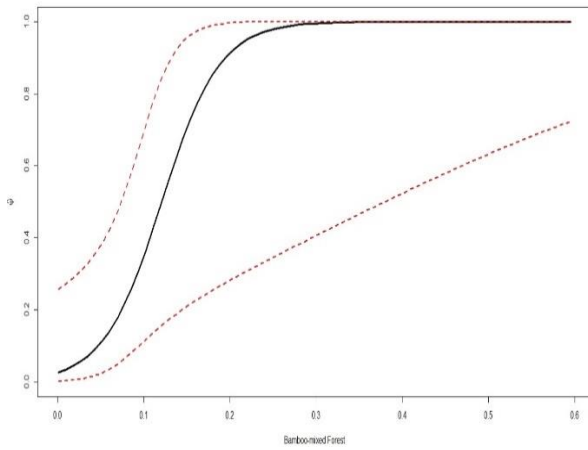
### Asian Golden Cat



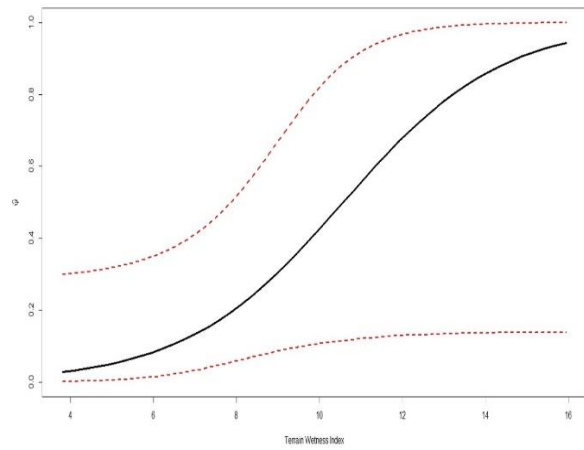
### Yellow-throated Marten



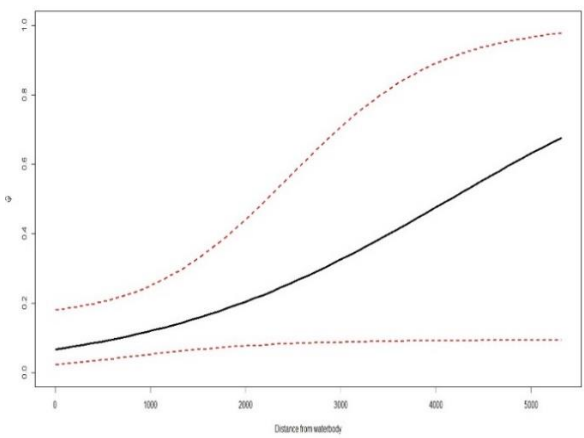
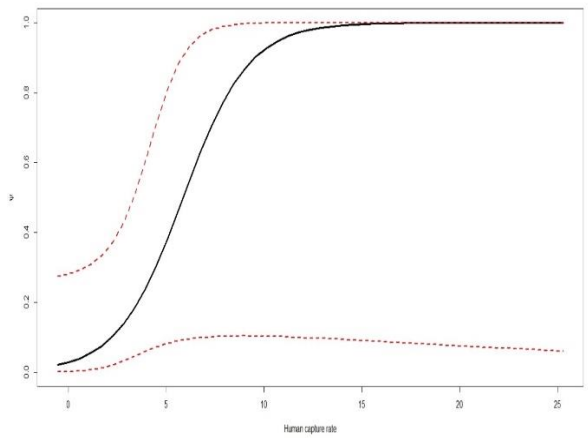
### Masked Palm Civet



Masked Palm Civet



Asiatic Brush-tailed Porcupine



**Figure 4. 6: Association between the probability and the highly influential covariates (based on estimates of regression parameters ( $\beta$ ) and 95% CI from the best models) of Northern Red Muntjac, Asiatic golden cat, Yellow-throated marten, Masked Palm Civet, Asiatic**

## Discussion

This study documented some rare and elusive species of Mehao WLS. During the camera trap survey and direct sighting, 26 species of mammals were recorded. However, our analysis of six distinct mammalian species revealed novel information regarding the conservation value of the study area. The response of mammals to disturbance varies with body size, home range size, and disturbance intensity (Estrada et al., 1994; Martinoli et al., 2006). We document that the forest of Mehao WLS has the potential to support rare and threatened species like a Clouded leopard, Spotted linsang, Marbled cat, Hoolock gibbon, Sambar, Mainland serow, etc. The studied mammalian fauna responded to ecological and anthropogenic factors in various ways but species-specific, as predicted. Species responded differently to different covariates, implying that management actions should be prioritised based on the relative importance of species in terms of conservation needs. We did not do sampling outside the sanctuary, but the species may be present in agricultural or human-occupied landscapes.

Given our predictions, the detection probability of Northern Red Muntjac showed positively significant to the presence of Mithun because compared to Mainland serow, Northern Red Muntjac is a more generalist species (Paudel & Kindlmann, 2012). However, it was observed that Northern Red Muntjac is close to human settlement areas with gentle slopes (Paudel & Kindlmann, 2012), so Mithun is a semi-domesticated bovid species that prefer to live near the human settlement area. Our occupancy estimate revealed that Northern Red Muntjac mainly chooses dense forests with low-growing vegetation, like a bamboo-mixed forest, to provide suitable habitats foraging and rest (Song & Zeng, 2004; Odden & Wegge, 2007). However, this study shows that Northern Red Muntjac avoids open areas like riverbeds for their movement to avoid humans' or hunters' presence.

Mainland serow showed a significant association with waterbody. Due to the absence of dense understory vegetation on steep slopes, serow is primarily found in deeply dissected mountains, rocky gorges, and ravines, which also provide shelter (Wu & Zhang, 2004). There are steep hills, deep valleys, multiple rocky streams, and some perennial rivers; densely wooded patches of grass provide suitable habitat for Serow because it feeds on vegetation that grows near the water body and provides cover from the predator-like black bears and humans. Serow uses dense forests near water habitats to help them maintain their body temperature (Aryal, 2009). However, the Asiatic

Brush-tailed porcupine is considered a lesser-known rodent species in northeast India (Molur, 2020; Talukdar et al., 2019), the first record of this species from Mehao WLS. The result showed that it avoids the open area near the waterbody and prefers dense forests to avoid human disturbances. They prefer the plain area with a gentle slope in the dense forest of Mehao WLS because of the moderate temperature tolerance. The dense forest provides cover to maintain their body temperature. The species were recorded from the forest of Arunachal Pradesh, such as Namdapha NP, Pakke WLS, and Changlang district (Agarwal, 2000; Datta et al., 2008a, b).

Occupancy of the Asiatic Golden Cat revealed that it prefers mostly high elevated areas. The Asiatic golden cat is the least studied in tropical Asia (Youngdrup et al., 2019), and it is thought to be even fewer with rare sightings (Grassman *et al.*, 2005). It is a solitary hunter and terrestrial forest-dependent species whose range is threatened by significant habitat loss and fragmentation (McCarthy et al., 2015). Over time, land use has changed forest cover, and human pressure on natural resources is more significant at lower elevations where they may be easier to access. The species were also recorded in the high altitude range from India and Bhutan (Bashir et al., 2011; Jigme, 2011; Dhendup et al., 2016). During the survey, we captured four different morphs of the Asiatic Golden Cat in Mehao WLS.

We found that yellow-throated marten has a positive relationship with elevation. The quality of the forest habitat is correlated with elevation. It is due to less anthropogenic disturbance in higher elevations, where urban areas, agricultural fields, and orchards are found at lower altitudes (Lee et al., 2021). Yellow-throated Marten occurrence declined with terrain ruggedness because it was covered by shrubs which avoid by marten because of its arboreal behavior (Duckworth, 1997; Appel & Khatiwada, 2014). The Masked palm civet preferred bamboo mixed forest habitat in lowland areas where an ample amount of water is present for species to feed on berries and seeds, molluscs, small mammals, amphibians, insects, and arthropods as food (Zhaou et al., 2008; Matsuo & Ochiai, 2009; Belden et al., 2014). Due to anthropogenic pressure, the species still survive in the lowland area, which is tolerant to some degree of habitat alteration (Zhaou et al., 2008; Semiadi et al., 2016).

Although evidence of incidental or retaliatory hunting was recorded for most species, by contrast, Takin is highly threatened in Mehao WLS due to considering hunting for their meat (Pers. Obs.). Hunters from the Nyishi tribe (laborers working in a cane-cutting camp) and local hunters (Idu

Mishmi) reportedly hunt mammalian species for meat. Idu Mishmi people regard hunting (aambe) as a strenuous activity, and many restrictions and taboos (aangi) are observed during hunting and trapping. We saw the hunting of other taxonomic groups, such as birds and fish, in the study area. Hunting mainly occurred near Sally Lake and Mehao Lake for Northern Red Muntjac (Manjo) and Wild Pig (Aamme). However, for the Asiatic Black bear (Aahun) and Mishmi Takin (Aakroo), the hunter goes deep inside the forest of Mehao WLS to hunt these species. During the field survey, we found the hunting evidence of Takin, Asiatic Black Bear, Northern pig-tailed macaque, and Pallas's Squirrel. Also, record some hunting camps and photographs in camera traps of hunters with guns inside the protected area.

The spirits who look after these resources and provide them to humanity play a significant role in the relationship between Idu Mishmi and the forests. To encourage locals to value and voluntarily participate in community-based conservation projects, the concept of taboos by the local population might be incorporated into conservation programmes.

### **Conservation implications**

Mehao WLS is an essential abode for mammalian species due to its diverse topography, habitats, and climatic conditions. Our study offered a quantitative approach for pensive decision-making in multi-species conservation, which took significant ecological variables into account. Using multi-species occupancy modeling, forest officials' models predicted mammalian species' responses to land-use changes. Locals must be persuaded to stop cutting down timber trees and cane in the sanctuary, as this would greatly benefit many mammalian species in formulating new and informed land-use policies.

This study provides crucial ecological data for mammalian species. It exemplifies a simple method for examining the distribution and habitat occupancy of rare and elusive mammals in the Mehao WLS. However, microhabitats are essential for managing and conserving mammalian species. The data is crucial for carrying out conservation initiatives for the species and effectively managing protected areas. To date, there has been little supporting information on mammalian species in Mehao WLS, and thus it is essential to do a long-term study on mammals (Katti et al., 1982).

Eco-awareness campaigns among the local populace (*Idu Mishmis and Adis*) should consider the adverse effects of hunting and habitat degradation on mammalian community populations. Like

this, our strategy for supporting alternative livelihoods (such as piggery, poultry, and dairy farming) can only be successful if the government and other organizations continue to raise money and inspire residents until they can support themselves. However, it is adequate to make aware youth to motivate them to sustainable tourism activities such as bird watching, trekking, and camping in the diverse, rich region as an alternative livelihood opportunity. The effectiveness of patrolling and other management and conservation interventions will be shown by continued monitoring, which will also reveal the presence of native species, threat areas, the involvement of invasive species, and an indication of their prevalence. Our cameras were fully operational for twenty-four hours, and the data indicate that the arboreal nature of certain species may limit the number of photographs taken. However, we believe that this cannot be assumed. So we propose that conservation efforts for the species be conducted on the available data, which indicates that the species occurs in small numbers and should be given more excellent protection consideration. Data analysis of mammalian species throughout their ranges is critical for effectively and efficiently conserving these species in a continuously changing landscape.

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## Chapter 5

Objective: To analyse the land use/land cover change patterns and to identify the main driving factors.

## Introduction

Changes in land use and land cover (LULC) have been acknowledged as one of the main factors influencing biodiversity change around the world over the last few decades (Sala et al., 2000; Hansen et al., 2004). Each year, vast areas of diverse tropical forests are lost or degraded, profoundly impacting biodiversity (Morris, 2010). The primary causes of tropical forest biodiversity loss include deforestation and fragmentation, overexploitation, invasive species, and climate change (Millennium Ecosystem Assessment 2005). With peak deforestation occurring in the 1980s and 1990s, approximately half of the tropical forest that existed at the beginning of the 20th Century has already vanished (Wright, 2005). It is difficult to track the long-term worldwide trend in tropical forest areas and forest regeneration, which may cause the lack of unambiguous evidence of continued loss in tropical forest areas (Grainger, 2008). The difficulty of using ground-based inventory and monitoring techniques for large land areas is exacerbated by the remoteness and inaccessibility of many tropical forest locations (Hayer & Sader, 2001). Anthropogenic change can be tracked through land use change trajectories from undeveloped rural areas to fully developed or metropolitan areas (Hansen et al., 2004). These landscapes may experience numerous phases of transition or reversal, resulting in a mosaic of remaining native habitats, farmland, and urban areas. Due to the homogenisation of vegetation types (Flather et al., 1998), vulnerability to edge effects in areas where habitat fragmentation has occurred (Laurance et al., 2001; Harper et al., 2005), or an increase in the intensity of human activities such as logging, farming, grazing, and hunting; these land use changes may result in a decrease in biodiversity (Brashares et al., 2001). LULC changes can impact the state of land through pressures exerted by various aspects of this change. Different factors will influence how the landscape changes and how biodiversity is preserved. However, it is evident that local, national, and international economic, political, and conservation pressures are responsible for driving changes in land cover (Homewood et al., 2001; Jokisch & Lair, 2003) and influencing the establishment and management of protected areas (Zimmerer et al., 2004; Bonta, 2005).

The number of protected areas has increased worldwide to conserve ecological and cultural resources (Rodriguez & Young, 2000; Chape et al., 2003; Zimmerer et al., 2004). Although local species still go extinct inside reserves (Woodroffe & Ginsberg, 1998), protected areas are known to facilitate biodiversity conservation (Bruner et al., 2001). The loss of biodiversity inside a

protected area may be related to the size or isolation of the reserve as well as changes in land use and land cover (LULC) surrounding the reserve (Baker, 1989; 1992; Hansen & Rotella, 2001; Hansen et al., 2004; DeFries et al., 2005). As a management strategy to reduce the impact of surrounding land use activity on biodiversity within the protected area, buffer zones with limited or restricted land use have been proposed (Schonewald-Cox & Bayless, 1986; Schonewald-Cox, 1988; Byers, 2000; Lynagh & Ulrich, 2002). People living in a protected area's buffer zone may modify the frequency and type of disturbances, changing the vegetation types associated with such disturbance regimes.

Evaluating LULC and its effects as a prerequisite to planning and sustainably managing natural resources (Verburg et al., 1999; Lambin et al., 2000; Petit et al., 2001; Read and Lam, 2002). Land use substantially impacts how socioeconomic and environmental systems function, considerably impacting sustainability, food security, biodiversity, and the socioeconomic vulnerability of humans and ecosystems (Hayes & Sader, 2001). The most apparent factors influencing these changes, which vary within and across different land systems and give rise to predictable land use changes, are population expansion, concurrent demand for land-use goods, and other human actions (Fresco, 1993; Mas, 1999; Opeyemi, 2006; Desta & Fetene, 2020; Berihun et al., 2019; Qasim et al., 2013; Tiwari, 2000, 2008). As a result, it is necessary to simulate how different physical and socioeconomic elements or land use change drivers impact land use change (Turner et al., 1993).

Arunachal Pradesh has large tracts of tropical wet-evergreen, subtropical, temperate, and alpine forests. However, human-induced landscape encroachment due to settlement and agricultural expansion and over-exploitation of natural resources has reached alarming levels in the study area in the eastern Himalayan region, which has been recognised as a global biodiversity hotspot. There have been few studies on LULC change analysis in the Lower Dibang Valley district (Singh et al., 2013; Areendran et al., 2018; Deka et al., 2019). The present study's objectives include (1) evaluation and quantification of land use/land cover change in Mehao WLS, (2) illustration of spatial characteristics and determinants or drivers of LULC, (3) assessment of the effects of human-induced LULC change on protected areas in this area, and (4) the use of landscape metrics to evaluate changes in the extent and pattern of cover types. From a management and conservation aspect, the current study is important to understand and manage land cover and change patterns,

which would otherwise harm the existing biodiversity in Mehao WLS. The study uses geospatial technology to identify and quantify LULC change in and around Mehao WLS from 1998 to 2020. The information that emerges from this process can assist decision-makers in identifying and addressing potential problems, such as identifying if an increased population in the area will result in increased forest loss. This could help develop effective land use management strategies for the area's sustainable growth.

## **Study Area**

As mentioned in Chapter 4.

## **Methodology and Data Analysis**

The LULC classes of Mehao WLS were mapped from 1998 to 2020 using geo-corrected satellite data from Landsat-5 Thematic Mapper (TM) images from 1998 and 2008 as well as a 10m resolution cloud-free Sentinel 2A MSI (Multispectral Imager) Level-1C image from 2020 (Table 1). Both sensors (TM and MSI) are primarily used for LULC mapping and monitoring forests, agriculture, and built-up areas. The USGS Earth Explorer website (<http://earthexplorer.usgs.gov/>) was used to obtain these satellite images. The USGS Earth Explorer allows access to Level-1C top-of-atmosphere (TOA) reflectance of Sentinel-2A data. Level-1C processing includes radiometric and geometric corrections and orthorectification in the UTM/WGS 84 projection to generate highly accurate geolocated products. Landsat 5 TM level 1 dataset was also available in TOA Reflectance and projected in the UTM/WGS 84 projected coordinated system. The image preprocessing, such as mosaic and layer stacking, was done using ERDAS IMAGINE 2016 (Hexagon Geospatial, Peachtree Corners Circle Norcross). The LULC classes were considered when creating the LULC map using satellite images. Supervised classification was used to create the spectral signatures into defined image features. The training sample sites are chosen as the first step in the supervised classification. Training sample sites are pre-identified geographical features of areas that reflect a particular class based on ground truthing (Purkis & Klemas, 2011). The sites were chosen based on field sampling data collected during a camera trapping and sign survey from November 2017 to May 2020. Some regions were inaccessible because of the hilly geography, harsh terrain, and steep slopes. Ground truthing points were collected for all the classes attempted in the image classification. Eight major LULC classifications were selected for mapping:

grassland, riverbed, built-up land, mixed forest, barren land, and riverine forest (Table 5.1). The area used for horticulture was classified as agricultural land. The maximum likelihood classification technique was used to classify the image pixels into LULC categories using ArcGIS 10.3 (ESRI, Redlands, CA, USA). The classification error in the images was corrected by comparing the classified image to the corresponding satellite image and cleaned by recoding the misclassified or overlapped class to the correct class (Kaliraj et al., 2017).

**Table 5. 1: Land uses land cover classification scheme.**

<b>Class</b>	<b>Description</b>
Agriculture land	The class represents the land used for crop cultivation and horticulture.
Barren land	The class includes a landslide and other surfaces with minimal vegetation cover.
Built up	This class represents the residential, road, industrial, and commercial zones.
Grassland	Area in which vegetation is dominated by grass species such as <i>Imperata cylindrical</i> , <i>Phragmites karka</i> , <i>Saccharum arundinaceum</i> , <i>Setaria glauca</i> , etc.
Mixed forest	This class represents tree species such as <i>Ailanthus grandus</i> , <i>Betula alnoides</i> , <i>Castanopsis indica</i> , <i>Cyathea spp.</i> , <i>Duabanga grandiflora</i> , <i>Michelia champaca</i> , <i>Phoebe cooperiana</i> , <i>Quercus semecarpifolia</i> , <i>Terminalia myriocarpa</i> , etc. without a single species being numerically dominant.
Riverbed	This category includes sand, small rocks, and pebbles along river channels.
Riverine forest	This category represents mostly riverine tree species such as <i>Bombax ceiba</i> , <i>Cassia fistula</i> , <i>Albizia lebbeck</i> , <i>Alstonia scholaris</i> , <i>Shorea</i>

	<i>assamica</i> , <i>Boehmeria macrophylla</i> , <i>Ficus hispida</i> , etc. on dry sandy bars along rivers and streams.
Water	This category includes rivers, lakes, and ponds.

To match the spatial resolution of all classed maps, the LULC map of the 2020 image was resampled on 30 m, and the post-classification change detection technique was employed to evaluate the changes. The change matrix provides crucial details regarding the spatial distribution of changes in LULC (Shalaby & Tateishi, 2007). To evaluate the overall changes in LULC classes, categorised images from 1998, 2008, and 2020 were used to create a change matrix illustrating land cover changes in each decade.

### Accuracy assessment

The classification accuracy was tested using a random stratified approach. On each classed image, random points were chosen, and the data were compiled and quantified using the error matrix. Points with class values of 0 were excluded. To determine the accuracy of the classified maps from 1998, 2008, and 2020, we calculated the accuracy of the users and producers, the Kappa coefficient, and total accuracy. The error matrix reports for each classified image provide correctly classified reference points percentages. Generally, the Kappa coefficient value exceeds the classification accuracy of the images (Jensen, 2005; Lillesand et al., 2014; Ganaie et al., 2017). Accuracy was evaluated using the discrete multivariate method known as the Kappa index (Cohen, 1960). Following the Kappa analysis, the accuracy of the land use imagery is determined using KHAT statistics using the following formula:

$$K = \frac{N \sum_{i=1}^r x_{ii} - \sum_{i=1}^r (x_{i+} * Xx_{+i})}{N^2 - \sum_{i=1}^r (x_{i+} * Xx_{+i})}$$

where;  $N$  = a total number of observations (pixels),  $r$  = a number of rows in matrix,  $x_{ii}$  = observation in row  $i$  and column  $i$ ,  $x_{i+}$  = marginal total of row  $i$ , and  $x_{+i}$  = marginal total of column  $i$ . The Kappa coefficient was also computed for each classified image. The concordance between the data shown on the classified maps and the accurate information on the ground is used to divide the Kappa values into three categories. When the Kappa value is greater than 0.80, there is high agreement; when it is less than 0.40, there is poor agreement; when it is between 0.40 and 0.80, there is moderate agreement (Rahman et al., 2004; Congalton & Green, 1999). Thus, a Kappa index was calculated to estimate the overall classification accuracy of all LULC images.

### **Landscape Metrics Analysis**

In landscape ecology, landscape metrics analysis has been frequently used to assess changes that may have happened over time. Examining spatiotemporal change in different LULC classes uses landscape structure analysis based on various metrics. Many landscape metrics derived from remote sensing data are used to study and quantify these changes. These metrics relate to the landscape's quantity, size, shape, and other characteristics (Ji et al., 2006; Seto & Fragkias, 2005). We investigated changes over time in the eight current land cover classes (mixed forest, riverine forest, grassland, riverbed, barren land built-up, and agriculture). Thus, our study focussed on the class-level scale. Metrics at the class level need the integration of all patches in a specific class. Below, we have listed the statistics used to integrate all patches and a description of the selected metrics. We used the eight-cell neighbours to allocate each pixel to a different patch.

This study used seven class metrics to analyse the spatial structure of the landscape, including the Edge Density (ED), Area-weighted mean patch radius of gyration (GYRATE AM), Landscape Division Index (DIVISION), Patch Cohesion Index (COHESION), Aggregation index (AI), Clumpiness index (CLUMPY), and Interspersion and juxtaposition index (IJI) (Cao et al., 2017; Herzog et al., 2001; Michel et al., 2021). ED and GYRATE AM are usually an 'Area and Edge metric.' Edge effects are one of the most prominent factors causing ecological change (Laurance et al., 2011). We chose edge density (ED) over the total edge to make it easier to compare sites with different areas. ED is calculated by adding the lengths (m) of all patch edge segments within each land cover class. This is then divided by the size of the entire landscape.  $ED = 0$  if there is

only one patch (and the landscape boundary is not considered), and it keeps going up indefinitely as the patchiness of the landscape increases.

The radius of gyration (GYRATE) multiplied by the proportional abundance of the patch results in GYRATE AM (area-weighted mean), which is calculated at the class level (i.e., the patch area divided by the sum of all patch areas of the corresponding patch type). The connectivity of the landscape habitat is assessed using the DIVISION and COHESION indices. The COHESION index has a scale from 0 to 100. A highly fragmented landscape exhibits null value and is physically less connected. The DIVISION ranges from 0 to 1. When the focal patch type consists of a single small patch or one cell in the area, the value of 1 is observed rather than the zero value, which is used for homogeneous landscapes (landscapes with a single patch).

The AI measures the specific class ranges from 0 to 100. If the focal patch type of a landscape is maximally aggregated into a single compact patch, the index value is 100. The COHESION and AI indices have high values when various types of land use are combined and geographically self-connected. On the other hand, landscapes with disparate land use types are defined by high values of the division index. A normalized index called the CLUMPY index shows how a particular land cover class is distributed or aggregated across the landscape. The range of its values is -1 (maximally disaggregated) to 1 (maximally clumped). The value is zero when the patch distribution is identical to randomness. Values above zero indicate a more clumped landscape, whereas values below zero indicate more excellent dispersion (or disaggregation). This metric is essential to comprehend spatial connectivity between forest patches (Donald & Evans, 2006). The Interspersion and juxtaposition index (IJI), first proposed by McGarigal and Marks in 1995, is derived from the relationship between the length of each edge type and the overall edge of the landscape, divided by a term based on the number of land use types. If adjacencies are evenly distributed between all patch types, then IJI approaches 0; if they are not, then it equals 100. The FRAGSTATS software (version 4.2) was used to conduct these quantitative analyses.

## **Social Survey**

The satellite-based remotely sensed data were used to comprehend the changes that have taken place in LULC in a particular area between different periods. However, it only explains the ‘how’ of these changes. To explain ‘why’ these changes have taken place, a semi-structured interview

schedule was used to collect information on the socio-economic aspects of local communities and understand their perception of the trends of LULC changes. A semi-structured interview schedule was used to conduct a questionnaire survey to collect information on socioeconomic aspects of local communities and human-wildlife interactions. 81 households from 13 villages were included in this survey and focus group discussions in and around the study area. The interview schedule to assess the socio-economic status of Idu communities and their natural resource dependence sought household information about essential socio-demographic factors, source of income, mean annual income, land, and livestock holding, agricultural practices, non-timber forest produce dependence, availability of fuel sources, and contingent questions.

## Result

### Accuracy Assessment

Using Landsat and Sentinel images and change detection techniques, past patterns of land use and land cover changes between 1998 and 2020 were identified. For 1998, 2008, and 2020 classified images, the overall classification accuracy was greater than 80%. User accuracy (UA) and producer accuracy (PA) for each LULC class are listed in Table 5.2. These findings provide a crucial base for the subsequent evaluation of LULC changes.

**Table 5. 2: Verification values for classification accuracy.**

LULC Categories	1998		2008		2020	
	Producer accuracy (%)	User Accuracy (%)	Producer accuracy (%)	User Accuracy (%)	Producer accuracy (%)	User Accuracy (%)
Water bodies	100	80	100	80	100	80
Grassland	87.5	70	100	70	83.33	70
Riverbed	64.28	90	81.82	90	100	90
Agriculture	88.89	80	88.88	80	90.91	80
Barren land	100	70	100	70	100	70
Mixed forest	71.43	100	90.91	100	90.91	100

Riverine forest	75	90	71.43	90	90.91	90
Built up	100	80	100	80	100	80
Overall accuracy (%)	82.5		90		93.75	
Kappa coefficient	0.74		0.85		0.9	

### Trend of LULC changes from 1998 to 2020

Eight classes extracted with proportionate coverage areas for each show the pattern of LULC change from 1998 to 2020 in Tables 5.3 and 5.4 and Figure 5.1. These were Waterbodies, Riverbeds, Grassland, Agriculture land, Barren land, Mixed forests, Riverine forests, and Built-up.

From the perspective of land use change, Figure 5.2 shows the land use change between 1998, 2008, and 2020. Mixed forest dominated the LULC in 1998 when it accounted for 74.43% of the total area investigated, followed by Riverine forest (11.45%), Agricultural land (3.67%), Barren ground (3.39%), Grassland (2.34%), Riverbed (1.60%), Built up (0.96%), and Waterbodies (0.27%). In 2008, the dominant LULC class was still Mixed forest (75.09%), followed by Riverine forest (11.08%), Agricultural land (4.75%), Grassland (2.34%), Riverbed (1.76%), Barren land (1.89%), Built up (0.98%), and Waterbodies (0.28%). In 2020, the observed LULC pattern was dominated by Mixed forest (72.17%) followed by Riverine forest (8.80%), Barren land (6.33%), Agricultural land (5.59%), Grassland (2.81%), Built-up (1.86%), Riverbed (1.19%), and Water bodies (0.44%) (Table 5.3). Figure 5.3 displays the spatial representation of LULC types from 1998 to 2020.

Table 5.4 shows a general decline in natural areas, including Mixed forest (11.28 sq km), Riverine forest (12.86 sq km), and Riverbed (2.03 sq km), during the study period (1998-2020). The Grassland (2.28 sq km) and Water bodies (0.81 sq km) were the only natural areas that increased in size. The land use reflects population growth and increased economic activities as indicated by Built-up (4.34 sq km) and Agricultural land (9.26 sq km).

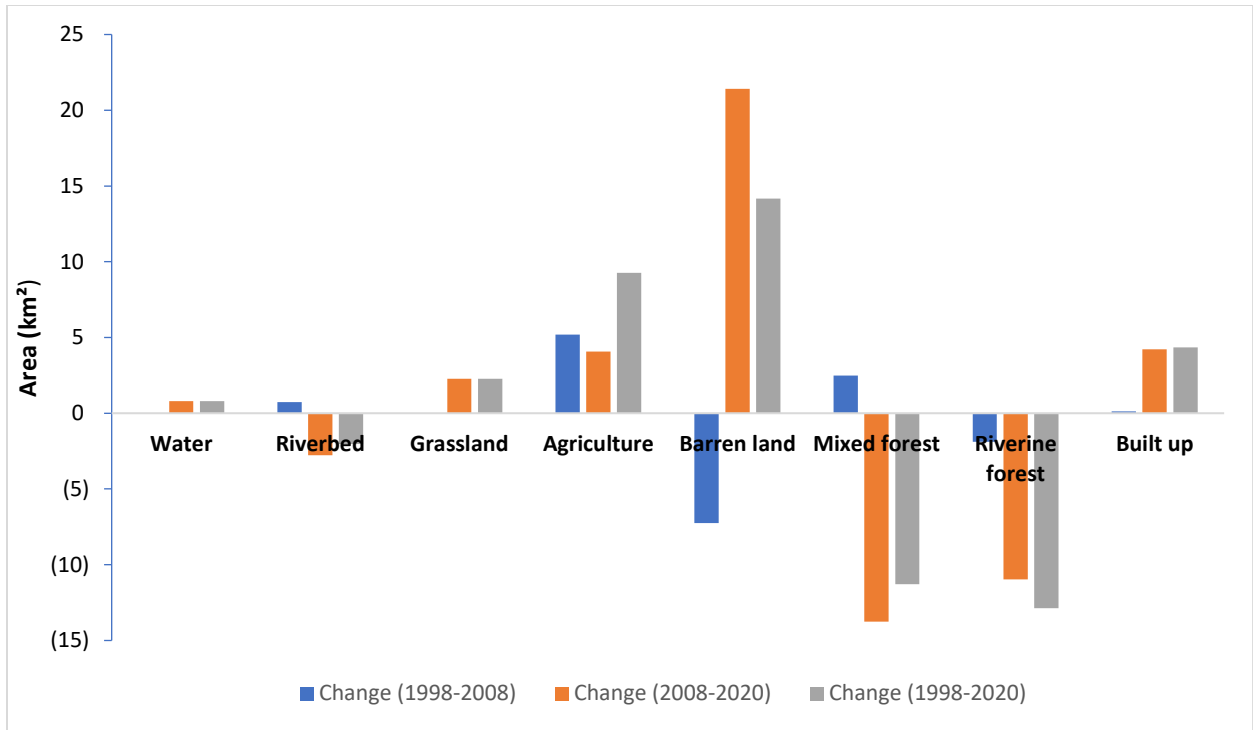
**Table 5. 3: Results of the LULC classification for 1998, 2008, and 2020 images showing the area of each category and category percentages.**

LULC	1998	2008	2020
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<b>Categories</b>	<b>Area/km<sup>2</sup></b>	<b>Area (%)</b>	<b>Area/ km<sup>2</sup></b>	<b>Area (%)</b>	<b>Area/ km<sup>2</sup></b>	<b>Area (%)</b>
Water bodies	1.31	0.27	1.33	0.28	2.12	0.44
Riverbed	7.75	1.60	8.50	1.76	5.72	1.19
Grassland	11.28	2.34	11.28	2.34	13.56	2.81
Agriculture	17.71	3.67	22.89	4.75	26.97	5.59
Barren land	16.37	3.39	9.11	1.89	30.54	6.33
Mixed forest	359.63	74.43	362.11	75.09	348.35	72.17
Riverine forest	55.34	11.45	53.45	11.08	42.48	8.80
Built up	4.63	0.96	4.74	0.98	8.96	1.86

**Table 5. 4: Results of the LULC classification for 1998, 2008, and 2020 images showing the area changed (km<sup>2</sup>) and percentage.**

<b>Class</b>	<b>Change (1998-2008)</b>		<b>Change (2008-2020)</b>			<b>Change (1998-2020)</b>		
	<b>Area (Km<sup>2</sup>)</b>	<b>%</b>	<b>Area (Km<sup>2</sup>)</b>	<b>%</b>	<b>%</b>	<b>Area (Km<sup>2</sup>)</b>	<b>%</b>	<b>%</b>
Water bodies	0.02	0.00	0.79	0.16	0.81	0.17		
Riverbed	0.74	0.16	-2.78	-0.60	-2.03	-0.44		
Grassland	-0.01	0.00	2.28	0.45	2.28	0.45		
Agriculture	5.18	1.10	4.08	0.80	9.26	1.90		
Barren land	-7.26	-1.53	21.42	4.45	14.17	2.93		
Mixed forest	2.49	0.62	-13.76	-3.72	-11.28	-3.10		
Riverine forest	-1.89	-0.38	-10.97	-2.42	-12.86	-2.80		
Built up	0.12	0.03	4.22	0.87	4.34	0.90		



**Figure 5. 1: Changes within each land use and land cover class (1998–2008–2020) showing the area changed in km².**

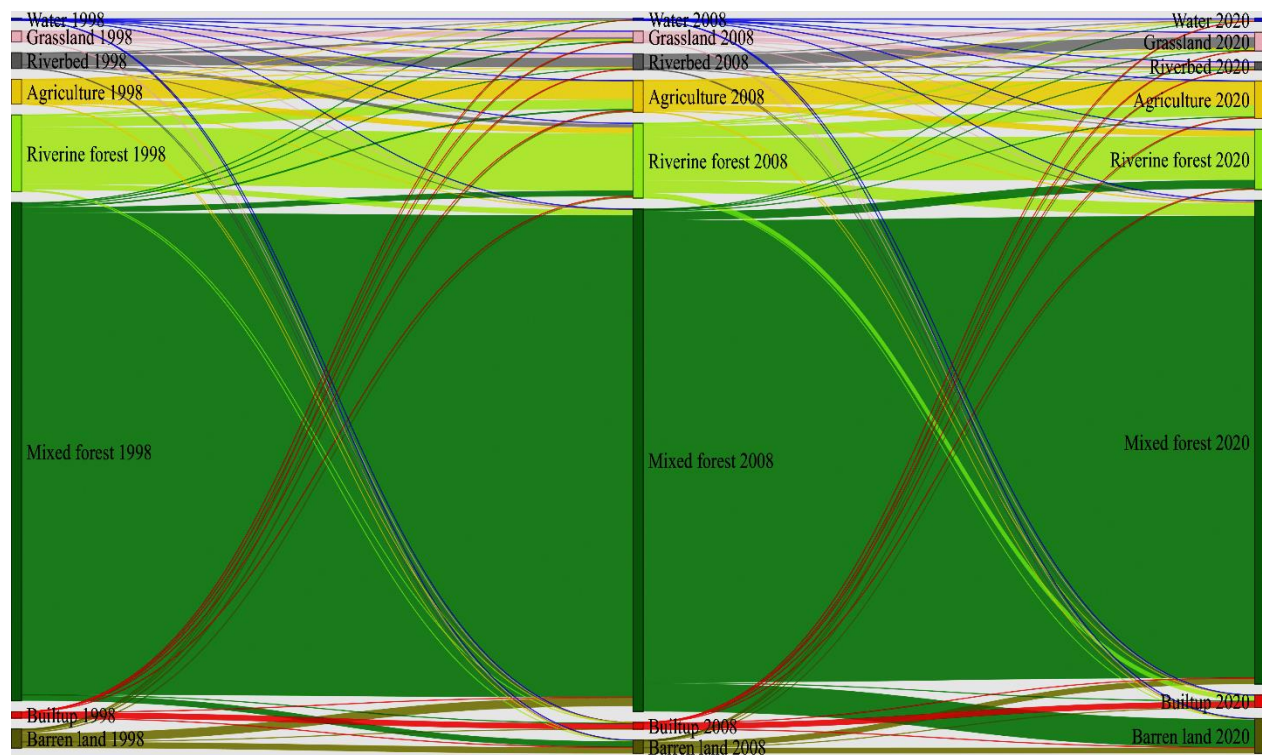
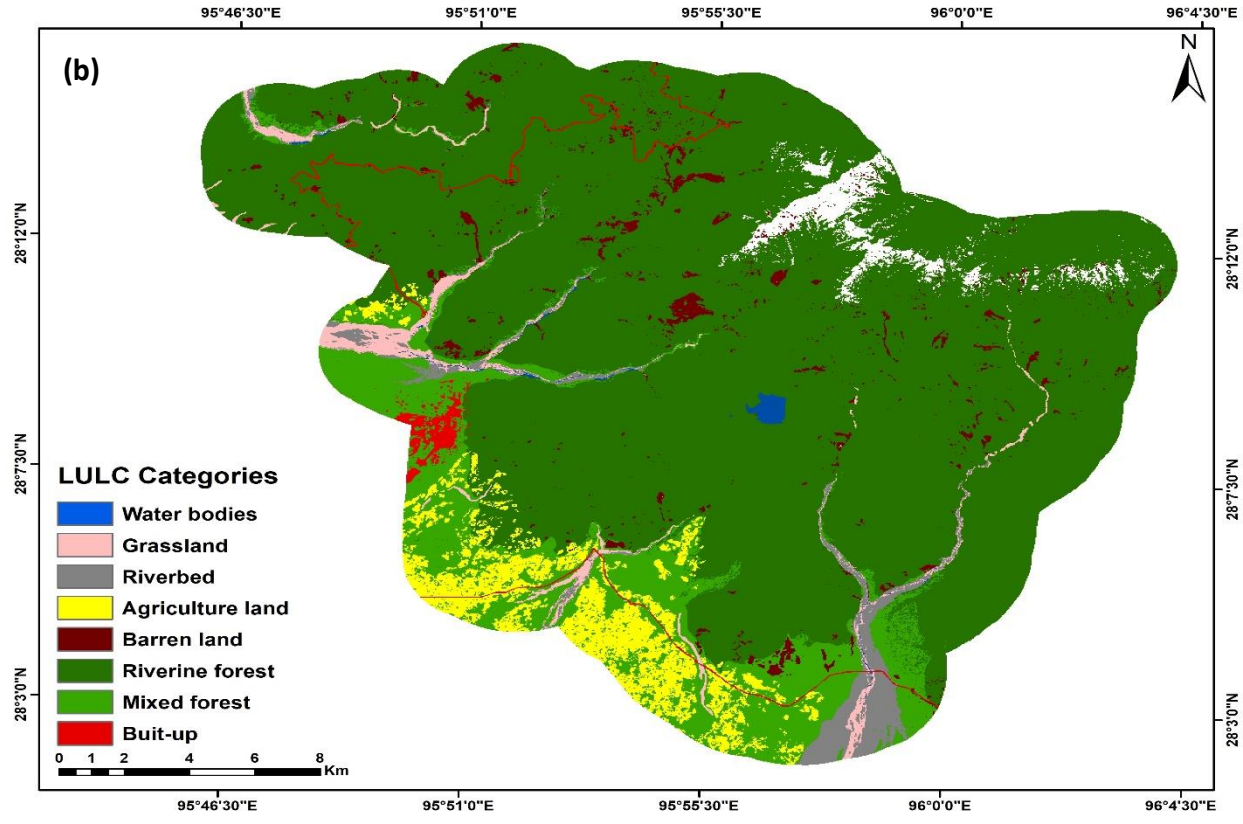
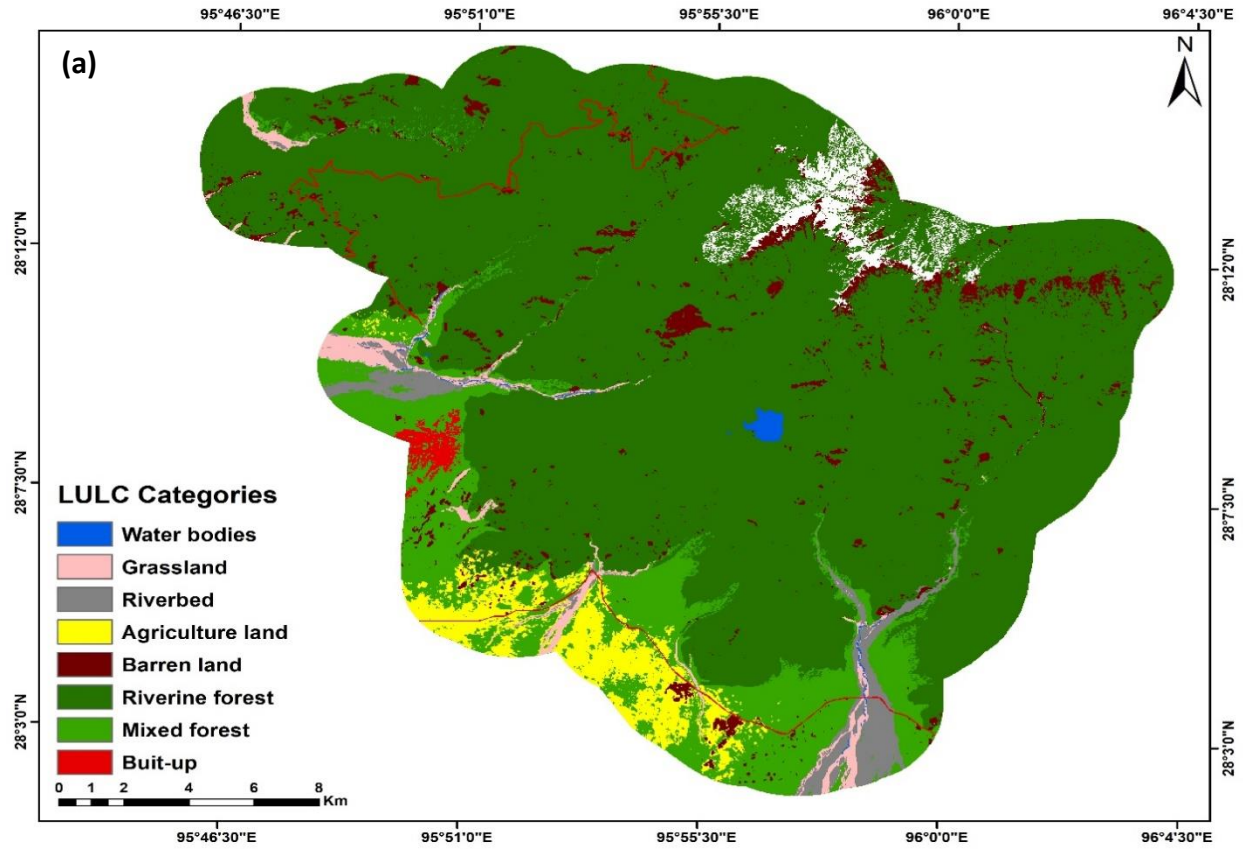
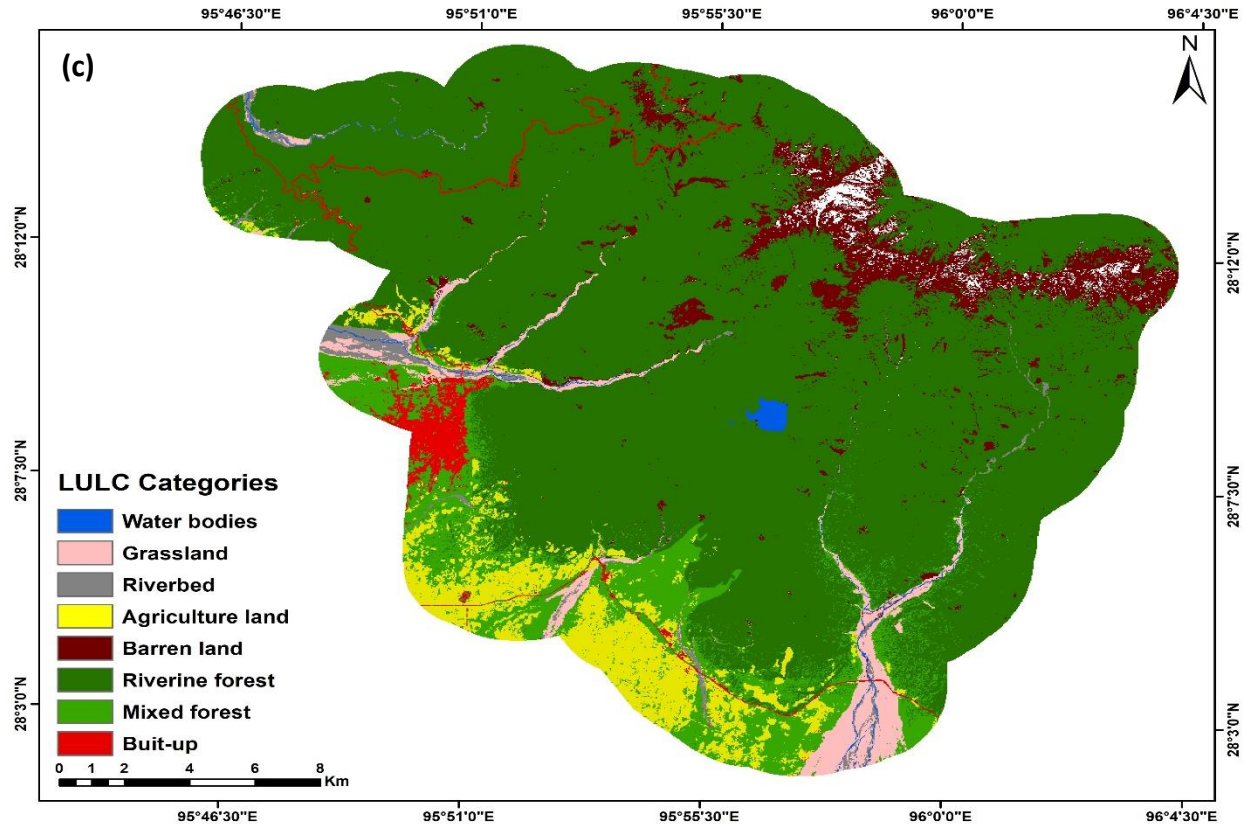


Figure 5. 2: Sankey plot showing changes from one land use land cover class to another between 1998, 2008, and 2020.





**Figure 5. 3: Figure 4: Land use/land cover maps for years (a) 1998, (b) 2008, and (c) 2020**

### **Transition among Land Use/Land Cover Types from 1998 to 2020**

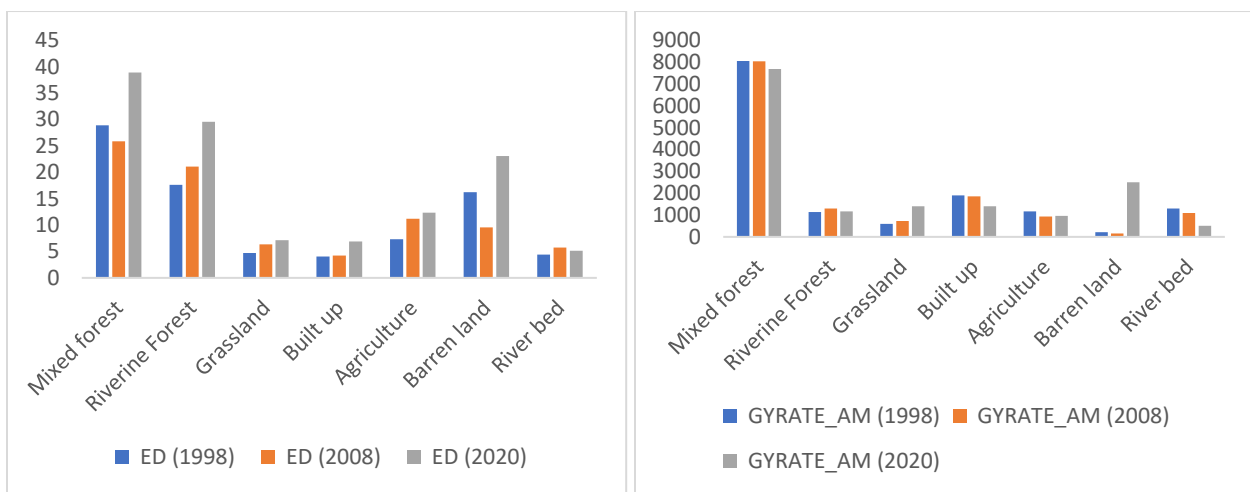
According to the change matrix cross-tabulation from 1998 to 2020, Table 5.5 lists the areas that changed together with the corresponding percentage. The table compares the LULC classes based on their total area. During the study period, changes were detected for Mixed forest (92.2%) followed by Built-up (85.89%), Agriculture land (75.91%), Water bodies (73.65%), Grassland (71.43%), Riverine forest (58.51%), Barren land (42.93%), and Riverbed (36.27%). As a result, the most significant conversion rate was observed in Barren land, where Mixed forests comprised over 44.69% of the total area. Most of the Riverine forests were converted into Mixed forest (16.15%) and Agriculture land (14.44%). Although Agricultural land did not change much, almost 14.44% was gained from Riverine forest (7.71 sq km), followed by Mixed forest (0.79 sq km), Barren land (0.57 sq km), and Riverbed (0.27 sq km). Between 1998 and 2020, the Riverine forest predominately replaced Agriculture and Built-up, while Riverbed was transformed into Grassland and Mixed forest.

**Table 5. 5: Transition matrix showing LULC change in Mehao WLS between 1998 to 2020**

<b>LULC Class 1998/2020</b>	<b>Unit</b>	<b>Agric ulture</b>	<b>Barren land</b>	<b>Built up</b>	<b>Gras sland</b>	<b>Mixed forest</b>	<b>River bed</b>	<b>Riverin e forest</b>	<b>Water</b>
<b>Agricultur e</b>	<b>Area (km<sup>2</sup>)</b>	17.36	0.02	0.47	0.01	0.89	0.03	4.10	0.00
	<b>(%)</b>	75.91	0.07	2.04	0.05	3.90	0.11	17.93	0.00
<b>Barren land</b>	<b>Area (km<sup>2</sup>)</b>	0.57	3.86	0.07	0.09	4.02	0.11	0.27	0.00
	<b>(%)</b>	6.36	42.93	0.76	0.96	44.69	1.23	3.05	0.05
<b>Built up</b>	<b>Area (km<sup>2</sup>)</b>	0.11	0.02	4.06	0.01	0.12	0.00	0.42	0.00
	<b>(%)</b>	2.22	0.38	85.9	0.12	2.51	0.05	8.87	0.00
<b>Grassland</b>	<b>Area (km<sup>2</sup>)</b>	0.10	0.15	0.14	8.05	0.52	1.37	0.46	0.48
	<b>(%)</b>	0.92	1.35	1.23	71.43	4.64	12.12	4.05	4.28
<b>Mixed forest</b>	<b>Area (km<sup>2</sup>)</b>	0.79	20.07	0.73	0.45	332.49	0.43	5.50	0.16
	<b>(%)</b>	0.22	5.56	0.20	0.12	92.20	0.12	1.53	0.04
<b>Riverbed</b>	<b>Area (km<sup>2</sup>)</b>	0.27	0.21	0.05	3.19	0.87	3.08	0.38	0.44
	<b>(%)</b>	3.20	2.44	0.56	37.67	10.21	36.27	4.45	5.20
<b>Riverine forest</b>	<b>Area (km<sup>2</sup>)</b>	7.71	0.23	3.44	1.49	8.62	0.61	31.24	0.05
	<b>(%)</b>	14.44	0.44	6.45	2.80	16.15	1.13	58.51	0.09
<b>Water</b>	<b>Area (km<sup>2</sup>)</b>	0.00	0.00	0.00	0.22	0.03	0.09	0.00	0.98
	<b>(%)</b>	0.00	0.33	0.07	16.42	2.48	6.82	0.11	73.65

## Landscape Metrics Analysis

Seven class metrics, including Edge Density (ED), Area-weighted Mean Patch Radius of Gyration (GYRATE AM), Landscape Division Index (DIVISION), Patch Cohesion Index (COHESION), Aggregation Index (AI), Clumpiness Index (CLUMPY), and Interspersion and juxtaposition Index (IJI), were calculated in the current study to analyse the landscape structure and change of various land use/land cover classes (Fig 5.4). In Mehao WLS, Mixed forest, and Riverine forest were the two most common land use/land cover classes. The changes that were brought about in both classes were strongly tied to eco-environmental problems such as deforestation, land degradation, biodiversity loss, destruction of wildlife habitats, and wildlife migration. Within the mixed forest, from 1998 to 2020, there was an increase in ED (28.90 to 38.92) and DIVISION indices (0.45 to 0.53), while in the Riverine forest, ED increased from 17.63 to 29.57. The GYRATE\_AM decreases in Mixed forest (8054.81 to 7683.81), Built-up (1905.2 to 1397.42), and Agriculture (1160.88 to 962.64), while it increases in Grassland (589.35 to 1404.55), and Barren land (208.66 to 2500.7). The COHESION index shows no changes in the Mixed forest but decreases in Riverine forest (98.06 to 97.87) and Agriculture (98.31 to 97.64). On the other hand, AI (97.11 to 96.09), CLUMPY (0.88 to 0.86), and IJI (69.2 to 64.58) decrease in the Mixed forest class. The Riverine forest showed a similar steady decline in AI (88.22 to 75.55), CLUMPY (0.87 to 0.73), and IJI (74.28 to 59.74). However, Built-up experienced an opposite trend for all three indices, AI (69.20 to 59.74), CLUMPY (0.69 to 0.73), and IJI (60.80 to 63.29).



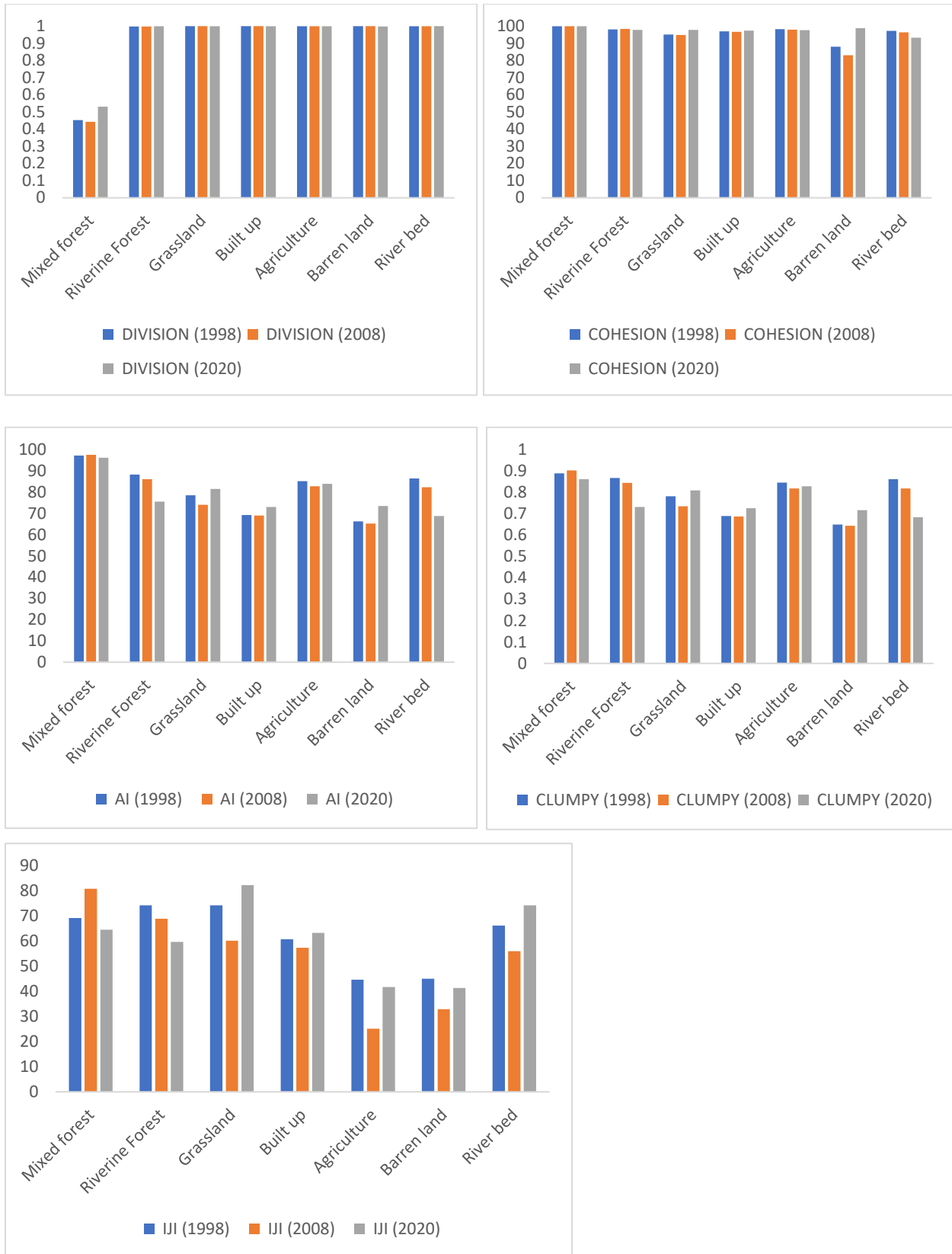


Figure 5. 4: Class matrices in the Mehao WLS for 1998, 2008, and 2020.

## Local community and their perception of biodiversity

The Idu Mishmi tribes are the indigenous dwellers of Roing town. 81 households were interviewed in 13 villages in the study area. Of the total sampled population, 16.05% (n = 13) were female, and 83.95% (n=68) were male (Table 5.6).

About 34.57 % (n=28) of respondents have wooden bamboo houses, followed by (33.33%, n=27) wooden-cemented-bamboo; (23.46%, n=19) wooden-cement and (7.41, n=7) concrete cement houses (Table 5.6). One of the most common natural resource dependences of proximate communities is fuelwood. Though every household had access to liquid petroleum gas (LPG), 82.72% (n=67) of the households used both LPG and fuel wood (Table 6). About 30.86% (n=25) of respondents collected fuelwood daily, weekly 24.69% (n=20), monthly 17.28% (n=14), and yearly 11.11% (n=9). The households collect various types of fuel wood, including *Duabanga grandiflora*, *Neolamarckia cadamba*, *Terminalia myriocarp*, and Bamboo species. *Bahunia variegata* 56.8% (n=47) consumed more than other fuel wood, followed by bamboo spp. (53.09, n=43), *Duabanga grandiflora* and *Terminalia myriocarp* were used equally (39.51%, n=32), and *Neolamarckia cadamba* (27.16%, n=22) (Table 5.6). People in the study region commonly domesticated livestock such as chickens, pigs, and goats. Around 76.54% (n=62) of respondents, we were reported that they have livestock.

**Table 5. 6: Socioeconomic status of the people in the study areas**

<b>Gender</b>	<b>Number of respondents</b>	<b>Percentage</b>
Female	13	16.05
Male	68	83.95
<b>Types of Houses</b>		
Bamboo	1	1.23
Concrete Cement	6	7.41
Wooden Bamboo	28	34.57
Wooden Cement	19	23.46
Wooden Cement Bamboo	27	33.33
<b>Types of Fuel</b>		

LPG	14	17.28
LPG and Fuelewood	67	82.72
<b>Frequency of collection</b>		
Daily	25	30.86
Weekly	20	24.69
Monthly	13	16.05
Yearly	9	11.11
Not collected	14	17.28
<b>Fuelwood species</b>		
<i>Duabanga grandiflora</i>	32	39.51
<i>Bamboo spp.</i>	43	53.09
<i>Bahunia variegata</i>	47	58.02
<i>Neolamarckia cadamba</i>	22	27.16
<i>Terminalia myriocarp</i>	32	39.51
<b>Livestock</b>		
Yes	62	76.54
No	19	23.46

In terms of agriculture, buckwheat (2.63%), rice (28.40), mustard (25.93%), orange (24.69%), and maize (22.22%) are the major cash crops grown by people in peripheral villages around Mehao WLS. About 28.4% (n=23) of the respondents reported practicing jhum or shifting cultivation (Table 5.7).

**Table 5. 7: Major crop cultivation and Jhum cultivation practice by the Idu community around Mehao WLS**

<b>Crop Cultivated</b>	<b>Number of respondents</b>	<b>Percentage</b>
Rice	23	28.40
Pineapple	8	9.88
Buckwheat	24	29.63
Ginger	11	13.58
Mustard	21	25.93

Orange	20	24.69
Broom grass	8	9.88
Maize	18	22.22
<b>Practice Jhum cultivation</b>		
Yes	23	28.40
No	58	71.60

When asked about wildlife encountered around Mehao WLS, respondents mentioned Indian muntjac (54.32%, n=44), wild pig (33.33%, n=27), civets (23.46%, n=19), mainland serow (20.99%, n=17), Asiatic black bear (16.05%, n=13), and leopard cat (14.815, n=12) (Table 8). During the survey, many indirect corroborations of hunting were observed in local houses, including horns, skin, skulls, and antlers of various species. Around 40.74% (n=33) of respondents reported that they were involved in hunting in and around the Mehao WLS. Guns and locally hand-made traps are used for hunting. Of the 33 hunters we interviewed, 54.55% (n=18) reported that they used guns, while 45.45% (n=15) used guns and traps to hunt wild mammals (Table 5.8).

**Table 5. 8: Wild animals reported, and people involved in hunting around Mehao WLS**

<b>Wild animals reported nearby villages</b>	<b>Number of respondents</b>	<b>Percentage</b>
Barking deer	44	54.32
Macaque	9	11.11
Mainland serow	17	20.99
Asiatic golden cat	6	7.41
Wild pig	27	33.33
Asiatic black bear	13	16.05
Civet	19	23.46
Leopard cat	12	14.81
<b>People involved in Hunting</b>		
Yes	33	40.74
No	48	59.26
<b>Hunting tools</b>		
Gun	18	54.55
Trap and gun	15	45.45

The Idu Mishmi communities know and believe in conserving forests and wildlife. During the interview, 44.44% (n=36) of respondents expressed positive views about conservation, and

62.96% (n=51) of the community are aware of the protected area and the laws for wildlife conservation (Table 5.9).

**Table 5. 9: Perception of people for conservation of wildlife and awareness about Protected areas**

<b>Conservation of wildlife</b>	<b>Number of respondents</b>	<b>Percentage</b>
Yes	36	44.44
No	45	55.56
<b>Aware of Protected Areas</b>		
Yes	51	62.96
No	30	37.04

## **Discussion**

This study identified seven types of LULC in and around the Mehao WLS from 1998 to 2020. We found that the forest areas have decreased, while the agricultural, barren land, and built-up regions have increased significantly. Our result shows that significant landscape-level changes have occurred within the southern buffer zone of Mehao WLS over a relatively short period.

Natural ecosystems are essential for human survival because they provide various ecosystem services such as pollutant removal, climate regulation, food production, environmental problem resolution, and water resource conservation (Michel et al., 2021). The transformation of natural ecosystems (forest, grassland, water, etc.) into built-up areas and agricultural land is mainly driven by population increase and the expansion of urban areas. An increase in population in the study area had a noticeable impact on land use changes, such as built-up and agricultural areas created from the riverine forests. The growing trend of LULC modification in the buffer region demonstrates the pervasive significance of economic factors in driving anthropogenic land alteration (Butt et al., 2015). Agriculture and urbanization were somewhat less prevalent inside the sanctuary's buffer zone.

In 2011, Lower Dibang Valley had a population of 54,080. From 2001 to 2011, the human population in Lower Dibang Valley increased by 7.20%. Roing is the closest urban area to Mehao WLS in the Lower Dibang Valley district of Arunachal Pradesh. Roing has a population of 11,389,

according to a report released by Census India in 2011. From 2001 to 2011, the human population of Roing town increased by 1.2%.

Most people living in the area belong to the Idu Mishmi tribe. In addition, there is a sizable migrant labour population from outside the village, including families from Jharkhand and Bihar who work in the construction sector. In addition, some Nepalese, Bengali, and Assamese people work as agricultural laborers (Pers Obs). Non-local cultures have influenced the Idu Mishmi lifestyle through these migrant populations. As the population grew in the town and villages, timber, cane, and bamboo demand increased to make homes and households. However, their cultural 'longhouses' gradually vanished in favour of modern cement-block houses, especially in Roing town (Pers. Obs.).

The developments in villages around Mehao WLS have concentrated along national highways (NH-115 and 15), which connect the city of Tinsukia in Assam with Roing Town in Arunachal Pradesh via India's longest bridge, the Bhupendra Hazarika bridge. This development has increased the demand for agricultural products and natural resources. This increase has increased the threats to the sanctuary's natural resources due to deforestation, degradation, exploitation, and the extinction of animal species (Michel et al., 2021). Similarly, economic growth has fuelled the transformation of different natural land cover types to agricultural, plantation, and degraded regions. Environmental issues have been primarily rooted in destroying natural ecosystems, intensifying agricultural areas, and urban growth.

A further issue that has emerged from urbanization and population growth processes is the fragmentation of the natural landscape (Qi et al., 2013; Shrestha et al., 2012; Munroe et al., 2005). According to Gkyer (2013), a study of landscape metrics can provide a better understanding of how natural resource management impacts landscape changes. Various landscape measures of division, aggregation, and cohesion show how human activities have caused the fragmentation of natural ecosystems (Gyker et al., 2013). The landscape division metric may be assessed over time, and its increase can help us understand the fragmentation of the landscape. Our findings for the Mixed and Riverine forest classes (Figs. 5) indicated an increasing edge density (ED) and a decline in the Area-weighted mean radius of gyration (GYRATE AM) indices. This implies that the forest is fragmenting because of the over-exploitation of timber, cane, and medicinal plants inside the sanctuary. IJI, which evaluates the adjacencies between various patch kinds, was developed by McGarigal and Marks in 1994. IJI decreased due to the more uneven distribution of LULC types

created by a few sizable patches of Mixed forest, Riverine forest, Agriculture, and Barren land. The IJI, however, differed amongst land use categories that make up the landscape matrix (Built-up, Grassland, and Riverbed), were adjacent to many other land use types, and so had higher values of IJI. Over time, the landscape division metric (DIVISION) increase can help us understand how the landscape is becoming more fragmented. When their values decline, the patch cohesiveness index (COHESION) and the aggregation index (AI) can also provide information on the landscape's fragmentation. Accordingly, Mehao WLS reported an increase in the landscape division measure for Mixed forest between 1998 and 2020, and declines in the COHESION and AI indices pointed to the Mixed and Riverine forest classes becoming more fragmented, reducing their self-connectivity. Mixed and Riverine forests have been subject to unsustainable exploitation due to anthropogenic activities, which has caused their fragmentation over time. For the DIVISION and COHESION metrics, the Barren land and Built-up classes showed the opposite trend from Mixed forest. These two classes have grown over time, which has caused COHESION metrics to increase and DIVISION metrics to decline. As a result of a larger aggregation and more concentrated class distribution, the CLUMPY index declined in the Mixed and Riverine forest classes while increasing in the Built-up and Barren land classes.

### ***Idu Mishmi and their perception of biodiversity conservation***

Idu Mishmis are Scheduled Tribes mainly living in Arunachal Pradesh's Lower Dibang Valley and Dibang Valley districts. They live in and around the forest-agricultural terrain around the study area centred on Mehao WLS. They have strong cultural ties to the forest and wildlife, intimately integrated with their animistic religion. The provision of fuel, wood, and food resources is valued in developing nations as these services are essential for the local population's ability to support their livelihood (Fagerholmetal.,2012). In the villages around Mehao WLS, fuel wood is the primary household energy source. The respondents freely collected fallen bamboo culms and branches, especially of specific trees species (*Bahunia variegata*, *Terminalia myriocarp*, *Duabanga grandiflora*, and *Neolamarckia cadamba*), not only from their agro-forest areas but also from the community reserve forest and the buffer areas of the sanctuary. In Roing town, most people purchased it from the 'ara shop' for Rs 2,000-3,000 per truck.

The Idu Mishmi are primarily subsistence farmers and depend on vegetative crops such as taro, bananas, and yams as well as cereals including rice (kākū), buckwheat (èkà), maize (àmbó), foxtail millets (yà), finger millets (yàmbā), and sorghum (ānggū). Rice has become an essential part of their diet relatively recently. Orange plantations (ōmtírāmbō) are very productive in and around the sanctuary area and are grown for local consumption and market sale. In Lower Dibang Valley, the Idu Mishmi perform shifting cultivation (mīpù mrā) and wet irrigated cultivation (màcì mrā). Owing to the mountainous terrain, shifting cultivation and kitchen gardens are the only practical cultivation method. People keep livestock such as pigs (ìlì), chicken (mètō), and goats (màbrē). Pigs are usually stall-fed and housed in a separate area either built beneath the house or adjacent to it (àndōnggō). The Mithun (sa) is never stall-fed and is generally allowed to forage in the surrounding forests. They are unable to enter the village regions due to Mithun-proof gates (sā àpā). Chicken and goat are housed in a compound attached to the house. The richness of the wild environment ensures that a significant proportion of protein still comes from wild resources, with large and small mammals and fish being consumed regularly (Gopi et al., 2010; Ambiaka, 2011). The Idu Mishmi are skilled hunters (àmrò) who travel to distant high-altitude locations during the winter to hunt (àprāmū). However, various limits and taboos (èná) are enforced while hunting and trapping. The members of the Idu Mishmi tribe hunt for a variety of reasons, including food, recreation, financial gain from the sale of precious animal parts (such as musk deer pods and bear gall), crop protection from animal raiding, and enhancement of one's subjective strength (Ambika, 2011; Nijhawan, 2018). Hunting is one of the primary threats to wildlife (Pawar & Birand, 2001; Datta, 2002; Mishra et al., 2006; Ambiaka et al., 2010). This study found that 33% of the respondents are hunting with a gun. However, most respondents avoid hunting due to èná restriction, which contributes significantly to maintaining high levels of wildlife abundance and diversity (Nijhawan, 2018). We frequently observed young boys putting up small traps on village farms for rodents and birds and hunting birds and squirrels with catapults, negatively influencing biodiversity (Ambiaka et al., 2010).

Expanding Agriculture and Built-up areas near the sanctuary increased the probability of human-wildlife conflicts. The survey respondents reported that conflicts between humans and wild animals occurred primarily in the winter season. The conflict was found to be high in villages near the sanctuary. Barking deer (mānjō), wild pig (yàmwē), civets (àmrà dà), leopard cat (āmrā ārhūlī), and yellow-throated marten (ākōkō) were identified as most problematic animal species in the

area. However, barking deer and wild pigs were blamed primarily for crop damage, while the carnivore species were blamed for livestock depredation. Eastern hoolock gibbon (àmē ló) is a forest-dwelling primate that prefers close canopy trees and sometimes visits the village periphery. The Idu Mishmi observe a taboo on hunting them; even seeing one is said to be a bad omen. Habitat fragmentation and agricultural activities such as orange, tea, and palm plantation are the primary threat to the species in this area (Chetry et al., 2008; Sharma et al., 2014).

This research uses satellite imagery to understand LULC change, which provides a partial framework for tracking land use change trajectories in and around Mehao WLS. The landscape pattern metrics provide a significant source of additional data on different change patterns. As a result, the entire eastern Himalayan region is highly vulnerable to a variety of environmental changes, including forest degradation leading to habitat fragmentation and biodiversity loss, climate change that results in a warming trend, increased weather variability, hydrological imbalances that cause more severe flooding and droughts, decreased agricultural productivity, etc. Therefore, it is crucial to comprehensively understand the connections between land use change patterns and factors influencing them to address the current population growth trend and manage LULC transformation (Kintz et al., 2006).

The introduction of various development initiatives, such as hydroelectric dams, road building, and commercial marketplaces in the Lower Dibang Valley district, is driving economic change in the area. Since 1947, in-migration from other states has increased the population (Anonymous, 2006). Ensuring that wildlife resources are conserved is extremely difficult due to rising population pressures and economic development. These developments also challenge the local way of life, which may change how villagers interact with wildlife and their natural environment. If conservation is to coexist with rural development, particular policies need to be carefully designed and implemented to encourage development that is sustainable with conservation (Harvey et al., 2008).

## **Conclusion**

In this study, we used remote sensing and GIS tools to evaluate and track changes in LULC patterns in the eastern region of Arunachal Pradesh from 1998 to 2020. Statistics collected from land use maps show the changing pattern and classes that have increased and decreased in this region in the study period. Various landscape metrics have effectively monitored significant changes within and

around the sanctuary. The metrics allowed for the quantification of landscape structures and included additional statistical information. The change-detection maps support ecological and socioeconomic studies of factors driving land cover, land use change in the area, and their environmental effects. The rapid change in LULC is mainly driven by the destruction of forests, rapid urbanization, and agricultural development, directly related to population growth. These changes also threaten traditional lifestyles, which may change how villagers interact with biodiversity.

The Idu Mishmi people inhabit a rich and biodiverse environment and have in-depth knowledge of the forests and mountains. Their connection to the forests is closely tied to the existence of spirits that oversee these resources and provide them to people. The Idu Mishmi make offerings to spirits, interact with them in an exchange process, and observe specific taboos. The Idu Mishmi people's concept of taboos can be integrated into conservation initiatives. Conservation projects must consider the social, economic, and cultural components of the Idu Mishmi communities to prevent wildlife decline. Their knowledge of the local ecology is vast, and this information and competence can be used to develop and implement more effective conservation projects.

This study's findings can help policymakers understand land use and land cover changes to develop an efficient and sustainable land use policy for Mehao WLS. This research can also be used to assess the consequences of LULC change on biodiversity in and around protected areas. It is necessary to plan various land use schemes and their implementation strategies to anticipate and meet rising demands of basic human necessities and welfare. Further in-depth research is required to understand the factors influencing LULC changes in this area using integrated socio-ecological data sets. Further research should be done in various villages and areas around them to determine how dependent local people are on forest resources.

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## Chapter 6

Objective: To develop a habitat suitability model for selected large mammals in and around Mehao wildlife sanctuary.

## Introduction

Human civilizations have altered biodiversity for centuries and are responsible for the declining population of megafauna and the prehistoric extinction of wildlife on Earth (Bartlett et al., 2016). More than 50% of the world's land cover is affected by rising human activity, population growth, and per capita resource use (McGill et al., 2015).

Almost every ecosystem on Earth has experienced changes due to human land use and climate change (Hansen et al., 2001). Numerous wildlife species cannot adapt quickly enough to retain their fitness in landscapes that have undergone human influence due to the rapid rate of anthropogenic change (Myers & Knoll, 2001). A growing number of human activities, such as farming, urban development, and the construction of transportation routes, have adverse effects on habitat quality and availability for wild animals (Dixo et al., 2009), as well as on species survival (Cushman et al., 2018; Kaszta et al., 2019), dispersal (Cushman et al., 2014; Mateo-Sanchez et al., 2014a), gene flow (Kaszta et al. (Scolozzi & Geneletti, 2012; Gao et al., 2013). There is an increasing need to understand the consequences of habitat fragmentation on animal communities to offer potential solutions for minimizing its adverse effects as human-induced habitat fragmentation of wildlife habitats continues to rise (Gonzalez et al., 1998; Crooks, 2002). In this crucial scenario, impacting population survival in human-modified environments will have a significant impact (Gardner et al., 2009). Animals require specific habitat sizes, patterns, and characteristics for living (Torres-Contreras et al., 1997; Kelt et al., 1999; Finlayson et al., 2008). Likewise, biotic and abiotic factors like food availability, predation, guild interaction, and competition affect how animals use and disperse in their habitat (Falkenberg & Clarke, 1998). Thus, to maintain, conserve and manage habitat, it is necessary to understand the factors affecting species' space use. Moreover, species react to environmental, topographical, and artificial elements on various scales (Wiens, 1989; Collingham et al., 2000; McGarigal et al., 2016). Scale is crucial to understanding how organisms exploit resources and space in varied ecosystems (Kotliar & Wiens, 1990; Holling, 1992). According to Roland and Taylor (1997), different species choose habitats at various scales, while a given species may choose different resources at various scales (Grand et al., 2004; Wasserman et al., 2012). Inadequate scaling in the analysis may distort species-habitat interactions resulting in an incorrect assessment of scales since the scale is the lens that concentrates on species ecological interactions (Rettie & Messier, 2000; Bradter et al., 2013; McGarigal et al., 2016). Scale

effects must be considered when analysing species-habitat connections and, more crucially, while planning and creating animal reserves (Thompson & McGarigal, 2002).

Given the significance of the adjacent native environment, the optimum spatial scale of a landscape remains debatable (Ferreira et al., 2020). Typically, the most appropriate landscape size is defined in terms of the research organism's dispersion capacity (Fahrig, 2013). Few studies have addressed the value of native habitat cover across enormous spatial scales, consequently supporting entire populations (Faria et al., 2006; Pardini et al., 2010; Martensen et al., 2012). The significance of scale in ecology is critical for understanding ecological patterns and processes (Jackson & Fahrig, 2015). Moreover, the scale at which modelling is undertaken can significantly impact model results (Cushman & McGarigal, 2004). The scale at which the linkages are studied can affect model prediction accuracy when examining species-habitat relationships, especially in complicated environments (Mateo-Sanchez et al., 2014a; Wan et al., 2017). Because organisms perceive and respond to their environment at several spatial and temporal scales (Wiens, 1989), it is advised to identify scales in addition to underlying environmental variables and factors influencing habitat selection by species the most (Levin, 1992; Mateo-Sanchez et al., 2014a; McGarigal et al., 2016).

An increasing number of habitat studies have indicated that multi-scale approaches can improve model predictions and make more accurate inferences (Shirk et al., 2012; Wasserman et al., 2012a; Vergara et al., 2015; Macdonald et al., 2018, 2019). These studies demonstrate that species-habitat relationships are scale-dependent, with organisms selecting different resources across a hierarchy of spatial scales. The importance of multi-scale assessment in determining the species-habitat relationships has been demonstrated in a wide range of species (Wan et al., 2017; Klaassen & Broekhuis, 2018; Khosravi et al., 2019; Atzeni et al., 2020; Rather et al., 2020b, 2020c; Ash et al., 2021; Dar et al., 2021). Since habitat selection is inherently scale-dependent, most studies on wildlife habitats do not incorporate a multi-scale framework, producing more robust inferences than single-scale models by identifying the operative scale. There is a need for broader adoption of formal scale optimisation of organism response to environmental variables (McGarigal et al., 2016).

According to Wright (2003) and Lacher et al. (2019), mammals have lost approximately 50% of their continental populations, mostly in areas with intense human habitation. These mammals have crucial ecosystem roles such as seed dispersion, predation, controlling the population of their prey,

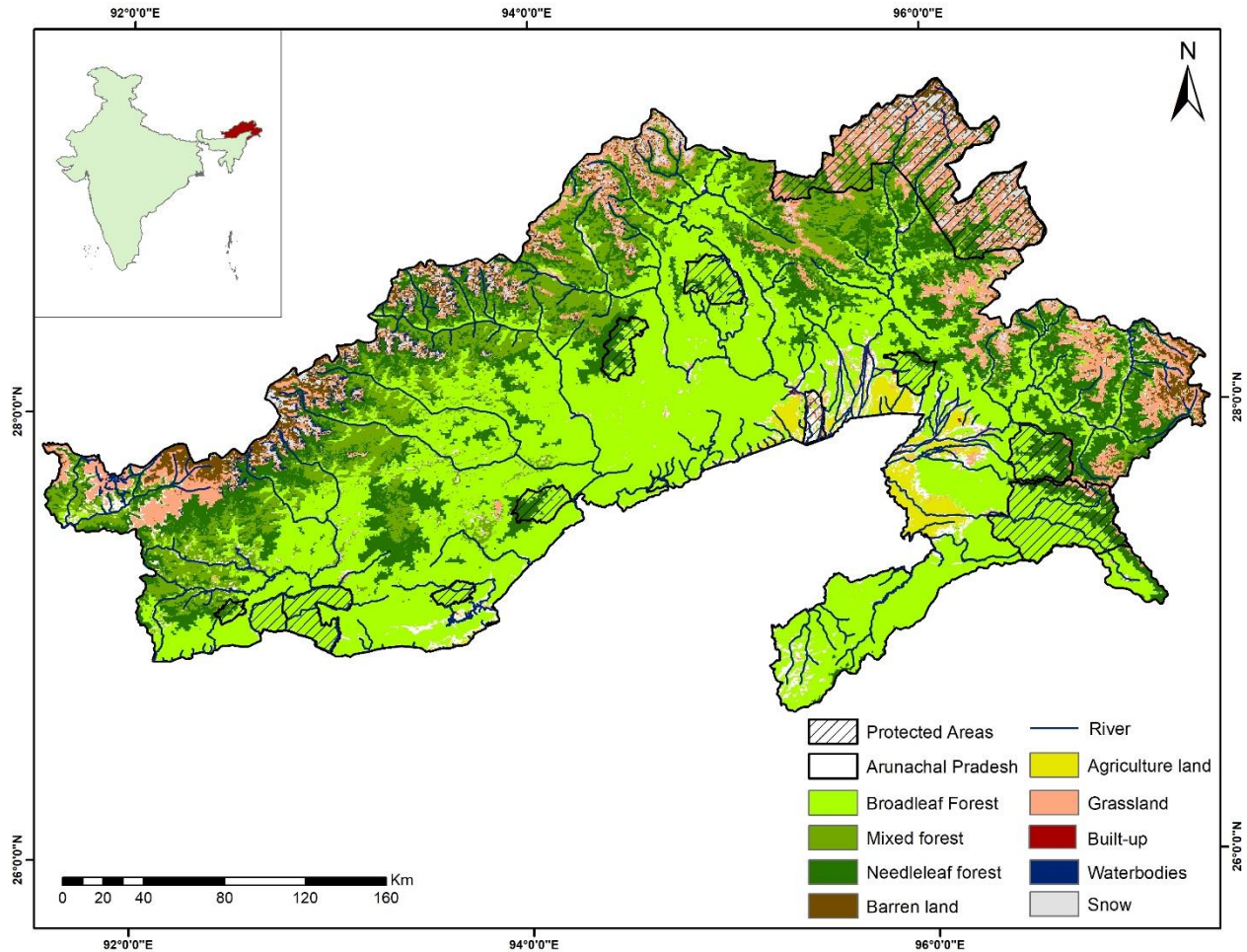
and herbivory (Ceballos & Ehrlich, 2002). Worldwide, animals frequently include agricultural matrices in their home ranges, particularly conventional agroforests that support multiple-use shade trees (Ferreira et al., 2018b; Harvey et al., 2006). Given the loss of native ecosystems, understanding mammals' distribution and land use responses in agroforestry landscapes is crucial to avoid further population declines.

Likewise, in the Eastern Himalayan state of Arunachal Pradesh, India's landscape change associated with expanding human settlements, agricultural expansion, and over-exploitation of natural resources have reached alarming levels. Moreover, the region's information on mammalian species distribution is minimal except for a few (Sarma et al., 2015; 2021; Sarania et al., 2016). Thus, I assessed the habitat choice of selected mammalian species using a multi-scale optimised approach and the General Additive Model (GAM) method. We aimed to develop an ecological understanding of the environmental variables and related scales affecting species distribution and identify locations where different species can coexist in Arunachal Pradesh's human-dominated landscape. The main goals of my research are to (1) clarify how the local mammalian fauna chooses its habitat in order to support conservation management decisions, (2) pinpoint the factors that have the most significant impact on mammal habitat choice, and (3) identify the scale at which each of these factors matters most. The persistence and possible growth of the species' populations in Arunachal Pradesh may be aided by the recommendations from these studies for spatially distributed landscape-scale management of elusive and rare mammalian fauna.

## **Study Area**

The Eastern Himalayan state of Arunachal Pradesh is located between 26°28' and 29°30' N latitude and 91°30' to 97°30' E longitude (Fig 6.1). Bhutan bounds it in the west, Tibet in the north, Myanmar in the east, and the northeastern states of Assam and Nagaland in the south. It is located transition zone between the Himalayan and Indo-Burmese regions (Mani, 1974; Rodgers & Panwar, 1988; Singh et al., 2007). It is one of the 200 most significant ecoregions on the planet and is situated inside the Indo-Myanmar biodiversity hotspot (Myers et al., 2000; Olson & Dinerstein, 1998). The variation of altitudes is considerable, ranging from 130 m in the lowlands to 6000 m and more in higher mountains. Nearly half of all flowering plant species in India are said to be found in this state, which also contains the northernmost tropical rainforest in the world (Rao & Hajra, 1986; Chowdhury, 1999; Procter et al., 1998; Whitmore, 1998). Additionally, there

are 26 indigenous communities in the state, 80% of which practice shifting agriculture and own most of the land. These indigenous communities mostly have a cultural affinity for wild meat, which is their way of life (Hilaluddin et al., 2005; Elwin, 1959). According to Anonymous (2006), the population of Arunachal Pradesh increased by 27% between 1991 and 2001, compared to an average increase of 21% for all of India. This increase coincided with the transition from a subsistence to a cash economy.



**Figure 6. 1: Location of Arunachal Pradesh with the landcover classes and protected areas**

## Methodology

### Species occurrence records, spatial autocorrelation, and pseudo-absences

The spatial occurrence data were gathered from reconnaissance, camera-trap surveys, and earlier systematic research. Using ArcGIS version 10.3, the data from the literature review were

georeferenced (ESRI, Redland, CA). Field surveys were carried out in Mehao WLS in two phases from October 2017 to April 2018 and from November 2019 to February 2020 to confirm the existence of the mammalian species based on direct and indirect evidence. This allowed the Garmin 20 etrex geographic positioning system unit (GPS) to record presence locations across the landscape. In the first phase, we used data from 58 camera trap pairs, and in the second phase, we used data from 50 units, both of which produced separate photo-captures of every species considered in this study. The camera traps (Cuddeback™, Model C1) covered the entire study region in 3 km<sup>2</sup> grids using ArcGIS (10.3). A concerted effort was made to place camera traps along stream beds, animal pathways, and other areas where there was a probability of seeing animals, as noted during the initial sign survey. They were designed with a trigger speed of 1.4 seconds, a detection range of 100 feet, and a fast-as-possible (FAP) mode. Cameras were set up 20 cm above the ground along the animal pathways and left on all day to record pictures of every mammalian species observed. With an average of 1 km separating each spatially rarefied camera trap site, each grid had at least one camera trap site. For fifty days, each camera was in place. The sample area had trap stations all over it. The inherent bias, also known as spatial autocorrelation, is connected to the spatial data (Dormann et al., 2007). Due to the non-independence of variables measured at close locations from one another, the phenomenon of spatial autocorrelation arises (Tobler, 1970). Various approaches have been developed for spatial autocorrelation (Dormann et al., 2007). In the data on species occurrence, we utilised two methods to adjust the spatial autocorrelation. First, we used ArcGIS (version 10.3)'s SDM toolbox to implement spatial filtering, reducing the spatial bias in species presence data.

Secondly, we calculated Global Moran's I (Moran, 1950) using the Spatial Autocorrelation tool in ArcGIS (version 10.3) to determine whether the spatially rarefied occurrence data assumed the random distribution after applying spatial filtering (version 10.3). After accounting for spatial bias, we retained a total of 55, 135, 48, 153, 147, and 80 spatially rarefied occurrence records of an Asiatic golden cat, leopard cat, Himalayan palm civet, Indian red muntjac, Mainland serow, and Wild pig, respectively, for further analysis. It can be challenging to find actual species absence data for big animals (Rather et al., 2020). To address the issues brought on by an unbalanced prevalence, we arbitrarily created pseudo-absence points in ArcGIS (version 10.3) equal to the actual occurrence points (Titeux, 2006). According to Chawla et al. (2003) and González-Irusta et al. (2014), an imbalance in the proportion of presence and absence classes leads to bias in model

predictions and model fit. The majority class overpredicts in the unbalanced data set because the data's bootstrap is skewed to support the majority class (presence or absence). The minority class's prediction is still too low. We produced twice as many random pseudo absence points for each species as the records of its occurrence to balance out the imbalanced prevalence. After that, we eliminated the absence points 500 m or less from the original occurrence points to decrease the probability of false negatives (Mateo et al., 2010) and produced a balanced data set with relatively similar amounts of presence and absence classes. The buffer distance may be arbitrary (as in the present study) or determined by the characteristics of the species (Graham & Hijmans 2006).

### Environmental predictors

To anticipate the association between the species and their habitat, we predetermined 38 variables. Five broad categories were used to classify the predictor variables: climatic, topography, landscape composition, vegetation, and human influence. The WORLDCLIM database provided the bioclimatic variables ([www.worldclim.org](http://www.worldclim.org)). To prevent multi-collinearity among predictor variables, we eliminated strongly correlated predictor variables ( $|r| > 0.70$ ) using the 'corr' package (Dormann et al., 2013). In ArcGIS, all variables were resampled to a spatial resolution of 30 m and projected to the 46 N UTM projection. The bilinear interpolation approach was used to resample continuous variables, whereas the nearest neighbourhood approach was used for categorical variables. Table 6.1 contains the entire list of variables, their source, and descriptions.

**Table 6. 1: Description of 38 predictor variables used in multi-scale habitat modelling to predict the potential distribution of Asiatic golden cat, leopard cat, Himalayan palm civet, barking deer, mainland serow, and wild pig.**

Predictor variable	Source	Description	Units
Group 1: Climate			
Actual evapotranspiration (AET)	CGIAR-CSI database ( <a href="http://www.cgiar-csi.org">http://www.cgiar-csi.org</a> )	Mean monthly estimates	mm / month
AET of summer		Calculated using mean	mm / month
AET of winter		monthly estimates	mm / month

Annual potential evapotranspiration (PET)	ENVIREM ( <a href="http://envirem.github.io">http://envirem.github.io</a> ; Title & Bemmela, 2017)	Mean monthly estimates	mm / month
PET seasonality		Monthly variability in potential evapotranspiration	mm / month
PET of coldest quarter		Mean monthly PET of coldest quarter	mm / month
PET of driest quarter		Mean monthly PET of driest quarter	mm / month
PET of warmest quarter		Mean monthly PET of warmest quarter	mm / month
PET of wettest quarter		Mean monthly PET of wettest quarter	mm / month
Maximum temperature of the coldest month		Maximum temperature of the coldest month, i.e., January	°C
Minimum temperature of the warmest month		Minimum temperature of the warmest month, i.e., June	°C
Isothermality	WorldClim ( <a href="https://www.worldclim.org/">https://www.worldclim.org/</a> ; Hijmans et al., 2005)		
Temperature annual range			
The mean temperature of wettest quarter			
Mean temperature of driest quarter			
Mean temperature of warmest quarter			

Mean temperature of coldest quarter			
Precipitation of Wettest Month		Mean estimates	mm
Precipitation of Driest Month		Mean estimates	mm
Snow and ice cover	MODIS ( <a href="https://lpdaac.usgs.gov">https://lpdaac.usgs.gov</a> )	Land cover type at 500 m resolution (MCD12Q1, version 051, year 2010)	%
Group 2: Vegetation			
<i>Land cover and vegetation indices</i>			
Normalised vegetation index (NDVI)	MODIS	16-day NDVI at 1 km resolution (MOD13A2, version 005, years 2002-2016)	-
NDVI of summer		Spring (March to May), Summer (June to August), Post-monsoon (September to November), and Winter (December to February)	-
NDVI of winter			-
NDVI of post-monsoon			-
Barren land		Land cover types at 500 m resolution (MCD12Q1, version 051, year 2010)	%
Broadleaf forest			%
Mixed forest			%
Grasslands			%
Needle leaf forest			%
Group 3: Topographic			
Elevation (DEM)	CGIAR-CSI	SRTM elevation data at 90 m resolution	m
Slope		Calculated based on the elevation data using the	radians
Aspect			radians

Topographical Positional Index (TPI)		Geomorphometry & Gradient Metrix Toolbox in ArcGIS (Evans et al., 2014)	-
Terrain ruggedness Index (TRI)			-
Compound topographic index (CTI)			-
Water bodies	MODIS	Land cover type at 500 m resolution (MCD12Q1, version 051, year 2010)	%
<b>Group 4: Disturbance</b>			
Combined class of croplands and cropland/natural vegetation mosaic	MODIS	Land cover type at 500 m resolution (MCD12Q1, version 051, year 2010)	%
human footprint	Last of the Wild, v2 ( <a href="http://sedac.ciesin.columbia.edu/wildareas/">http://sedac.ciesin.columbia.edu/wildareas/</a> )	Anthropogenic impacts on the environment for the period 1995-2004, Last of the Wild Data Version 2, 2005	%
Urban and built-up	MODIS	Land cover type at 500 m resolution (MCD12Q1, version 051, year 2010).	%

### Multi-scale data processing

Based on the average dispersal distance reported for all selected species, we estimated the focal mean of each variable around each presence and pseudo-absence site across seven geographical scales: 50, 100, 200, 400, 800, 1600, and 3200m radii (e.g., Mateo-Sanchez et al., 2014a). To achieve this, we used the above scales to search neighbourhoods in a moving window analysis

with the focal statistics tool in ArcGIS 10.3 (ESRI, Redlands, CA). We needed an output raster of each variable at each scale across the study area to extract the focal mean at each location.

### **Multi-scale optimised univariate modelling**

As McGarigal et al. (2016) suggested, we used the GLM as a multiscale optimization framework. The best scale with the most robust linear relationship between species presence/absence as a function of habitat variables within the landscape was determined for each species by fitting univariate scaling with logistic regression analysis (Thompson & McGarigal, 2002; Elliot et al., 2014; Zeller et al., 2014; Krishnamurthy et al., 2016; Progin, 2018; Scherrer et al., 2019; Tehrani et al., 2020). Using R v.4.2.1 (R Core Team, 2022), the 'glm' function (with logit link) was used for all univariate modelling while keeping in mind all the assumptions of this modelling technique (Hosmer Jr et al., 2013). As shown in Table 6.2, we used the Akaike information criterion (AIC) to select the most appropriate univariate model to establish the most supported scale for each variable. The AIC calculates the support for each model for the supplied data, given a set of univariate models. Each variable's geographic scale was determined by the AIC ranking it produced, and those variables were kept for further research. This analysis was completed using the 'MuMIn' package of Rv.3.3.3n (Barto, 2013) (R CoreTeam, 2022).

### **Multivariate modelling and model validation**

Using the suite of scale-optimized variables from step one, we used GAM to create multivariate models to estimate the probability of mammalian species occurrences. The gam package in R was used to fit a binomial GAM with a logit link function (Hastie & Tibshirani, 1990; Austin, 2002; Hastie, 2013). The final model's parameter estimates were produced using model averaging based on the AIC values. The model that best predicted the distribution of mammalian species was the one with the lowest AIC values.

**Table 6. 2: Optimal Scale of Environmental parameters used in assessing the species habitat suitability model.**

<b>Class Variable</b>	<b>Variable</b>	<b>Variable code</b>	<b>Asiatic golden cat</b>	<b>Leopard cat</b>	<b>Himalayan palm civet</b>	<b>Barking deer</b>	<b>Mainland serow</b>	<b>Wild pig</b>
<b>Climate</b>	<b>Annual Actual evapotranspiration (AET)</b>	<b>S16</b>	<b>100</b>	<b>800</b>	<b>200</b>	<b>800</b>	<b>50</b>	<b>50</b>
	<b>AET of summer</b>	<b>S20</b>	<b>400</b>	<b>400</b>	<b>200</b>	<b>800</b>	<b>50</b>	<b>50</b>
	<b>AET of winter</b>	<b>S21</b>	<b>400</b>	<b>1600</b>	<b>400</b>	<b>800</b>	<b>50</b>	<b>50</b>
	<b>Annual potential evapotranspiration (PET)</b>	<b>S25</b>	<b>50</b>	<b>50</b>	<b>50</b>	<b>50</b>	<b>50</b>	<b>50</b>
	<b>PET seasonality</b>	<b>S28</b>	<b>3200</b>	<b>3200</b>	<b>3200</b>	<b>3200</b>	<b>3200</b>	<b>3200</b>
	<b>PET of coldest quarter</b>	<b>S26</b>	<b>50</b>	<b>50</b>	<b>50</b>	<b>50</b>	<b>50</b>	<b>50</b>
	<b>PET of driest quarter</b>	<b>S27</b>	<b>200</b>	<b>50</b>	<b>50</b>	<b>50</b>	<b>50</b>	<b>50</b>
	<b>PET of warmest quarter</b>	<b>S29</b>	<b>3200</b>	<b>1600</b>	<b>50</b>	<b>1600</b>	<b>50</b>	<b>400</b>
	<b>PET of wettest quarter</b>	<b>S30</b>	<b>50</b>	<b>50</b>	<b>100</b>	<b>50</b>	<b>50</b>	<b>50</b>
	<b>Maximum temperature of the coldest month</b>	<b>S19</b>	<b>200</b>	<b>50</b>	<b>50</b>	<b>50</b>	<b>100</b>	<b>50</b>
	<b>Minimum temperature of warmest month</b>	<b>S22</b>	<b>400</b>	<b>50</b>	<b>50</b>	<b>50</b>	<b>50</b>	<b>50</b>
	<b>Isothermality</b>	<b>S6</b>	<b>200</b>	<b>50</b>	<b>200</b>	<b>50</b>	<b>200</b>	<b>50</b>
	<b>Temperature annual range</b>	<b>S7</b>	<b>100</b>	<b>50</b>	<b>200</b>	<b>200</b>	<b>50</b>	<b>50</b>

	Mean temperature of wettest quarter	S8	100	800	50	100	50	50
	Mean temperature of driest quarter	S9	50	200	100	50	100	50
	Mean temperature of warmest quarter	S10	50	100	800	800	100	100
	Mean temperature of coldest quarter	S11	100	50	50	200	50	100
	Precipitation of Wettest Month	S4	400	800	50	50	50	50
	<b>Precipitation of Driest Month</b>	<b>S3</b>	<b>400</b>	<b>1600</b>	<b>50</b>	<b>50</b>	<b>50</b>	<b>50</b>
	<b>Snow and ice cover</b>	<b>S33</b>	<b>1600</b>	<b>3200</b>	<b>3200</b>	<b>3200</b>	<b>3200</b>	<b>3200</b>
<b>Landscape composition</b>	NDVI of summer	S34	1600	3200	3200	3200	3200	400
	NDVI of winter	S38	1600	3200	3200	800	3200	800
	NDVI of Post monsoon	S31	3200	3200	3200	3200	800	100
	<b>Barren land</b>	<b>S5</b>	<b>3200</b>	<b>3200</b>	<b>3200</b>	<b>3200</b>	<b>3200</b>	<b>50</b>
	<b>Broadleaf forest</b>	<b>S12</b>	<b>200</b>	<b>3200</b>	<b>3200</b>	<b>800</b>	<b>800</b>	<b>100</b>
	<b>Mixed forest</b>	<b>S23</b>	<b>50</b>	<b>3200</b>	<b>3200</b>	<b>3200</b>	<b>3200</b>	<b>3200</b>
	<b>Grasslands</b>	<b>S17</b>	<b>800</b>	<b>3200</b>	<b>3200</b>	<b>3200</b>	<b>3200</b>	<b>400</b>
	<b>Needle leaf forest</b>	<b>S24</b>	<b>50</b>	<b>1600</b>	<b>1600</b>	<b>1600</b>	<b>400</b>	<b>800</b>
<b>Topographic</b>	Elevation	S15	200	50	50	50	50	50

	<b>Terrain ruggedness index</b>	<b>S36</b>	<b>3200</b>	<b>1600</b>	<b>400</b>	<b>200</b>	<b>200</b>	<b>800</b>
	<b>Compound topographical index</b>	<b>S14</b>	<b>50</b>	<b>3200</b>	<b>50</b>	<b>400</b>	<b>1600</b>	<b>50</b>
	<b>Topographical position index</b>	<b>S35</b>	<b>800</b>	<b>1600</b>	<b>200</b>	<b>100</b>	<b>800</b>	<b>200</b>
	<b>Slope</b>	<b>S32</b>	<b>50</b>	<b>800</b>	<b>50</b>	<b>50</b>	<b>1600</b>	<b>50</b>
	<b>Aspect</b>	<b>S2</b>	<b>3200</b>	<b>3200</b>	<b>3200</b>	<b>3200</b>	<b>3200</b>	<b>3200</b>
	<b>Water bodies</b>	<b>S37</b>	<b>3200</b>	<b>3200</b>	<b>3200</b>	<b>3200</b>	<b>3200</b>	<b>800</b>
<b>Human influenced</b>	<b>Agricultural land</b>	<b>S1</b>	<b>3200</b>	<b>800</b>	<b>50</b>	<b>400</b>	<b>1600</b>	<b>1600</b>
	<b>Human footprint</b>	<b>S18</b>	<b>50</b>	<b>3200</b>	<b>3200</b>	<b>3200</b>	<b>3200</b>	<b>3200</b>
	<b>Urban and built-up</b>	<b>S13</b>	<b>3200</b>	<b>3200</b>	<b>3200</b>	<b>3200</b>	<b>3200</b>	<b>3200</b>

**Abbreviation:** Variables in bold are not highly interrelated with Pearson's correlation (coefficient  $\geq 0.70$ ).

## Result

Examination of likelihoods and AIC values for seven (50m – 3200m) univariate linear regression models corresponding to each eco-geographical variable indicated that the mammalian species respond significantly to a particular scale of each eco-geographical variable. The selected scale (with the lowest AIC) determined from each eco-geographical variable of all mammalian species is presented in Table 6.3.

Multiscale analysis revealed that the intensity and nature of reported connections between mammalian presence/absence and all measured environmental and ecological variables strongly rely on the focal scale generated by the variable.

## Scale Optimization

The optimised multi-scale analysis showed strong relationships between mammalian fauna habitat selection and the scale analysis for each variable (Table 6.2). Overall, the scale optimisation at a broader spatial extent (3200 m) had the highest selection frequency (Table 6.2). In the Asiatic golden cat, the scale at fine (50m) and large scale (1600 and 3200m) spatial extent occurred more frequently. Leopard cat and Himalayan palm civet showed a strong relationship for predictor variables at the broadest scale (1600m and 3200m). Northern red muntjac selected variables more frequently at medium to a broader scale. Mainland serow and wild pig perceived habitat variables more regularly at the fine and broadest scales.

## Scale Performance

### *Asiatic Golden cat*

Four of the ten predictor variable in climate class were selected. The PET seasonality and PET warmest quarter were selected at a broader scale (3200m); one variable precipitation of the driest month was selected at a medium scale (400m), and annual actual evapotranspiration was set at a fine scale (100m). In the landscape composition class, barren land was selected at a broader scale (3200m); mixed forest and needle leaf forest were chosen at the fine scale (50m), and grassland was chosen at the medium scale (800m). The topographic variable showed that the aspect and terrain ruggedness index were selected at a broader scale (3200m); the compound topographical index and topographical positional index were chosen at a fine scale (50m). In human-induced

variables, agricultural land and built-up were selected at a broader scale (3200m); the human footprint was chosen at a fine scale (50m).

### *Leopard Cat*

A total of 17 essential variables were selected for the final multivariate model of the leopard cat. In the climate variable, PET seasonality, precipitation of driest month, and Snow were selected at a broader scale (3200m and 1600m); PET wettest quarter was chosen at fine scale (50m) in landscape composition variable, Barren land, mixed forest, grassland, and needle leaf forest was selected from a broader scale. In the topographic class variable, the slope was chosen at a medium scale (800m), terrain ruggedness index, compound topographical index, topographical positional index, aspect, and water bodies were selected at a broader scale (3200m and 1600m). In the human-induced class variable, two predictors, human footprint and built-up, were chosen at a broader scale (3200m); Agriculture land was selected from a medium scale (800m).

### *Himalayan Palm Civet*

A total of 14 critical variables were selected, and four of ten variables were chosen in the variable climate class. PET warmest quarter and precipitation of driest month were determined at a fine scale (50m); AET of summer was selected at a medium scale (400m); PET seasonality was selected at a broader scale (3200m), and in the landscape composition variable, mixed and needle leaf forests were chosen at a broader scale (3200m and 1600m, respectively). Terrain ruggedness index and topographical position index were selected at medium scale (400m and 200m, respectively); compound topographical index and slope were chosen at fine scale (50m); aspect and water bodies were selected at broader scale (3200m). Agriculture land was chosen at a fine scale (50m), and built-up was selected at a broad scale (3200m).

### *Northern red muntjac*

A total of 15 critical variables were selected, three predictor variables were selected in a class variable, and precipitation of the driest month was selected at a fine scale (50m). AET of summer and PET seasonality were selected at medium (800m) and broader scale (3200m). The landscape composition variable selected barren land, mixed forest, and grassland at a broader scale (3200m). In the topographical variable, slope and topographical positional index were chosen at a fine scale

(50m and 100m, respectively); terrain ruggedness index was chosen at a medium scale (200m); aspect and water bodies were selected at a large scale (3200m). The human footprint and built-up were elected at a large scale (3200m); agricultural land was chosen at a medium scale (400m) in human induced class.

### *Mainland serow*

Four of the ten predictor variable in climate class were selected. Annual actual evapotranspiration, PET of warmest quarter, and precipitation of driest month were selected at fine scale (50m); PET seasonality at large scale (3200m). Mixed forest and grassland were chosen at a broader scale needle leaf forest at medium scale (400m) in landscape composition variable. In the topographic class variable, terrain ruggedness index and topographical index were selected at medium scale (200m and 800m, respectively); slope (1600m), aspect, and waterbodies were selected at large scale (3200m). Agriculture land (1600m), human footprint, and built-up were selected at large scale (3200m).

### *Wild pig*

In the climate variable, precipitation of the driest month was chosen at a fine scale (50m); PET warmest quarter was chosen at a medium scale (400m); Snow at a larger scale (3200m). In the landscape composition variable, barren land and broadleaf forest were chosen at fine scale (50m and 100m, respectively); mixed forests as larger scale (3200m); grassland (400m) and needle leaf forest (800m) were selected at medium scale. In the topographic class, compound topographical index, slope, and topographical positional index were chosen at a small scale; aspect and water bodies were selected at a medium scale (800m); Aspect was chosen at a large scale (3200m). Agriculture land and built-up were selected at large scale (1600m and 3200m, respectively).

### **GAM model selection**

The GLMs were performed with the combinations of different independent variables and species presence/absence (Table 6.3). For an Asiatic golden cat, 20 models were tested for the best suitable model. The best model was evaluated employing AICc values (117.97) and retained five variables. The best model for golden cat revealed needle forest, mixed forest, Precipitation of Driest Month, and PET seasonality were positively responded. The topographic positional index was negatively

responded. Leopard cat retained eleven variables and was elected the best model with 53 % AIC weight. The best model revealed that terrain ruggedness, PET wet quarter, grassland, mixed forest, needle leaf forest, and water responded positively; PET seasonal, Precipitation of Driest Month, slope, and the topographic positional index negatively responded (Table 6.4). The Himalayan palm civet showed positive and highly significant Precipitation of Driest Month; and negatively related to ruggedness, mixed forest, AET of winter, and topographic positional index with 80% of AIC weight (Table 6.4). The best model for Northern Red Muntjac revealed that aspect, human footprint, mixed forest, needle leaf forest, Precipitation of Driest Month, and terrain ruggedness index showed positive and significant responses; landscape composition class, topographic positional index, and AET of summer showed negative respond with 66% of AIC weight (Table 6.4). The strongest correlate for mainland serow was a positively respond to mixed forest, aspect, and slope with 45% of AIC weight (Table 6.4). The best model was evaluated employing AICc values (263.4) retained seven variables. Whereas, for wild pigs, mixed forest, slope, Precipitation of Driest Month, aspect, and compound topographical index revealed positive and significant responses; terrain ruggedness, topographic positional index, and needle leaf forest responding negatively and significantly, with 85% of AIC weight (Table 6.4). The present habitat suitability modelling using GAM best model indicates that mammalian species' potential habitats extend from the forests to the snow-capped mountains. Our model performed well and revealed the probability distribution's strong predictive result (Fig 6.2). Asiatic golden cat and Himalayan palm civet are preferred, mainly needle leaf and mixed forest. In the case of the leopard cat and northern red muntjac, it avoids grassland; for wild pig, it avoids needle forest. Mainland serow preferred mainly mixed forest and avoiding grassland habitat (Fig 6.2).

**Table 6. 3: Models, AICc, and AIC model weights for all candidate models with non-zero AIC weights for different mammalian species. The variable acronyms correspond to those given in Table 1 Delta— difference in AICc between the model on that line and the model with the lowest AICc; wi—AIC weight of the model.**

Golden Cat

Model	AICc	delta	weight
S24+S23+S3+S28+S35	118.8	0	0.55
S3+S23+S24+S35+S28+S36	120.4	1.66	0.24
S3	121.5	2.74	0.14
S3+S36	123.6	4.83	0.05
S3+S24+S23	125.1	6.31	0.02
S28+S35+S24	136.7	17.95	0
S17	137.8	18.97	0
S24	143.9	25.13	0
S5	145.1	26.28	0
S37	145.4	26.57	0
S36+S35	146.2	27.38	0
S35	146.3	27.49	0
S23	146.5	27.75	0
S1	149.5	30.73	0
S36	150.6	31.81	0
S28	151.1	32.34	0
S2	152.4	33.57	0
S13	152.5	33.71	0
S32	153.2	34.44	0
S18	153.6	34.81	0

Leopard Cat

Model	AICc	delta	weight
S28+S36+S3+S32+S30+S17+S2+S23+S24+S35+S37	260	0	0.53
S2+S3+S14+S17+S18+S23+S24+S28+S30+S32+S33+S35+S36 +S37	261.7	1.7	0.23
S2+S3+S17+S23+S24+S35+S37+S36	262.3	2.34	0.16
S2+S3+S14+S17+S23+S24+S28+S30+S32+S36	265.4	5.46	0.03
S2+S3+S14+S17+S18+S23+S24+S28+S30+S32+S35+S36	265.8	5.82	0.03
S2+S3+S14+S17+S18+S23+S24+S28+S30+S32+S33+S35+S36	266.7	6.77	0.02
S3+S23+S24	314.4	54.39	0
S3+S24	316.6	56.61	0
S17	323.7	63.75	0
S3	324	64.06	0
S5	339.5	79.55	0
S24	340.3	80.32	0
S23	351.7	91.69	0
S32	360.1	100.15	0
S36	367.7	107.71	0
S28	371.4	111.39	0
S2	372.7	112.72	0
S18	374.8	114.78	0
S35	376	115.99	0
S1	377.5	117.55	0
S37	379.1	119.09	0
S13	382.3	122.35	0

#### Himalayan palm Civet

Model	AICc	delta	weight
S2+S24+S23+S36+S3+S21+S35	92.3	0	0.80
S3+S35	96.8	4.46	0.09

S3+S21+S35	97.2	4.87	0.07
S3+S21+S35+S36	98.4	6.12	0.04
S3	104.6	12.32	0.002
S2+S21+S23+S24+S35+S36	106.3	13.94	0.001
S3+S24	106.7	14.41	0.001
S3+S23+S24	108.5	16.21	0
S2+S36+S24	118.8	26.47	0
S2	131.8	39.51	0
S23	138.2	45.93	0
S36	140.5	48.18	0
S24	140.6	48.3	0
S35	141.1	48.75	0
S37	141.3	48.95	0
S21	142.2	49.88	0
S13	146.9	54.6	0
S28	151.9	59.54	0
S32	152	59.66	0
S14	152.1	59.8	0
S1	152.5	60.18	0

#### Barking Deer

Model	AICc	Delta	Weight
S36+S2+S18+S24+S3+S17+S20+S23+S35	270.6	0	0.66
S2+S3+S17+S18+S20+S23+S24+S35+S36+S13+S32	272.7	2.04	0.24
S2+S3+S17+S35+S24+S32	274.4	3.8	0.01
S36+S2+S18+S24+S3+S17+S20	283	12.35	0.001

S2+S3+S35+S20+S23	289.7	19.03	0
S17+S35+S23+S36+S20+S24+S18	309	38.39	0
S3+S17+S35+S23+S36+S20+S24+S18	311.1	40.45	0
S3+S17+S35+S23+S36+S20+S24	313.3	42.66	0
S2	346.1	75.43	0
S3	355.1	84.49	0
S17	363	92.33	0
S5	368.5	97.83	0
S23	388.1	117.49	0
S24	392.5	121.84	0
S18	392.8	122.19	0
S20	394.8	124.16	0
S37	400.6	130.01	0
S35	401.5	130.88	0
S36	413.1	142.5	0
S13	422.5	151.88	0
S1	424.1	153.42	0
S32	427.6	156.95	0
S28	431	160.35	0

#### Mainland Serow

Model	AICc	delta	weight
S17+S3+S30+S23+S2+S35+S32	263.9	0	0.45
S2+S3+S17+S23+S32+S35	265	1.13	0.26
S2+S3+S17+S23+S32+S36	265.3	1.42	0.22
S2+S3+S17+S32	267.6	3.74	0.1
S2+S16+S17+S18+S30+S32+S35+S36	282.5	18.66	0
S3+S17+S30+S23+S32+S35	293.8	29.92	0
S2+S30+S23+S32+S35	294.1	30.22	0

S17+S23+S30+S32+S35+S36	306.2	42.3	0
S3+S17+S30+S23	328	64.09	0
S30+S23+S32+S35	330.8	66.9	0
S23+S30+S32+S35+S36	332.9	68.98	0
S23+S32+S35	341.9	78	0
S17	357.7	93.84	0
S2	363.6	99.72	0
S3+S30+S23	367.8	103.93	0
S3	373.2	109.28	0
S23	384.6	120.72	0
S32	396.5	132.64	0
S37	400.3	136.4	0
S35	409	145.1	0
S30	411.9	148.03	0
S16	412.1	148.25	0
S18	412.2	148.29	0
S1	412.4	148.47	0
S36	413.1	149.24	0
S13	415	151.14	0
S24	418.5	154.62	0
S28	421.1	157.2	0

### Wild pig

Model	AICc	delta	weight
S24+S23+S32+S3+S35+S2+S36+S14	155.9	0	0.85
S3+S12+S23+S32+S33+S35+S36	160.6	4.68	0.08
S24+S23+S36+S14+S33+S17+S35	162.6	6.7	0.03
S2+S24+S23+S36+S14	163.3	7.41	0.02
S3+S12+S14+S17+S23+S24+S32+S33+S35+S36	163.9	8	0.02

S2+S3+S23+S36+S33+S17	166.2	10.36	0.005
S3+S23+S36+S14+S33+S17	169.3	13.46	0.001
S24+S23+S32+S3+S36+S14	170.6	14.76	0.001
S2+S23+S36+S33+S17	170.9	14.98	0
S3+S32+S35	174	18.07	0
S3+S14+S32+S35	175.4	19.53	0
S23+S36+S33+S17	182.6	26.73	0
S3	187.9	31.98	0
S12	192.4	36.47	0
S23	199.5	43.59	0
S32	208.2	52.27	0
S24	208.8	52.92	0
S35	216.3	60.45	0
S33	217.5	61.65	0
S36	217.7	61.82	0
S14	217.9	62.06	0
S17	223.5	67.62	0
S13	223.7	67.85	0
S2	225.4	69.57	0
S37	225.9	70	0
S1	229.6	73.76	0
S29	231.8	75.87	0

**Table 6. 4: Covariates of the best GAM model.**

Golden Cat

Variable	$\beta$ Estimate	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
S24	1.032	1	6.27	6.27	5.99	0.02	*
S23	-1.30	1	2.03	2.03	1.94	0.17	
S3	0.064	1	7.13	7.13	6.82	0.02	*

S28	0.003	1	6.30	6.30	6.03	0.02	*
S35	-0.81	1	3.12	3.13	2.99	0.09	.

### Leopard Cat

Variable	$\beta$ Estimate	Df	SumSq	MeanSq	Fvalue	Pr(>F)	
S28	-3.25E-04	1	2.34	2.35	2.63	0.11	
S36	4.31E+01	1	5.16	5.16	5.78	0.02	*
S3	-1.62E-02	1	4.61	4.61	5.17	0.023	*
S32	-4.06E-02	1	2.6	2.59	2.90	0.09	.
S30	4.89E-02	1	4.01	4.01	4.49	0.03	*
S17	1.94E+01	1	3.89	3.89	4.36	0.04	*
S2	4.49E-02	1	11.10	11.11	12.43	0.001	***
S23	4.37E+00	1	8.73	8.73	9.77	0.002	**
S24	3.48E+00	1	7.00	7.00	7.84	0.005	**
S35	-2.19E+00	1	2.94	2.94	3.30	0.1	.
S37	2.40E+01	1	5.46	5.45	6.11	0.01	*

### Palm Civet

Variable	$\beta$ Estimate	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
S2	0.07	1	3.26	3.26	3.24	0.07	.
S24	0.91	1	3.74	3.74	3.72	0.06	.
S23	2.22	1	3.12	3.12	3.11	0.08	.
S36	-39.73	1	3.86	3.87	3.85	0.05	.
S3	0.07	1	8.58	8.57	8.54	0.004	**
S21	-0.07	1	2.73	2.74	2.73	0.10	
S35	-0.28	1	3.42	3.42	3.40	0.07	.

### Barking Deer

Variables	$\beta$ Estimate	Df	Sum Sq	Mean Sq	Fvalue	Pr(>F)	
S36	10.25	1	4.53	4.53	5.0189	0.026	*
S2	0.06	1	26.73	26.73	29.5794	1.12E-07	***
S18	0.09	1	6.86	6.86	7.5979	0.01	**
S24	0.18	1	3.04	3.05	3.3732	0.07	.
S3	0.01	1	4.5	4.49	4.9788	0.03	*
S17	-21.19	1	7.39	7.39	8.1822	0.01	**
S20	-0.02	1	2.89	2.89	3.1988	0.07	.
S23	2.90	1	3.59	3.59	3.9767	0.05	*
S35	-0.15	1	11.18	11.18	12.3739	0.001	***

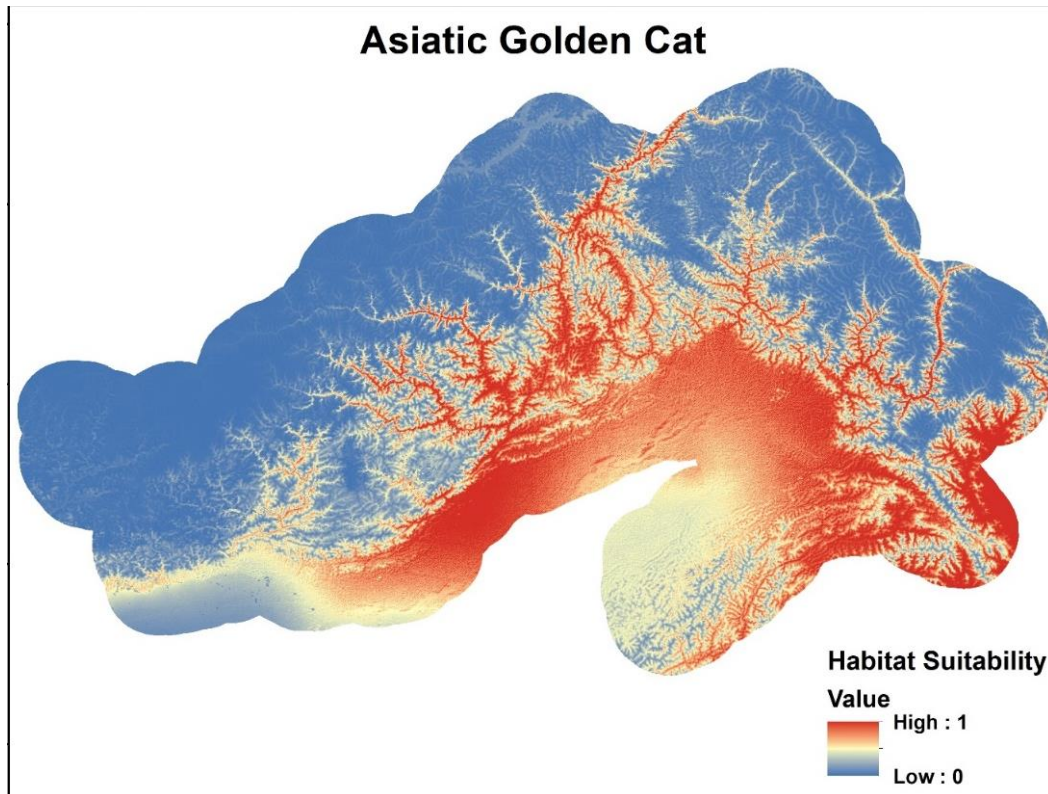
### Mainland Serow

Variable	$\beta$ Estimate	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
S17	-16.59	1	8.14	8.14	5.98	0.02	*
S3	0.04	1	4.11	4.11	3.02	0.08	.
S30	-0.05	1	3.73	3.73	2.74	0.10	.
S23	2.78	1	4.45	4.45	3.27	0.07	.
S2	0.06	1	25.03	25.03	18.39	2.45E-05	***
S35	-0.20	1	3.85	3.85	2.83	0.09	.
S32	0.14	1	17.25	17.25	12.67	0.0004	***

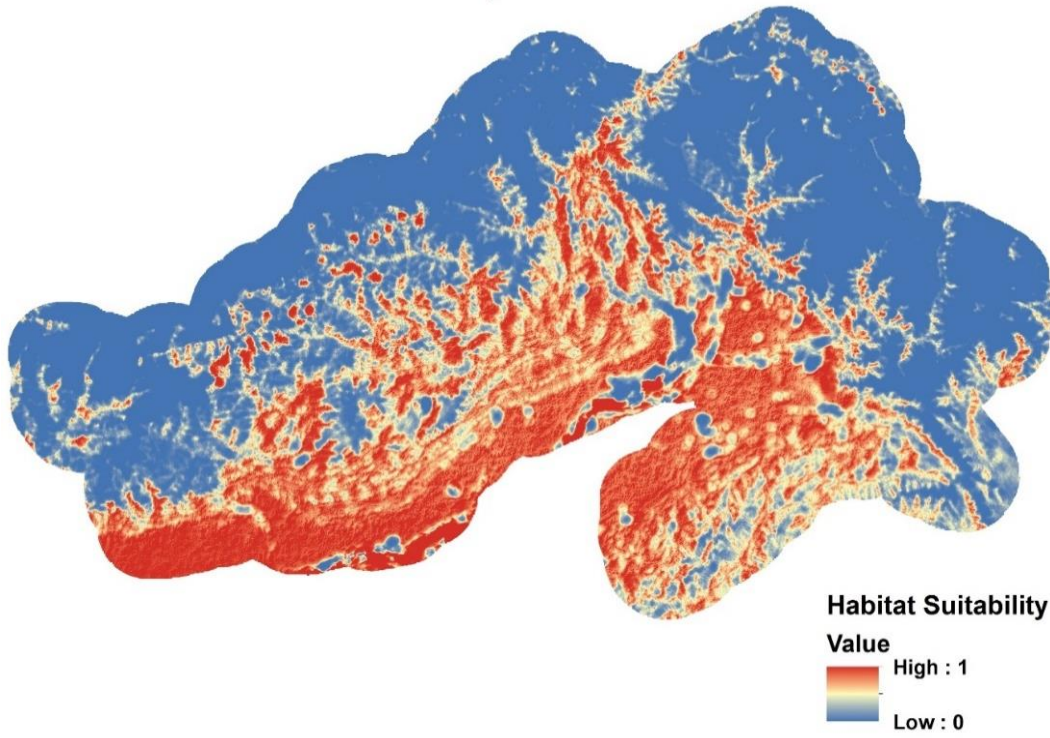
### Wild pig

Variable	$\beta$ Estimate	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
S24	-1.84	1	4.99	4.99	5.37	0.02	*
S23	3.12	1	4.44	4.43	4.77	0.03	*
S32	0.03	1	4.45	4.45	4.78	0.03	*

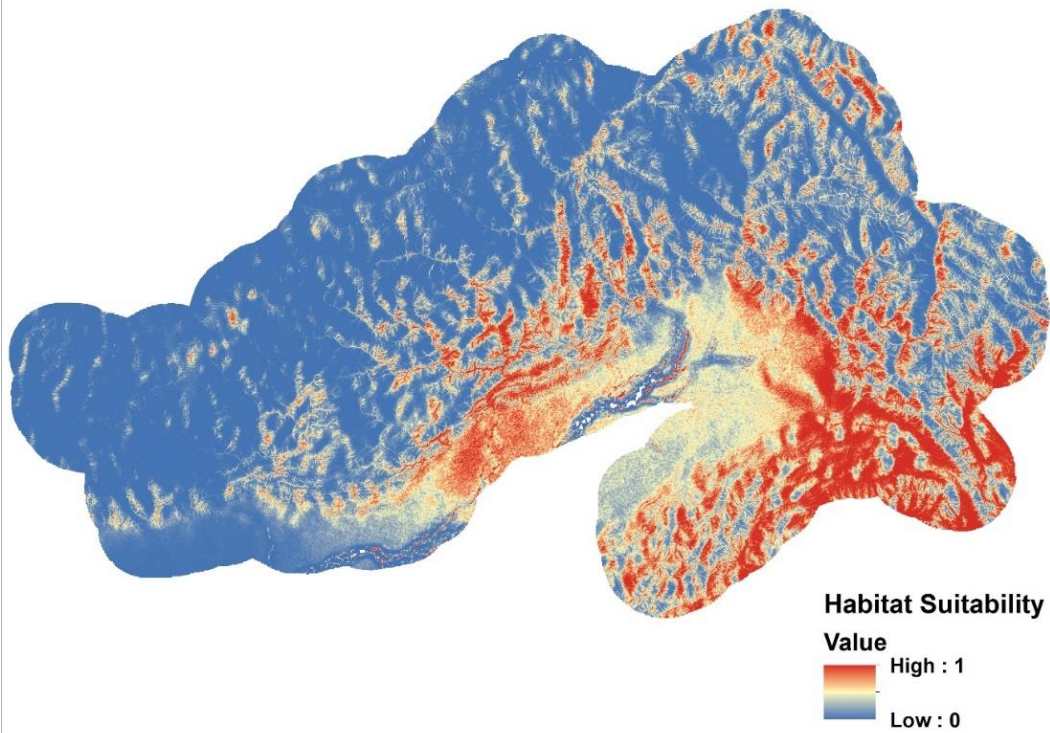
S3	0.03	1	5.31	5.31	5.70	0.02	*
S35	-0.18	1	4.39	4.39	4.72	0.03	*
S2	0.05	1	9.41	9.40	10.11	0.001	**
S36	-66.52	1	2.60	2.60	2.79	0.1	.
S14	1.14	1	2.73	2.73	2.94	0.08	.



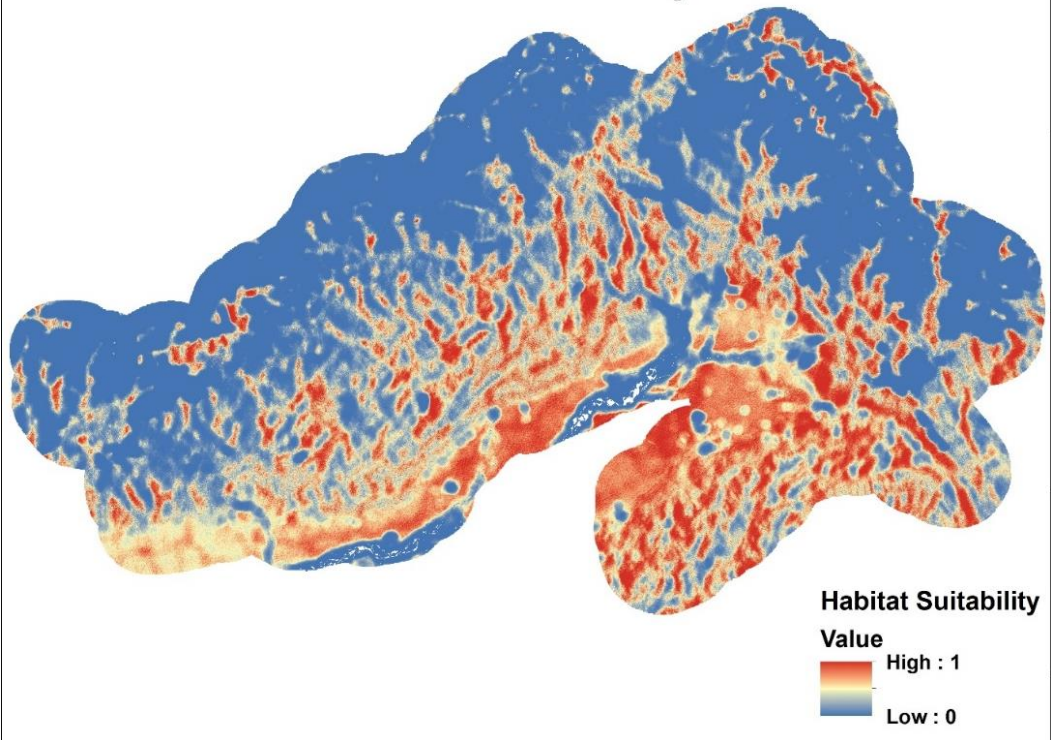
## Leopard Cat



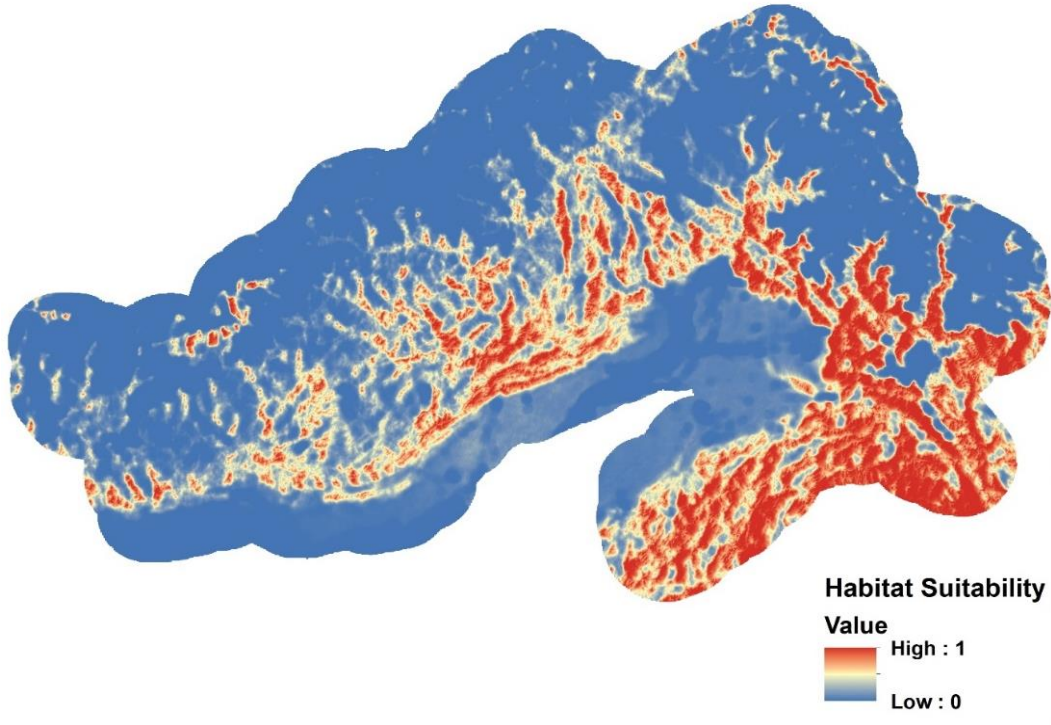
## Masked Palm Civet

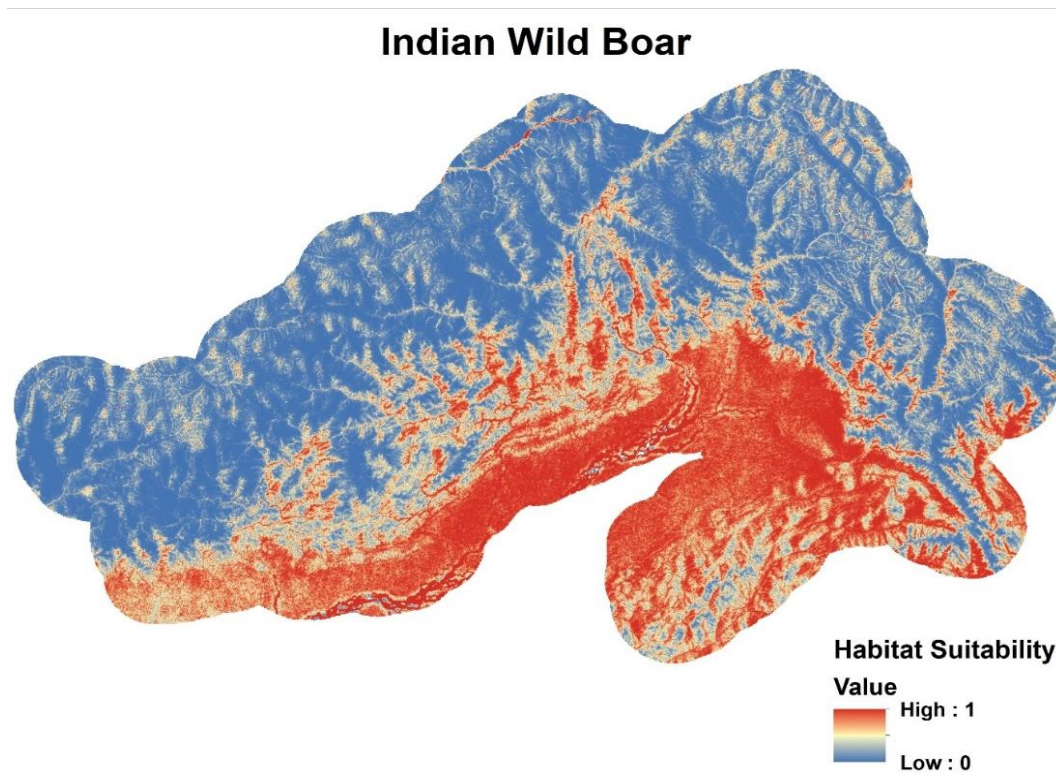


### Northern Red Muntjac



### Mainland Serow





**Figure 6. 2: Habitat suitable model of mammalian species using General additive model in Arunachal Pradesh.**

### Discussion

We highlight the potential utility of habitat mapping and distribution modelling mammalian species in human-dominated landscapes on a broad regional scale. Modeling habitat and environmental suitability are frequently used to inform our ecological understanding of the distribution of a mammalian species. However, restrictions and choices are still involved in creating spatial distribution models (Guisan & Thuiller, 2005; VanDerWal et al., 2009; Thuiller et al., 2010; Torres et al., 2012). Based on multiple-scale optimization models to predict the distribution of multiple species at the landscape level using GAM, we present distribution maps of six mammalian species in the region that are reported. The GAM result demonstrates that the maps accurately depict the broad distribution of appropriate habitats and target species.

Predictor variables were used for our multiscale and multispecies models at small (50 m and 100 m), medium (200-800 m), and broad spatial scales (1600 and 3200 m). All target mammalian species in this study significantly differed between the fine and broader spatial scales employed in

the multi-scale models. This suggests that distinct processes control how the species are dispersed across various spatial scales (Bradter et al., 2013). Our findings are consistent with studies that explicitly observe several variables at the geographical scales that are crucial for identifying the interactions between species and habitat in multiscale habitat modelling. All six species of mammals chose distinct predictor factors at varying spatial scales. The topographical positioning index influenced the golden cat at a medium size, and the forest affected it at a fine scale. On a larger scale, leopard cats favour forested, grassy, and rough terrain. This pattern shows that the impact of severe conditions and the decline in structural complexity of flora at higher altitudes may prohibit certain species from establishing or surviving (Graham et al., 2014). The main diets of the golden cat and leopard cat consist primarily of small mammals and birds (Choki et al., 2023; Rajaratnam et al., 2007). Due to its relatively small size, the leopard cat will likely have a smaller home range than the golden cat. Leopard cats preferred the rough terrain to prevent human disturbance and avoid niche overlap with other large carnivores, including tigers, leopards, and dholes (Rho, 2009). Leopard cats' flexible nature as habitat generalists, which frequently benefit from forest margins and open habitats, is one of the reasons they may be able to adapt to a severely disturbed environment (Duckworth et al., 2014; Ross et al., 2015), which often benefit from forest margins and open habitats. They are conceivable to hunt murids and sciurid prey species in open areas like grassland at lower elevations (Rostro-Garca et al., 2021; Chung & Lee, 2022). However, our distribution model portrayed the leopard cat as a generalist species in the region. Even though this species is common throughout most of its distributional range in India (Mukherjee et al., 2010), we found it only in the lower elevation of the entire Arunachal Pradesh landscape. This cat's distribution was thought to be significantly influenced by its proximity to perennial water bodies (Sunquist & Sunquist, 2002; Mukherjee et al., 2010). However, the predilection for ruggedness and aspects needs to be explained, considering how climatic factors affect the distribution of leopard cats (Mukherjee et al., 2010).

The masked palm civet is still a poorly researched and poorly understood nocturnal animal even though it is classified as Least Concern on the IUCN Red List of Threatened Species. The basic knowledge about the habitat needs of the masked palm civet has been provided by the present habitat suitability modelling, which also serves as a foundation for further study. Masked palm civets were positively associated with mixed and needle leaf forest variables (Penjor et al., 2021). The palm civet mainly feeds on seasonal fruits and small mammals in forested environments.

According to our predictions result, the species will thrive best in the lowland area of the landscape. The masked palm civet avoided rugged terrain and preferred lowland habitats with wetness and wet grounds to eat rodents, birds, seeds, insects, molluscs, fruits, seeds, and amphibians (Zhaou et al., 2008; Matsuo & Ochiai, 2009; Belden et al., 2014). The persistence of palm civets in lowland areas with high regional anthropogenic pressure can be associated with their habitat modification tolerance (Zhaou et al., 2008; Semiadi et al., 2016).

However, our prediction map for barking deer shows suitable habitats throughout the study area. This could be due to its ability to dwell in various environments, including degraded forests near human settlements (Ohtaishi & Gao, 1990; Prater, 1990; Oka, 1998; Paudel & Kindlmann, 2012a). Similarly, Timmins et al. (2016) assert that barking deer are widely dispersed from lowlands to high mountains, proving that height alone has no direct bearing on the distribution of barking deer. Instead, it is recognised that elevation relates to other climatic predictors (Elith & Leathwick, 2009) that cause a change in the habitat's characteristics and the quality to allow the presence of the species. According to our findings, barking deer was positively impacted by the presence of grassland and forest habitats (Teng et al., 2004). Hameed et al. (2009) have revealed that the availability of herbs and the amount of tree canopy can directly impact the occurrence of barking deer. It has been suggested by Nagarkoti and Thapa (2007) and Roberts (1977) that this may be because the forest provides a lot of food, shelter, and water. Barking deer are selective browsers that consume small mammals that they kill and eat with their teeth and forelegs, as well as flowers, twigs, fruits, bamboo shoots, foliage, bark, herbs, sprouts, seeds, grasses, birds' eggs, and carrion (Hofmann & Stewart, 1972; Jarman, 1974; Hofmann, 1989). In a human-dominated agricultural setting, all of this is easily accessible. Therefore, it is believed that barking deer prefer to live close to populated areas. (Oka, 1998; Paudel and Kindlmann, 2012).

Mainland Serow is classified as Vulnerable due to a decline of more than 30% over three generations based on local surveys, a decline in the occupied area and habitat quality, and actual levels of exploitation (IUCN, 2020). The suitable habitat map for mainland serow depicts its distribution along the research area's mountain ridges. Our findings revealed that it is found in protected areas and community-owned forests ranging in elevation from lowland to 3,500 m. The mainland serow is a forest animal, and our findings reveal that it likes forest habitats with rugged, steep hills on a broad scale (Li et al., 2014; Phan et al., 2014; Paudel et al., 2015; Buzzard et al.,

2018; McShea et al., 2018; Phan et al., 2021). Serow avoids the plains to avoid predators and prefers gentle to steep slopes. They graze on mild hills while resting in steeper places (Aryal, 2008). Despite being susceptible to human disturbance, mainland serow can withstand moderately degraded forests (Lekagul & Mcneely, 1988). Serow is characterised as a typical browser since the species consumes a wide variety of leaves and twigs on low-growing trees. The serow is frequently hunted for both commercial and subsistence purposes. Gun hunting is uncommon in the Upper Siang district, where native hunters set snare traps close to salt licks. Hunting in these communal forests is carefully regulated by local authorities (Datta-Roy, 2019). Large-scale habitat degradation is becoming more common due to infrastructure development, including dams and motorways in Sikkim and Arunachal, which may represent the species' strongholds.

According to Ballari and Barrios-Garc'a (2014), the wild pig is a generalist species whose extensive distribution is attributed to their high plasticity diet. According to the suitable habitat map, it was mainly on a gentle slope (fine-scale) and avoided rugged, steep terrain (medium-scale). The suitability of the wild pig habitat was significantly predicted by topological factors (Seo & Park, 2000; Lee et al., 2022). Indicating that resources typically influence preferences in forested areas, forests significantly impacted the habitat suitability of wild pig occurrences. The abundant availability of food supplies in the forest via the mast has been cited as a potential factor by Thurfjell et al. (2009), Fonseca (2008), and Rho (2015). Forests must significantly provide wild pigs with food resources since they shun open spaces like grasslands (Caruso et al., 2018). The contribution and significance of Precipitation of Driest Month (fine-scale) to the model may suggest that wild pigs avoid extreme temperature fluctuations. The habitat suitability was only somewhat adversely affected by the urban cover. Wild pigs have been shown to have a high degree of behavioural adaptability to situations that humans dominate (Stillfried et al., 2017a). Wild pigs adapt their spatial use (using recreational forests with high human presences) and even use human-associated habitat classes by controlling their perception of harmless anthropogenic risk, as demonstrated by lower evacuation distances for urban compared to rural pigs. The wild pigs' adaptive and highly flexible habitat use in response to human disturbances was confirmed by the lack of importance given to habitat diversity (Calenge et al., 2002; Maillard & Fournier, 2014). These results suggest that the ability of wild pigs to use human-dominated habitat types, or habitats like a scrub and other low natural covers, which are frequently not expected to boost habitat compatibility while adjusting to anthropogenic landscapes, has not yet reached its limit. The

Compound Topographical Index can explain water availability in our study area, which demonstrates a positive relationship to species at a fine scale. This relationship may be related to the vegetation that it feeds on. Pigs may rely on roots during the winter when above-ground supplies become scarce and are more readily available in nearby water bodies. Snares and other tools are frequently used for hunting wild pigs in this area, and the flesh is in high demand there (pers. obs.). Studies, however, also noted that the species' fast rate of reproduction makes it highly resilient to pressure from hunting (Choquenot et al., 1996; Pepin et al., 2017).

### **Limitations, conclusion, and management implications**

One of the study's primary limitations is that we used distributional data from a small sample size to predict the probability distribution of the target mammalian species over a broader landscape region. Another drawback is our model's reliance primarily on topographic and landscape characteristics and the lack of diverse land cover models. As a result, our models might not accurately depict the distribution of all the species considered in this study. As a result, data from the scientific literature are excellent supplementary sources since they frequently describe how the data were gathered, giving additional detailed information. However, it is not always simple to directly get underlying information from the literature, such as georeferenced records.

Models of habitat appropriateness do not accurately reflect species distribution (Rondinini et al., 2011). However, the modelling efforts in this study advance our knowledge of multispecies habitat choice in one of India's biodiversity hotspots. It is a valuable indicator for prioritising conservation efforts and for other scientists looking to assess if a particular habitat is suitable for other elusive and endangered species. To provide plausible forecasts of the dangers to the species posed by humans and climate change, it is essential to jointly understand the interplay between environmental and ecological factors and the range of scales across which mammalian species choose habitats.

Predictor variables in this study played a significant role in determining the occurrence of the species at various spatial scales. Therefore, a single-scale strategy can significantly skew the data and influence managerial decisions. By creating species distribution models, our findings also present an opportunity to increase our understanding of mammal ecology and regional distribution. These models can be used to evaluate potential areas of occurrence and identify variables (climatic,

landscape, topographic, and anthropogenic) that affect mammal species distributions. Future research aiming to evaluate mammal distribution patterns more precisely should therefore concentrate on investing in more precise sampling techniques to increase the reliability of data collected, ii) increasing the sampling effort in regions where information is lacking, and iii) ensuring a broader compilation of historical records, assessing both geographic range and periods. We believe this study will inspire officials and give them access to a conceptual toolset to manage various ecosystems and species effectively. In the meantime, we anticipate that our findings will serve as a foundation for regionally specific conservation initiatives to save biodiversity against the effects of climatic and land-use changes.

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**Table A 1: Mammals recorded in different habitats from Mehao Wildlife Sanctuary through different methods, Camera Trap (CT), Sign Survey (SS), Direct Sighting (DS), IUCN status (LU- Least concern, NT- Near Threatened, VU- Vulnerable, EN- Endangered).**

Order	Family	Species	IUCN	Record Through		
				CT	SS	DS
Primates	Hylobatidae	Eastern Hoolock Gibbon ( <i>Hoolock leuconedys</i> )	EN	-	*	*
	Cercopithecidae	Northern Pig-tailed Macaque ( <i>Macaca leonina</i> )	VU	-	*	*
		Assamese Macaque ( <i>Macaca assamensis</i> )	NT	-	-	*
Carnivora	Felidae	Clouded Leopard ( <i>Neofelis nebulosa</i> )	VU	*	*	-
		Marbled Cat ( <i>Pardofelis marmorata</i> )	VU	*	*	-
		Asiatic Golden Cat ( <i>Catopuma temminckii</i> )	VU	*	-	*
		Leopard Cat ( <i>Prionailurus bengalensis</i> )	LC	*	*	*
	Canidae	Asiatic Wild Dog ( <i>Cuon alpinus</i> )	EN	*	*	*
		Golden Jackal ( <i>Canis aureus</i> )	LC	-	*	*
	Ursidae	Asiatic Black Bear ( <i>Ursus thibetanus</i> )	VU	*	*	-
	Mustelids	Yellow-throated marten ( <i>Martes flavigula</i> )	LC	*	*	*
	Herpestidae	Crab-eating Mongoose ( <i>Herpestes urva</i> )	LC	-	-	*
	Viverrids	Masked Palm Civet ( <i>Paguma larvata</i> )	LC	*	*	*
	Prionodontidae	Large Indian Civet ( <i>Viverra zibetha</i> )	VU	*	-	-
		Spotted Linsang ( <i>Prionodon pardicolor</i> )	LC	*	-	-
Artiodactyla	Bovidae	Red Goral ( <i>Naemorhedus baileyi</i> )	VU	*	-	-
		Himalayan Serow ( <i>Capricornis thar</i> )	NT	*	*	*
		Mishmi Takin ( <i>Budorcas taxicolor</i> )	VU	-	*	-
	Cervidae	Barkin Deer ( <i>Muntiacus muntjak</i> )	LC	*	*	*
		Sambar ( <i>Rusa unicolor</i> )	VU	*	*	-
Suidae	Indian Wild Pig ( <i>Sus scrofa</i> )	LC	*	*	-	
Rodentia	Sciuridae	Pallas's Squirrel ( <i>Callosciurus erythraeus</i> )	LC	-	-	*
		Black Giant Squirrel ( <i>Ratufa bicolor</i> )	NT	-	-	*
		Himalayan Striped Squirrel ( <i>Tamiops maccllellandi</i> )	LC	-	-	*
	Hystricidae	Himalayan Crestless Porcupine ( <i>Hystrix brachyura</i> )	LC	*	*	-
		Asiatic Brush-tailed Porcupine ( <i>Atherurus macrourus</i> )	LC	*	-	-

**Plate 1: Camera traps images of Fauna in Mehao Wildlife Sanctuary.**



**1. Large Indian Civet**



**2. Leopard Cat**



**3. Himalayan Serow**



**4. Gongshan Muntjac**



**5. Indian Wild Pig**



**6. Asian Golden Cat (Melanistic)**



**7. Asiatic Brush-tailed Porcupine**



**8. Yellow-throated Marten**



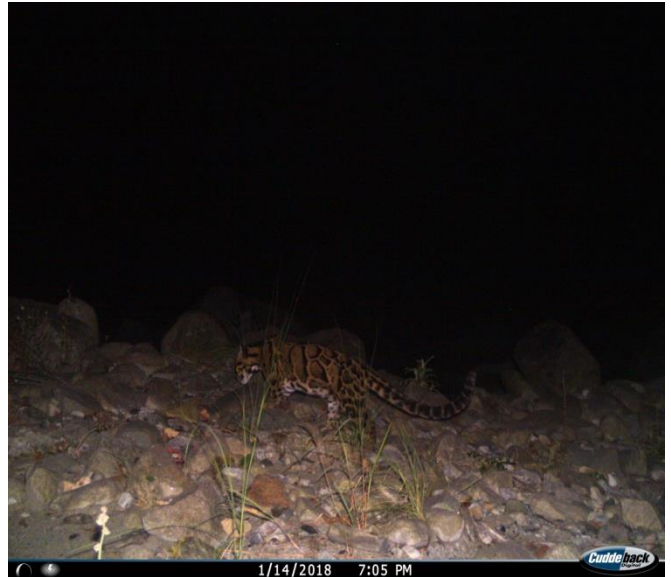
**9. Himalayan Palm Civet**



**10. Dhole**



**11. Marbled Cat**



**12. Indo-Chinese Clouded leopard**



**13. Indian Muntjac**



**14. Pallas Squirrel**



**15. Mithun**



**16. Spotted Linsang**



**17. Himalayan Black Bear**



**18. Kalij Pheasant**



**19. Assamese Macaque**



**20. Mishmi Takin**

**PLATE 2: Photographs of Mehao WLS.**



**1. A Landscape view of Mehao WLS.**



**2. Sub-tropical and temperate forest of Mehao Lake in Mehao WLS.**



**3. A view of Ezee river in post-monsoon season, Mehao WLS.**



**4. Mithun near Mayodia in Mehao WLS.**



**5. Camping during field work inside the forest of Mehao WLS.**



**6. Collecting data for camera traps and vegetation plots in Mehao WLS.**



**7. Crossing Diphu river over temporary wooden bridge inside the Mehao WLS.**



**8. Field survey during winter season near Mayodia pass, Mehao**



**9. Deploying camera traps inside the Mehao WLS.**



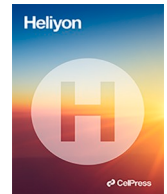
**10. Interaction with local villagers around the periphery of Mehao WLS.**

## List of Publication

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## Research article

# Wildlife habitat mapping using Sentinel-2 imagery of Mehao Wildlife Sanctuary, Arunachal Pradesh, India

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## ABSTRACT

Mehao Wildlife Sanctuary, situated in the state of Arunachal Pradesh, is part of an important biodiversity hotspot in the north-eastern part of India in the Himalayas. The current study deals with the identification of important wildlife habitats in the sanctuary. We used a supervised classification technique to delineate these habitats in the sanctuary, which are used by several mammals and bird species encountered during camera trap and sign surveys conducted between November 2017 and May 2020. Satellite images from Sentinel – 2A were used to classify the land use land cover (LULC) of the sanctuary. The LULC information was generated by using a maximum likelihood classifier. We classified a total of thirteen LULC classes, i.e., water, built-up, agriculture, orchard, grassland, bamboo forest, bamboo-mixed forest, riverbed, barren land, snow, wild banana, riverine forest and mixed forest. LULC classification reveals a high percentage of mixed forest, about 69.9%, followed by wild bananas at 7.2%. The commission and omission error rates, however, are high for riverbed and agriculture (0.5) and bamboo forest (0.5), respectively. The accuracy assessment showed an overall classification accuracy of 88.5% with a Kappa coefficient of 0.87. The abundance of mammals was high in the mixed forest, but Ivlev's electivity index shows that species generally avoided this habitat and preferred specialized forest habitats, such as bamboo forest, bamboo-mixed forest, grassland, riverbed and riverine forest. Our LULC map will provide a baseline for potential planning and monitoring changes of wildlife habitats in Mehao WLS.

## 1. Introduction

Mapping of land use land cover (LULC) distribution plays a vital role in conservation planning and practices by helping to identify and quantify farmland, built-up land and wildlife management areas for effectively maintaining and preparing resources for long-term sustainability [1–4]. The LULC information is important for environmental conservation and spatial planning because of its spatial specifics; for example, the LULC information can be used as an input for models that deal with the environment, climate change, socioeconomic factors, and policy development [5–7]. Remote sensing is an essential tool for LULC classification as it provides accurate, comprehensive, and high-temporal spatial-resolution data [8]. Digital image classification is a way of separating remotely sensed data, obtained from satellites or aircraft, into useable forms by grouping image pixels with identical values and defining the general features of the objects identified according to these pixels [9]. As a result, a perfectly classified image will depict areas on the ground that contributes unique characteristics defined in the classification scheme [10].

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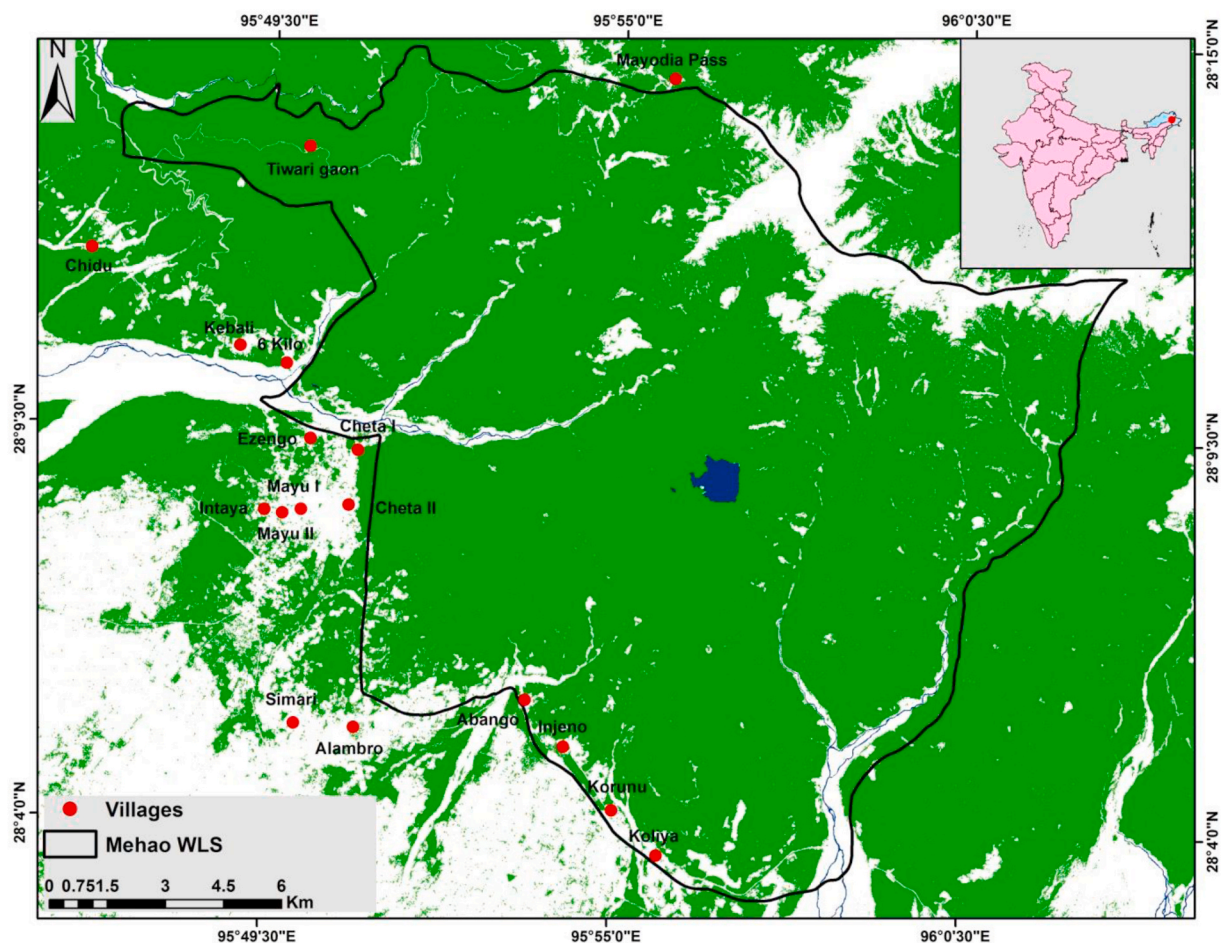
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The Sentinel-2A provides high-resolution satellite images to acquire data on vegetation, LULC and environmental monitoring [11]. The scientific community, government agencies and private sectors have used Sentinel-2 data for different applications, such as agricultural, urban development, water resources and forest monitoring [11–13]. Recent publications have used Sentinel-2 data to estimate leaf area index [14,15], normalized difference vegetation (NDVI) [16–19], forest area [20,21] and forest types [22–24].

Although the increased usage of remote sensing has made geospatial processes quicker and more effective [25], the reliability of such processes should always be scrutinized. Accuracy assessment has become a significant process for calculating the accuracy of a classification result. The error matrix and kappa coefficient are the most informative statistical estimates used to assess image classification accuracy [26].

In the present study, we acquired Sentinel-2 data and used a maximum likelihood supervised classification technique to map the LULC pattern of Mehao Wildlife Sanctuary (WLS). Many studies on Sentinel-2 data have shown that a supervised classification approach is applied more than an unsupervised classification approach [27]. Among the supervised classification methods, the algorithm of maximum likelihood is one of the most applied methodologies for the characterization and monitoring studies of forested areas [28–30]. The maximum likelihood classifier (MLC) has also proved to produce high classification accuracies [27,31–33].

The sanctuary is situated in the state of Arunachal Pradesh in India in the eastern Himalayas. This region is rich in wildlife and harbors many endangered and rare species [34,35]. However, it is threatened by a variety of factors changing socio-economic patterns, deforestation, infrastructure development and an increase in agriculture. This study aims to delineate different forest and vegetation types in the Mehao WLS, including highly inaccessible parts of the sanctuary, at a medium spatial resolution using Sentinel-2 satellite imagery. Based on our LULC information, we also aimed to identify important habitat areas for mammals based on a camera trap and sign survey. Therefore, a study that provides a more accurate interpretation of the scientific production of LULC in tropical forests would support the conservation and sustainable management of tropical forests, complement previous research, and enable the exchange of knowledge, methods, experiences, ideas, and models. The LULC map developed in this study can help in the environmental monitoring efforts of the Arunachal Pradesh forestry sector. Considering that no such study has been carried out for the sanctuary, it is



**Fig. 1.** Map showing the forest cover (green) in the study area inside the state of Arunachal Pradesh in India (shown in inset) along with locations of villages. Solid line: Mehao wildlife sanctuary boundary. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

crucial to obtain a deeper understanding of wildlife habitats and their structure to fill the information gap about the LULC of Mehao WLS for future studies and to assist in gauging changes in wildlife habitats that could arise in the future.

## 2. Materials and methods

### 2.1. Study area

The Mehao WLS, an important wildlife habitat in the Lower Dibang Valley district of Arunachal Pradesh, lies between  $93^{\circ} 30'$  and  $95^{\circ} 45'$  E longitudes and  $28^{\circ} 05'$  and  $28^{\circ} 15'$  N latitudes and covers an area of  $281.5 \text{ km}^2$  (Fig. 1). It was notified as wildlife sanctuary in the 1980 for the conservation of threatened and rare flora and fauna species in the region. The area is within the North-East (Northeast hills province) biogeographic. The terrain is flat in the southern part and hilly in the northern part with an altitude range between 400 and 3568 m asl with numerous lean rivers and streams flowing through the valley.

Major perennial rivers and streams that flow through the sanctuary are Ashupani, Deopani, Enjopan, Diphu and Jowe. All streams fall into the Dibang River, which later joins the Lohit River, a major tributary of the Brahmaputra River. There is also several seasonal streams which channel through these rivers during the monsoon season. The sanctuary contains three natural water bodies, Mehao Lake, mini Mehao Lake and Sally Lake, with the former lying at the centre of it. The forest type changes with altitude. The small undulating land with intermixed vegetation at various elevations provides covers for various wildlife species. The forest types are tropical evergreen forest (900 m), sub-tropical and temperate forest (900–1800 m), temperate broad leaf forest (1800–2800 m) and

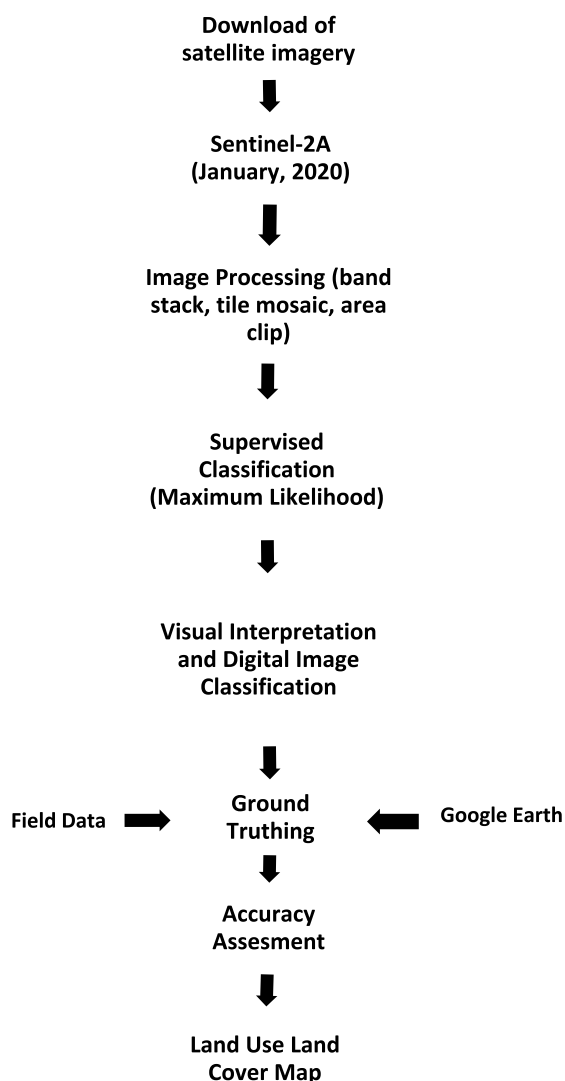
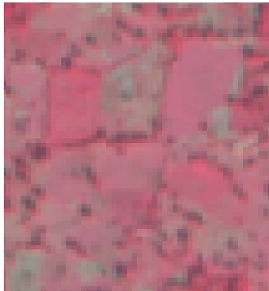
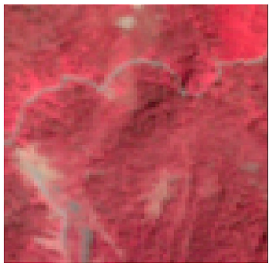

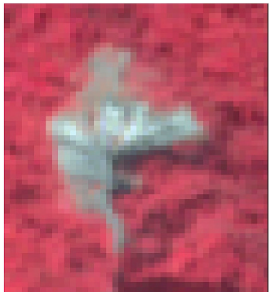
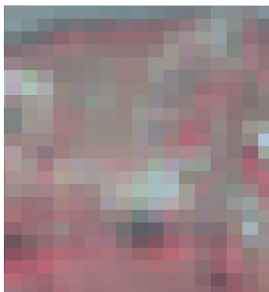


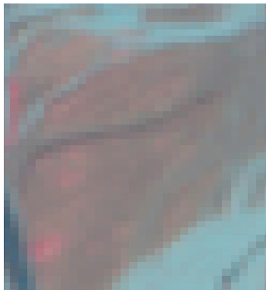
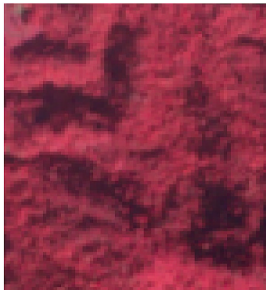



Fig. 2. Flow chart of the supervised classification scheme adopted in this study.

**Table 1**  
Land use land cover classification scheme.

Class	Description	Clipping of LULC classes on FCC
Agriculture land	The class represents the land used for crop cultivation, mainly rice, vegetables and maize.	
Bamboo forest	This class represents a pure patch of bamboo species like <i>Bambusa pallida</i> , <i>Dendrocalamus hamiltonii</i> , <i>Melocanna baccifera</i> , etc.	
Bamboo-mixed Forest	This class majorly dominated by bamboo with other tree species like <i>Terminalia bellirica</i> , <i>Canarium strictum</i> , <i>Pinus roxburghii</i> , <i>Quercus griffithii</i> , <i>Castanopsis indica</i> etc.	
Barren land	The class includes land slide and other land surfaces with very low or no vegetation covers.	
Built up	This class represents the residential and commercial zones.	
Grassland	A present of grass species like <i>Imperata cylindrica</i> , <i>Phragmites karka</i> , <i>Saccharum arundinaceum</i> , <i>Setaria glauca</i> , etc.	



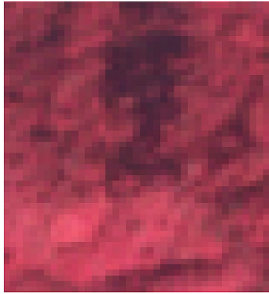
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**Table 1** (continued)

Class	Description	Clipping of LULC classes on FCC
		
Mixed forest	This class represents a different type of tree species like <i>Ailanthus grandis</i> , <i>Betula alnoides</i> , <i>Castanopsis indica</i> , <i>Cyathea</i> spp., <i>Duabanga grandiflora</i> , <i>Magnolia champaca</i> , <i>Phoebe cooperiana</i> , <i>Quercus semecarpifolia</i> , <i>Terminalia myriocarpa</i> etc. without anyone species being numerically dominant.	
Orchard	Orange orchards dominate this category.	
Riverbed	This category includes sand, small rocks and pebbles near the river.	
Riverine forest	This category represents mostly riverine tree species like <i>Bombax ceiba</i> , <i>Cassia fistula</i> , <i>Albizia lebbeck</i> , <i>Alstonia scholaris</i> , <i>Shorea assamica</i> , <i>Boehmeria macrophylla</i> , <i>Ficus hispida</i> , etc. on dry sandy bars along the rivers and streams.	
Snow	A surface that remains covered with snow throughout the year.	

(continued on next page)

**Table 1** (continued)

Class	Description	Clipping of LULC classes on FCC
Water	This category includes rivers, lakes and ponds	
Wild Banana	This class represents only wild banana species ( <i>Musa</i> spp.)	
		

temperate conifer forest (2800–3500 m). The forests are dominated by tree species such as *Albizia lucidior*, *Bombax ceiba*, *Butea monosperma*, *Castanopsis indica*, *Dipterocarpus retusus*, *Dillenia indica*, *Mesua ferrea* and *Terminalia myriocarpa*, while mainly shrub and herb species comprise *Clerodendrum infortunatum*, *Maesa indica*, *Solanum khasianum* and *Tephrosia candida*. Bamboos such as *Bambusa pallida*, *Melocanna baccifera*, *Dendrocalamus giganteus*, *Dendrocalamus hamiltonii*, and *Phyllostachys bambusoides* likewise exist. The small undulating land with intermixed vegetation at various elevations inhabits and provides cover for rare and elusive species like the Asiatic golden cat (*Catopuma temminckii*), clouded leopard (*Neofelis nebulosa*), leopard cat (*Prionailurus bengalensis*), marbled cat (*Pardofelis marmorata*), Mishmi takin (*Budorcas t. taxicolor*), sambar (*Rusa unicolor*), Northern red muntjac (*Muntiacus vaginalis*), wild pig (*Sus scrofa*), Malayan porcupine (*Hystrix brachyura*) and Pallas's squirrel (*Callosciurus erythraeus*).

## 2.2. Satellite image and land use land cover classification

The Sentinel-2A image of January 26, 2020, was downloaded from the United States Geological Survey (USGS; <https://earthexplorer.usgs.gov/>) and was used for the LULC classification. This image had the lowest cloud cover in the study area during our camera trap sampling period, so we choose this image for further analysis. The USGS Earth Explorer allows for the access to Level-1C top-of-atmosphere (TOA) reflectance of Sentinel-2A data. Level-1C processing includes radiometric and geometric corrections along with orthorectification to generate highly accurate geolocated products (<https://earthexplorer.usgs.gov/>). Bands 2, 3, 4 and 8 of the Sentinel images i.e., Blue (490 nm), Green (560 nm), Red (665 nm) and Near Infrared (833 nm), at 10 m spatial resolution, were used for classification. Pre-processing of the image, such as mosaic and layer stacking, was done using ERDAS IMAGINE 2016 [36].

Supervised classification was used to create the spectral signatures into defined features of the image. The training sample sites are chosen as the first step in the supervised classification. Training sample sites are pre-identified geographical features of areas that reflect a particular class based on ground truth [9]. The sites were chosen based on field sampling data collected during a camera trapping and sign survey from November 2017 to May 2020. Ground truth points were collected for all the classes attempted in the image classification. The satellite image was classified into 13 LULC classes, i.e., water, built-up, agriculture, orchard, grassland, bamboo forest, bamboo-mixed forest, riverbed, barren land, snow, wild banana, riverine forest and mixed forest. The LULC classification scheme adopted during this study is described in (Fig. 2 and Table 1).

The maximum likelihood classification technique was used to classify the image pixels into LULC categories using ArcGIS 10.3 (ESRI, Redlands, CA, USA). The classification error in the images was corrected by comparing the classified image to the corresponding satellite image and cleaned by recoding the misclassified or overlapped class to the correct class [37].

### 2.3. Accuracy assessment

The accuracy assessment is an important step in the classification process. The accuracy evaluation objective is to determine how well pixels were assigned to the relevant LULC classes in a quantitative form. The overall accuracy of the classified image is determined by comparing how each pixel is classified to the definite LULC classes based on the ground truth points. The producer’s accuracy (Eq. (1)) measures how well the actual class of LULC can be classified depending on errors of omission. The probability of a classified pixel identical with the LULC form of its respective real class position is measured by the user’s accuracy (Eq. (2)), which is expressed as errors of commission. We also estimated the commission errors (Eq. (3)) or Type I error, which indicates the probability that a pixel assigned to one class belongs to a different class. The omission errors (Eq. (4)), or Type II error, indicates locations in a classified map that were not allocated to the correct class.

In the classified image, 104 random points for LULC validation were generated, and from each LULC class, eight validation points were selected. The classifications of the associated points in the classified images were validated on the ground-truthing points and Google Earth for accuracy assessment.

The accuracy assessment was estimated following Jenness and Wynne [38]. The confusion matrix’s columns indicate the assigned class, while the row shows the actual class in the image. The pixels that are correctly classified are shown on the diagonal. Pixels not allocated to the appropriate class do not appear in the diagonal, suggesting that the class assignment between the different LULC classes is misclassified [38].

Furthermore, overall accuracy (Eq. (5)) was computed based on the formulation, as shown below:

$$\text{Producer's accuracy} = 1 - \text{Omission Error} \tag{1}$$

$$\text{User's Accuracy} = 1 - \text{Commission error} \tag{2}$$

$$\text{Commission error} = \frac{\text{Sum of the incorrect classified sites in rows}}{\text{Total number of classified sites}} \tag{3}$$

$$\text{Omission error} = \frac{\text{Sum of the incorrect classified sites in columns}}{\text{Total number of classified sites}} \tag{4}$$

$$\text{Overall accuracy} = \frac{\text{Sum of correctly classified sites}}{\text{Total number of reference site}} \tag{5}$$

KAPPA analysis is a discrete multivariate method for evaluating the LULC classification accuracy [39]. The Khat statistic (a KAPPA estimate) is a measure of consensus or accuracy derived from KAPPA analysis [40–42]. The Khat statistic (Eq. (6)) was calculated following:

$$K = \frac{N \sum_{i=1}^r x_{ii} - \sum_{i=1}^r (x_{i+} * Xx_{+i})}{N^2 - \sum_{i=1}^r (x_{ii} * Xx_{+i})} \tag{6}$$

where; N = total number of observations (pixels), r = number of rows in matrix,  $x_{ii}$  = observation in row i and column i,  $x_{i+}$  = marginal total of row i, and  $x_{+i}$  = marginal total of column i.5).

A Kappa coefficient of 100% depicts perfect agreement between the reference image and the classified image. At the same time, a value near or equal to zero indicates no agreement between the reference image and the classified image. Overall accuracy above 85% is considered reliable for LULC [43], while the Kappa coefficient should be more significant than 80% [44].

### 2.4. Identification of preferred habitats

Habitat preference refers to the relative use of different habitats by species within the entire classified forest. Preferred habitats for other wildlife species were identified using the camera trap and sign survey data (see section “2.2 Satellite image and land use land cover classification”). To determine the preferred habitat for a species, we first calculated the percentage of use for all the vegetation types where the species were observed by dividing the number of occurrences in a particular classified vegetation type by the total number of events of the species in the study area. Thus, higher percentage values represent habitat preference for that specific classified vegetation type by the given species.

We used relative habitat use to calculate habitat preference as an indicator of Ivlev’s electivity index [45–47]. The index was calculated as  $s = (a - b)/(a + b)$ , where “a” is the percentage of particular species using a given habitat and “b” is the habitat area as a percentage of the total available habitat area [48]. For each habitat, we obtained an electivity value ranging from –1.0 (never used) to

+1.0 (exclusively used), with 0.0 representing the habitat used in proportion to its availability [45]. Thus, positive and negative electivity values represent habitat preference and avoidance, respectively.

To understand how the mammal community assemblages differ between the different habitat types, we did non-metric multidimensional scaling (NMDS) analysis on Bray-Curtis distances. The variation in mammal communities among different LULC was compared using NMDS based on the Bray–Curtis dissimilarity index using the ‘metaMDS’ function in library *vegan* [49] in R (version 4.1.1; R Core Development Team, 2020).

### 3. Results

The land use land cover map based on Sentinel-2A satellite data for the Mehao wildlife sanctuary was developed with thirteen classes, namely, water, built-up, agriculture, orchard, grassland, bamboo forest, bamboo-mixed forest, riverbed, barren land, snow, wild banana, riverine forest and mixed forest for the winter season of 2020. Fig. 3 shows the LULC map based on the result from the supervised classification, and the area and proportion of each LULC class are summarized in Table 2. Mixed forest is the most significant class, dominating around 70% of the study area, followed by wild banana forest (7.2%), barren land (6.09%) and riverine forest (4.59%). Agriculture occupies only 0.94% of the study area.

#### 3.1. Accuracy assessment

The relationship between the LULC classes and the random points derived from the confusion matrix (error matrix) and various

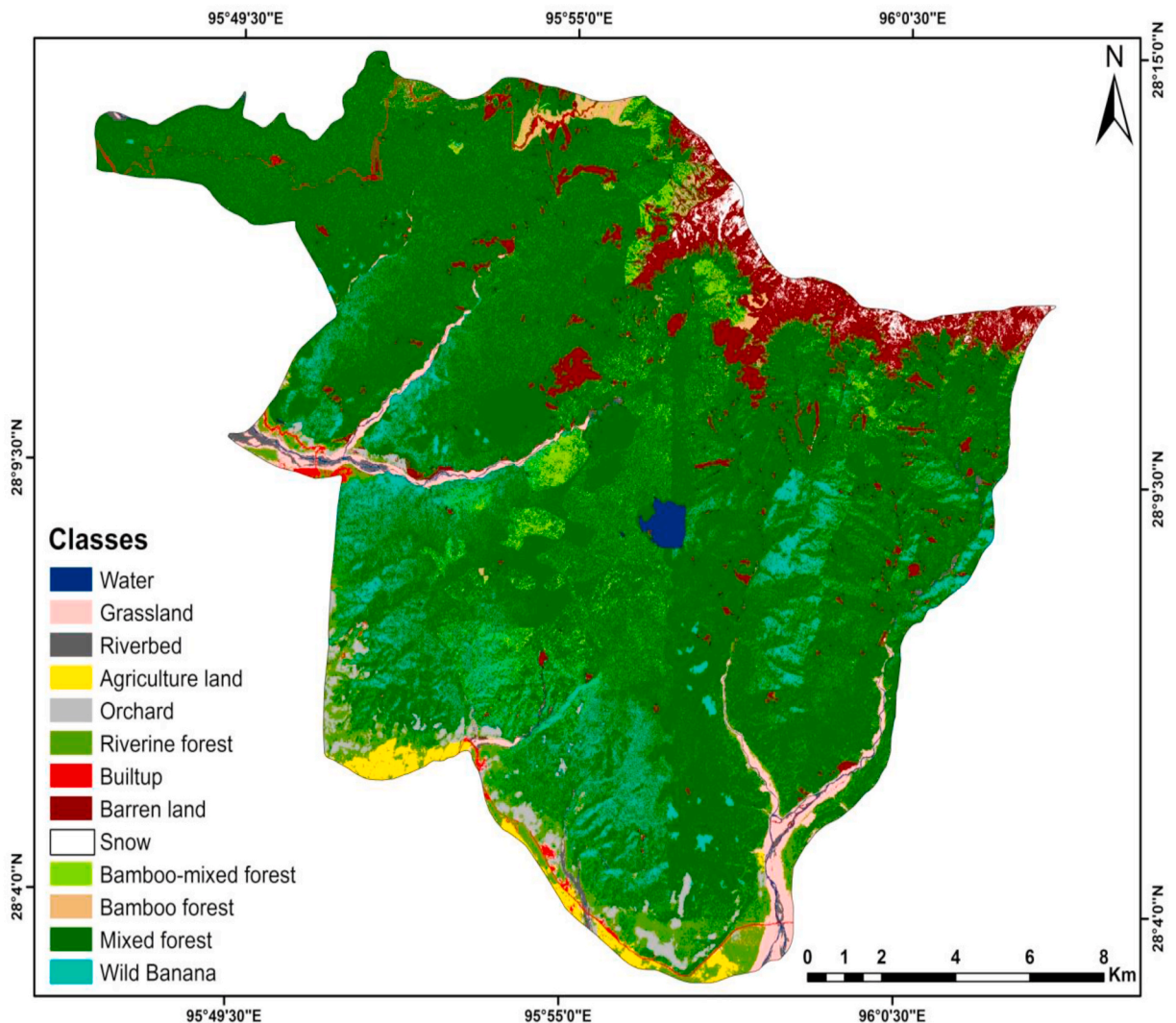


Fig. 3. Land use and land cover classified map of the study area.

**Table 2**  
Classified area under different LULC classes in the study area.

Classes	Area (sqkm)	Area cover (%)
Water	1.69	0.57
Grassland	5.49	1.85
Riverbed	2.06	0.69
Agriculture	2.81	0.94
Orchard	4.47	1.50
Riverine forest	13.66	4.59
Built up	1.42	0.48
Barren land	18.12	6.09
Snow	1.92	0.65
Bamboo-mixed forest	12.46	4.19
Bamboo forest	3.78	1.27
Mixed forest	208.42	69.99
Wild Banana	21.44	7.20

estimated accuracy parameters are summarized in Table 3. The LULC map had an overall accuracy of 88.46% and a Kappa coefficient of 87.5%. The producer accuracy varied from 63.63% to 100%, and the user accuracy ranged from 50% to 100%. The commission error was high in riverbed and agriculture areas (0.5), and the omission error was high in the bamboo forest (0.5).

### 3.2. Habitat use and preference

In total, we recorded 27 species of mammals during the camera trap survey in Mehao WLS. 14 of the 27 recorded species are listed in the threatened category of the IUCN red list, with two being endangered, nine being vulnerable, and three are near threatened [50], (Supplimentary.1). Mixed forest supported a high number of mammal species, followed by riverine and bamboo mixed forests (Fig. 4; Supplimentary.1). Barking deer, serow, leopard cat, Asian wild dog, yellow-throated marten, and wild boar were most frequently observed in these vegetation types. The NMDS result showed two distinct groups of LULC classes, separating forest and non-forest areas in the sanctuary (Fig. 5). Forested habitats (i.e., mixed forest, riverine forest, bamboo forest, grassland and bamboo mixed forest) was majorly preferred by all the species (Fig. 5).

Human-modified land-use types (i.e., orchard and agriculture) were preferred by a Himalayan striped squirrel and yellow-throated marten (positive selection). At the same time, wild pig showed avoidance of these habitats (negative selection). Although high numbers of mammal species were found in the mixed forest, Ivlev's electivity index showed that species, in general, showed avoidance of this forest type (Fig. 6D). In contrast, the majority of the mammal species showed a preference for specialized vegetation types, such as bamboo forest, bamboo mixed forest, grassland, riverbed and riverine forest (Fig. 6A, B, 6C, 6E).

## 4. Discussion

The growing human population's dependence on forest resources and the unbridled habitat destruction poses a significant threat to wildlife [51–53]. Understanding the LULC pattern can help determine the past, present, and predict the future distribution of species and their habitat relationship within an ecosystem [54,55]. Habitat provides food, shelter, cover, water, and space, among the few fundamental necessities critical for the survival of animals. Several studies conducted on vertebrate fauna, such as birds [56,57] and mammals [58], suggest that species diversity increases with habitat heterogeneity (presence of many different habitats) and the amount of available habitat [59,60]. Mapping important wildlife habitats in Mehao WLS provides an essential baseline for understanding the species distribution and planning their conservation.

The mixed forest, which covers a large area of the Mehao WLS, is an assortment of tree species like *Ailanthus grandis*, *Betula alnoides*, *Duabanga grandiflora*, *Michelia champaca*, *Terminalia myriocarpa*, *Phoebe cooperiana*, *Quercus semecarpifolia*, *Castanopsis indica*, *Cyathea* spp. It serves as a suitable habitat for mammalian species like Muntac and Sambar, which prefer dense mixed forests for food and conceal themselves from predators or avoids human presence [61–64]. Clouded Leopard, Marbled Cat, Leopard Cat, Asian Golden Cat, Asiatic Wild Dog and Spotted Linsang are nocturnal carnivores at the lower elevation of the sanctuary where this mixed forest habitat provides good cover at the time of hunting. Mainland Serow mainly prefers mixed forests with extensive shrub cover, which includes food (leaves and shoots), protection against predators and inclement weather [64,65]. Eastern Hoolock Gibbon and Black Giant squirrel prefers mostly closed canopy mixed forest habitats with common food tree species like *Terminalia myriocarpa*, *Anthocephalus kadamba*, *Ailanthus itegrifolia*, *Bombax ceiba*, *Duabanga grandiflora*, *Michelia champaca*, *Ficus* spp., *Bischofia javanica*, *Shorea assamica* etc. [66–70] which shows an effective seed disperser by feeding on their leaves and fruits of these trees. Asiatic Black Bear is an omnivore and utilizes mixed forest habitat efficiently by feeding on plant species like *Mesua ferrea*, *Dysoxylum* spp., *Ficus* spp., *Rubus* spp., *Mikania scandens*, *Quercus* spp., etc. and feed on freshly sprouted grass, herbs and insects on the floor of the forest [71–73]. Avifaunal species like Wreathed Hornbill, Rufous-necked Hornbill are known to disperse seed which feeds mainly on fruits of tree species like *Canarium strictum*, *Ficus* spp., *Phoebe cooperiana*, *Dysoxylum* etc., and *Terminalia myriocarpa*, *Duabanga grandiflora*, *Dipterocarpus macrocarpus* are important hornbill nesting trees [74,75].

The wild Banana Forest provides suitable habitat for species like Wild Pig, Northern red muntjac, Brush-tailed Porcupine and Malayan Porcupine. They mainly feed on the soft inner core of pseudostem of *Musa* spp. (pers. obs.). Bamboo and Bamboo-mixed

**Table 3**  
Confusion matrix table of LULC classification and category-wise accuracy assessment.

	Water	Grassland	Riverbed	Agriculture	Orchard	Riverineforest	Settlement	Barren	Snow	Bamboomixed	Bambooforest	Mixedforest	WildBanana	Total(User)	CommissionError	UserAccuracy(%)
Water	2	0	1	0	0	0	0	0	0	0	0	0	0	3	0.33	66.66
Grassland	0	5	0	0	0	0	0	0	0	0	0	0	0	5	0	100
River bed	0	1	3	0	0	0	0	0	0	0	0	0	0	4	0.5	75
Agriculture	0	0	0	3	1	0	0	0	0	0	0	0	0	4	0.5	75
Orchard	0	0	0	0	6	0	0	0	0	0	0	0	0	6	0	100
Riverine forest	0	0	0	0	1	8	0	0	0	0	0	0	0	9	0.11	88.88
Settlement	0	0	0	1	0	0	3	0	0	0	0	0	0	4	0.25	75
Barren	0	0	0	0	0	0	0	11	0	0	0	0	0	11	0	100
Snow	0	0	0	0	0	0	0	0	4	0	0	0	0	4	0	100
Bamboo mixed	0	0	0	0	0	0	0	0	0	8	1	0	0	9	0.22	88.88
Bamboo forest	0	0	0	0	0	0	0	0	0	1	3	0	0	4	0.25	75
Mixed forest	0	0	0	0	0	1	0	0	0	1	2	24	0	28	0.14	85.71
Wild Banana	0	0	0	0	0	0	0	0	0	0	0	1	12	13	0.15	92.30
Total (Producer)	2	6	4	4	8	9	3	11	4	10	6	25	12	<b>104</b>		
Omission Error	0	0.16	0.25	0.25	0.25	0.11	0	0	0	0.2	0.5	0.04	0			
Producer Accuracy	100	83.33	75	75	75	88.88	100	100	100	80	50	96	100			

Overall accuracy assessment (%) = 88.46%, Kappa coefficient (%) = 86.86%.

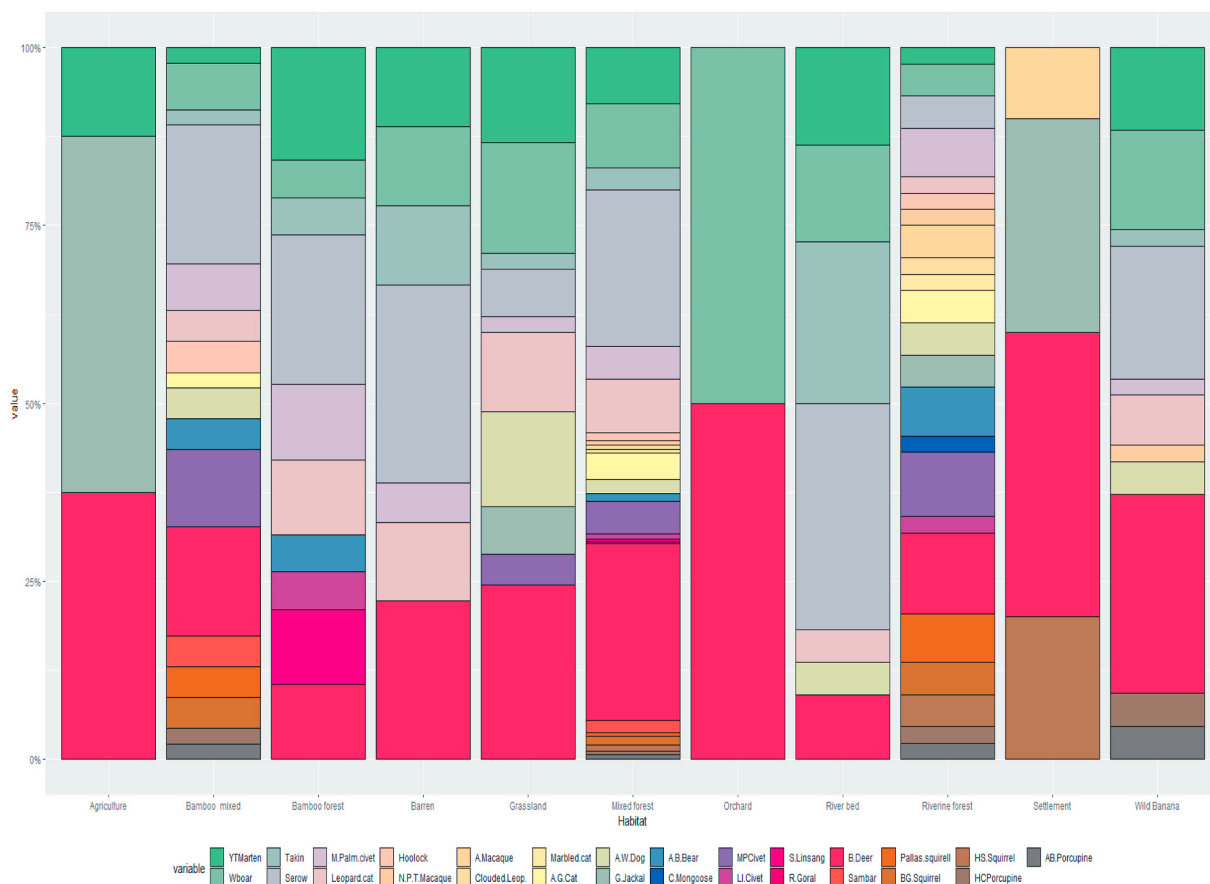


Fig. 4. Proportional abundance of mammals in different classified habitat.

Forest which comprises plant species like *Bambusa pallida*, *Dendrocalamus hamiltonii*, *Melocanna baccifera*, *Pinus roxburgii*, *Quercus griffithii*, *Rhododendron* spp., are suitable home for Mismi Takin, Mainland Serow, Barking deer, Himalayan palm civet and birds like Kalij Pheasant, Rufous-throated Partridge, etc. [76–78]. Riverine forest is dominated by tree species like *Bombax ceiba*, *Cassia fistula*, *Albizia lebbeck*, *Alstonia scholaris*, *Ficus hispida*, *Cyathea* spp., *Angiopteris evecta*, etc., along with available water sources may provide suitable habitat for species like Crab-eating mongoose, Northern red muntjac, Large Indian Civet, Yellow-throated marten [79–81], and avian species like White-capped Redstart, Spotted Forktail, White Wagtail, etc. [82].

Grassland, which is present at the lowest part of the sanctuary around the bed of the river with dominant grass species like *Imperata cylindrical*, *Phragmites karka*, *Saccharum arundinaceum*, *Setaria glauca*, etc. is supporting species like Asiatic Wild Dog, Indian Jackal, Indian Hare, Himalayan Palm Civet, Northern red muntjac, etc. [83–86] and avifaunal species like Black-breasted Parrotbill, Ashy Prinia, Bengal florican, etc. [87–89]. Riverbeds are often used as egg and seed banks for aquatic invertebrates, birds, and plants [90, 91]. Reptiles bask in this area and seek shelter in damp depressions, leaf litter, woody debris, and crevices under rocks when they sense danger [92]. Birds like White-capped redstart, White-throated Kingfisher, etc., also use this habitat for hunting fish or resting on the riverbed's rocks. (Perso. Obs.)

Cultivation for agriculture and orchards have been practiced inside or on the fringes of the sanctuary which may create negative human-wildlife interaction. Majorly grown crops like rice, maize, tea, orange, and vegetables are eaten by wild species like Wild pig [93–96]. Wild animals generally avoid built-up areas like Northern red muntjac, Mainland Serow [97] and Sambar [61,62]. However, Golden Jackal shows close affinity with human habitation [95,98,99].

Accuracy assessment compares the classified data to the reference data [38,100]. The Kappa coefficient is a measure of agreement or precision used to determine whether a LULC map developed by remotely sensed data is significantly better than a randomly assigned map [101]. The classification accuracy was 88.46%, and the Kappa coefficient was 87.5%, which means that land use classification accuracy is appropriate and acceptable for usage [43].

## 5. Conclusion

This study used remote sensing data and spatial techniques to generate thematic maps that provide updated information on LULC that can help monitor and sustain natural resources. The LULC-supervised classification was precise, with an overall accuracy of

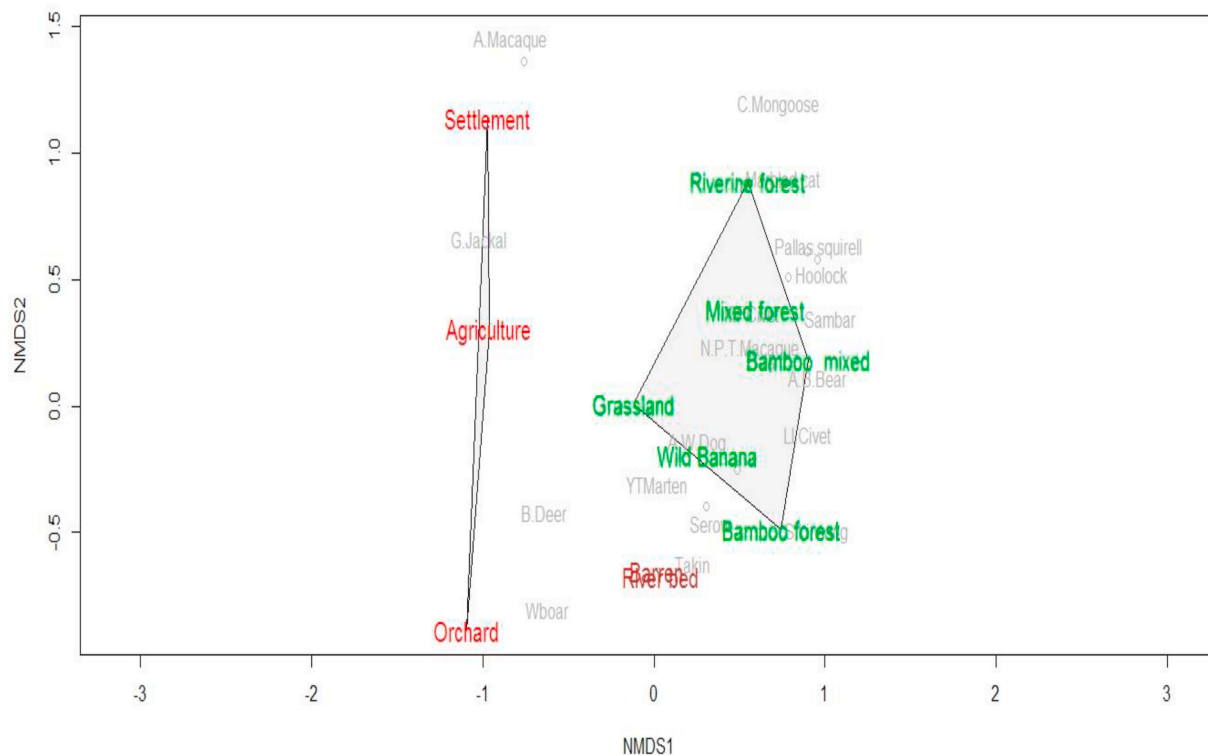


Fig. 5. NMDS plot showing mammalian community composition in different classified habitat.

88.46% and a Kappa coefficient of 87.5%, suggesting that the classified image was appropriate for further analysis. The spatial knowledge of the Mehao WLS is essential for developing an efficient management and conservation plan. The various habitats in Mehao WLS are necessary for different wildlife species categorized under the IUCN Red List of Threatened Species and Schedule species of the Indian Wildlife (Protection) Act-1972. As a result, the current data is a preliminary step for assessing critical wildlife habitats in the Mehao WLS. This will assist in implementing Sanctuary management policies that are more rational for protecting biodiversity. The outcome of this study can be further used for advanced spatial analysis and modelling.

#### Ethical statement

The author declares that all ethical practices have been followed in relation to the article's development, writing, and publication as per journal requirements.

#### Author contribution statement

Arif Ahmad: Performed the experiments; Analyzed and interpreted the data; Contributed, materials, analysis tools or data; Wrote the paper.

Dr Gopi GV: Conceived and designed the experiments; Contributed, materials, analysis tools or data.

Rajapandian Kanagraj: Contributed, materials, analysis tools or data.

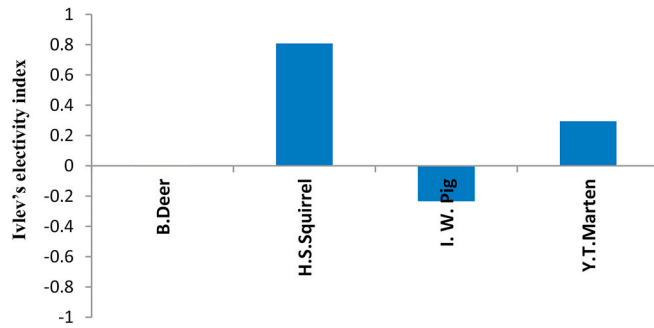
#### Funding statement

This work was supported by the Department of Science and Technology (DST) and Science Engineering Research Board (SERB), Government of India.

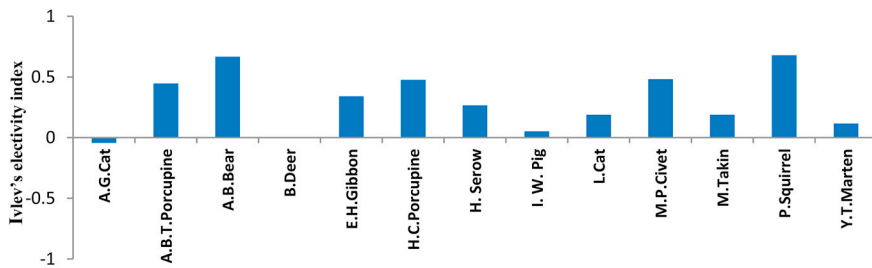
#### Data availability statement

Data included in article/supplementary material/referenced in article.

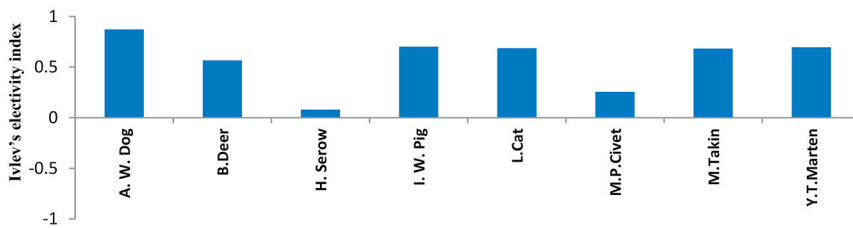
**A. Agriculture and Orchard**



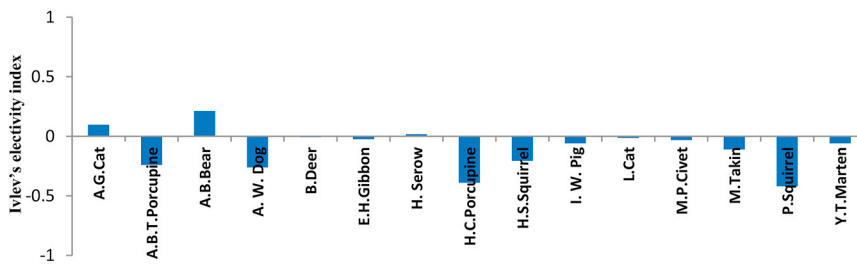
**B. Bamboo forest and Bamboo-mixed forest**



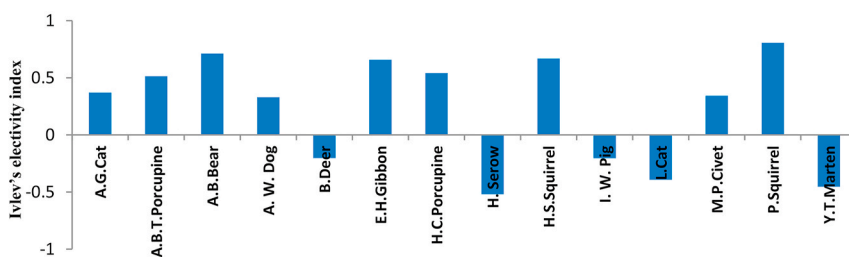
**C. Grassland**



**D. Mixed forest**



**E. Riverine forest**



**Fig. 6.** Habitat preferences of mammalian species in different classified habitat of Sanctuary.

## Declaration of interest's statement

The authors declare no conflict of interest.

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## Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.heliyon.2023.e13799>.

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## List of Conferences

1. Participated in International conference on “British Ecological Society Annual Meeting: 18-21 December 2022” held in Scotland and produced an online ORAL presentation titled: Influence of ecological and anthropogenic factors on the occupancy of mammalian fauna in Eastern Himalayan tropical forest.
2. Participated in National conference on “Biodiversity Conservation and Natural Resource Management” held in Dev Sanskriti Vishwavidyalaya, Haridwar and presented a paper on the topic “Wildlife habitat mapping using Sentinel 2A imagery in tropical forest of Mehao WLS, Arunachal Pradesh”

**BES Annual Meeting:  
18 - 21 December 2022 (Online)**

This certificate confirms that

**ARIF AHMAD**

Attended BES2022 online and produced an online  
**ORAL** presentation titled:

*Influence of ecological and anthropogenic factors on  
the occupancy of mammalian fauna in Eastern  
Himalayan tropical forest.*

Rachel Kudlick



Events Manager  
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# DEV SANSKRITI VISHWAVIDYALAYA, HARIDWAR

Reg. No. *NC/48*.....



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## National Conference

ON

### “BIODIVERSITY CONSERVATION AND NATURAL RESOURCE MANAGEMENT”

(28 February, 2021)

This is to certify that Prof. / Dr. / Mr. / Ms. *ARIF AHMAD*.....

From.....

Participated in National Conference organized by Department of Environmental Science, Dev Sanskriti Vishwavidyalaya, Haridwar and delivered an invited lecture/presented a paper/ poster on the topic entitled *“Wildlife habitat mapping using Sentinel-2A imagery in tropical forest of Mehao wis, Anabakhil Pradent”*..... on 28 February, 2021 at Haridwar, Uttarakhand.

(Dr. Chinmay Pandya)  
Pro-Vice Chancellor  
(DSVV, Haridwar)

(Dr. Sudhanshu Kaushik)  
Organizing Secretary

(Dr. Vijay Sharma)  
Co-ordinator  
Department of Environmental Science  
D.S.V.V., Haridwar