MANIPAL
ACADEMY of HIGHER EDUCATION
(Deemed to be University under Section 3 of the UGC Act, 1956)

INSPIRED BY LIFE

Ecology of elephants (*Elephas maximus*) and their interactions with humans in south West Bengal, India.

THESIS TO BE SUBMITTED TO
MANIPAL ACADEMY OF HIGHER EDUCATION

FOR FULFILLMENT OF THE REQUIREMENT FOR THE AWARD OF THE DEGREE
OF

DOCTOR OF PHILOSOPHY
BY

AAKRITI SINGH
Reg. No. 179000020

UNDER THE GUIDANCE OF

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Principal Scientist
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Tamil Nadu, India

SÁLIM ALI CENTRE FOR ORNITHOLOGY AND NATURAL HISTORY (SACON)

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The work has not been submitted for the award of any other degree/diploma of the same University / Institution where the work was carried out, or to any other University / Institution.

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DECLARATION BY THE CANDIDATE

I declare that this thesis, submitted for the degree of Doctor of Philosophy to Manipal Academy of Higher Education, is my original work, conducted under the supervision of my guide **Dr. H. N. Kumara**. I also wish to inform that no part of the research has been submitted for a degree or examination at any university. References, help and material obtained from other sources have been duly acknowledged

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CERTIFICATE

This is to certify that the work incorporated in this thesis "**Ecology of elephants (*Elephas maximus*) and their interactions with humans in south West Bengal, India.**" submitted by **Ms. Aakriti Singh** was carried out under my supervision. No part of this thesis has been submitted for a degree or examination at any university. References, help and material obtained from other sources have been duly acknowledged.

Research Guide

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This has been a journey, a long journey from when I started. There have been many ups and downs in this journey and I am really thankful to a lot of people. People who have made this journey possible and memorable. I wish I could take back all my failures that I had during this journey but I won't because those minor hurdles have made me what I am today and helped me meet some wonderful people on the way. So, here I am to express my gratitude to all those who have been a part of my journey and take a trip down the memory lane.

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Thank you

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Contents

The thesis delves into the intricate dynamics surrounding the range expansion of Asian elephants in South West Bengal, catalyzing heightened human-elephant conflicts. It meticulously outlines the evolution of this phenomenon, starting from the elephants' modest presence in the 1950s to their expansive spread across 13200 km² by 2010–18. Through structured surveys and field observations, the elephants' footprint has been delineated across 163 grid cells in the region, showcasing their adaptability to varied habitat conditions.

Central to understanding this expansion is the interplay between habitat factors and elephant presence. The thesis elucidates how the elephants' utilization of grid cells correlates positively with the forest edge, forest area, agricultural area, and barren land. As forests recede and agricultural land expands, elephants find themselves increasingly encroaching upon human settlements, leading to heightened conflict situations.

Population estimation methodologies, ranging from dung count surveys to distance sampling, shed light on the elephant demographic in the region. However, the thesis highlights the challenges inherent in accurately gauging elephant numbers, particularly in areas where human activities disrupt their natural movement patterns. Despite these hurdles, the presence of a substantial number of immature elephants signifies a thriving population, albeit one grappling with human-induced disturbances.

The thesis also sheds light to the ecological intricacies of elephant habitat use and feeding behavior. By overlaying grid cells on selected elephant habitats and analyzing geo-coordinates, the intensity of elephant habitat utilization was ascertained. The elephants' dietary preferences, encompassing a diverse array of wild plant species alongside agricultural crops, underscore their adaptive prowess in navigating human-altered landscapes. However, this dietary reliance on crops exacerbates conflicts, as elephants frequently venture into agricultural fields, triggering retaliatory measures from local communities.

Moreover, the thesis underscores the profound impact of human activities on elephant movement patterns. Hula drives and local interventions aimed at curbing crop depredation drastically alter elephants' natural movement trajectories, perpetuating a cycle of conflict and agitation. The nocturnal forays of elephants into agricultural fields underscore their strategic adaptation to minimize human interactions during daylight hours, further complicating conflict mitigation efforts.

Against this backdrop of escalating human-elephant conflicts, the thesis delineates the staggering toll exacted on both human and elephant populations. Between 2010 and 2018, the region witnessed 640 recorded elephant attacks on humans, resulting in 268 fatalities and 372 injuries. The fluctuating incidence of attacks underscores the volatile nature of human-elephant interactions, with factors like habitat availability and seasonal crop cycles exerting profound influences.

Notably, the thesis also illuminates the gendered dynamics of human casualties, with men bearing a disproportionate brunt of elephant attacks. The temporal distribution of human fatalities underscores the diurnal and seasonal variations in conflict intensity, with early morning hours and the months preceding the monsoon witnessing heightened conflict activity. Furthermore, the thesis unveils the spatial distribution of attacks, with a majority occurring in non-forested areas, highlighting the pervasive nature of conflicts across diverse landscapes.

Amidst this confluence of ecological and anthropogenic factors, the thesis elucidates the multifaceted drivers underpinning retaliatory killings of elephants. From poisoning to electrocution, elephants face myriad threats emanating from human interventions, exacerbating conflict dynamics. This retaliatory violence, driven by economic losses and perceived threats to livelihoods, perpetuates a vicious cycle of human-elephant conflicts, underscoring the urgent need for holistic mitigation strategies.

In light of these challenges, the thesis advocates for concerted efforts towards elephant management and conflict resolution. Large-scale awareness campaigns targeting farmers and local communities emerge as pivotal interventions to foster coexistence. Concurrently, forest restoration initiatives aimed at replenishing native flora and enhancing elephant habitat viability offer a long-term solution to mitigate conflicts. Moreover, proactive measures by the forest department, coupled with community engagement, are essential to engendering trust and cooperation among stakeholders.

In essence, the thesis elucidates the intricate interplay between ecological dynamics and human activities in shaping the trajectory of human-elephant conflicts in South West Bengal. By unraveling the complexities of elephant habitat use, dietary preferences, and conflict patterns, it underscores the imperative of adopting a holistic approach towards elephant management and conservation. Only through concerted efforts encompassing ecological restoration, community engagement, and conflict mitigation strategies can a sustainable balance be struck between human development and wildlife conservation in the region.

Chapter 1
Introduction

1.1 General Overview

The presence of elephants in South West Bengal dates back to early 1900, where large elephant herds were reported in dense sal forests of West Medinipur and adjoining areas during the colonial period (O'Malley, 1911). In consecutive years, elephants probably disappeared from the landscape due to the loss of forests in South West Bengal (Palit, 1991). By 1955 when private forests were transferred to the forest department, barely any resident wild elephants were known to be present in the region (Palit, 1991). Later on, until the mid-1980s elephants got were limited only to the border areas of West Bengal and Bihar with a few individuals scattered in Ajodhya hill, Bandawan, Banspahari and Ranibandh area (Chatterjee, 2016). However, in the late 80s as vast areas of these degraded forests regenerated through Joint Forest Management (JFM) (Malhotra and Poeffenberger, 1989), the elephants started getting attracted into the area (Palit, 1991; Malhotra, 1995; Panda, 1996). In addition, land mining in Singhbhum district of Jharkhand adjoining Dalma Wildlife Sanctuary that led to severe disturbances in the once flourishing forests (Singh and Chowdhury, 1999) probably forced the elephants to move out towards forests of Mayurjharna in South West Bengal. Herds from Dalma Wildlife Sanctuary started moving in the months between October and December attracted by the paddy crop fields, but they were restricted to the west of Kangsabati River (Dey, 1991). Shahi (1980) reports the visit of 42 elephants in 1976 into Purulia District from Dalma to Sindri, wherein they stayed for 20 days and damaged paddy fields killing two people. He also reported elephant movement through Banspahari and Belpahari region in the month of September and some incidences of crop damage in West Medinipur during the same time. The first long-distance movement by elephants from Dalma Wildlife Sanctuary to East Medinipur district beyond the Kangsabati river was recorded in the year 1987 (Dey, 1991; Datye and Bhagwat, 1995). According to the study by Dey (1991), 50 elephants from Motgoda range of Bankura district crossed the river Kangsabati in 1987 and moved southward to enter the Lalgarh Range of East Midnapore Forest Division. This movement of elephants in successive years continued and expanded to the east, exploring new areas, which resulted in prolonged stays of elephants in south-West Bengal. This increased extent of stay has led to increased interactions between humans and elephants.

This study arose from the need to understand the way the elephants move and expanded their range in this landscape, and how their movement has affected the humans in this agricultural landscape. I conducted a study on the range expansion, feeding habits, and the human- elephant interactions for my thesis, which helps in understanding the species in this landscape where they have never been studied earlier.

1. 2 Study Site

The South Bengal lies between 85°30'– 88°30' E and 22°0' – 24°0'N which includes administrative districts, i.e., Purulia, Bankura, Jhargram, Birbhum, Paschim Medinipur, Paschim Bardhaman, and Purba Bardhaman. These districts include 13 forest divisions, i.e., Rupnarayan, Purulia, Panchet, Medinipur, Kharagpur, Kangsabati South, Kangsabati North, Jhargram, Durgapur, Burdwan, Birbhum, Bankura North, and Bankura South, with an area of 37091.24 km^2 (Fig. 1.1). The study area is bounded by the state of Jharkhand on the north-west, Hooghly, Howrah, and Purba Medinipur districts of West Bengal on the east, and the state of Odisha on the south (Mondal, 2017). The western part of the study area is hilly and undulating, being an extension of the Chota-Nagpur plateau, while the eastern part consists of flat Gangetic plains, and it varies in altitude from 200 m to 670 m asl. The study area is having four major river systems *viz*., Subarnarekha, Kangsabati, Silabati, and Darakeswar, and a few small rivers e.g., Kumari, Totko, Tarafeni, Tamal, and Kubai. The canal networks of the Kangsabati dam in Bankura district are a major source of irrigation in the region (Singh *et al*., 2002).

Topography and Soil: The topography of the landscape is gently undulating, with small hills on the western side and a stretch of flatlands towards the east, and it varies in altitude from 200 m to 670 m. Contour spacing reveals that the eastern elevation is still gentler. Elevation becomes prominent as it approaches Chotanagpur plateau. The Ajodhya hill is the highest peak reaching an altitude of 670 m. The second highest peak is Lakaisini Pahar, which reaches an altitude ca. 500 m and is located westward on the Jharkhand -Bengal border. The soil is the red, sandy, lateritic, and alluvial type with red and black soils in a few pockets.

Hydrology: There are four major river systems in the area under study *viz*., Subarnarekha, Kangsabati, Silabati, and Darakeswar. However, there are a few minor rivers and perennial streams e.g., Kumari, Totko, Tarafeni, Tamal, and Kubai. The region also has numerous man-made water bodies and ponds in the villages. The canal networks of the Kangsabati dam at Mukutmanipur in Bankura district is a major source of irrigation in the region (Singh *et al.*, 2002)

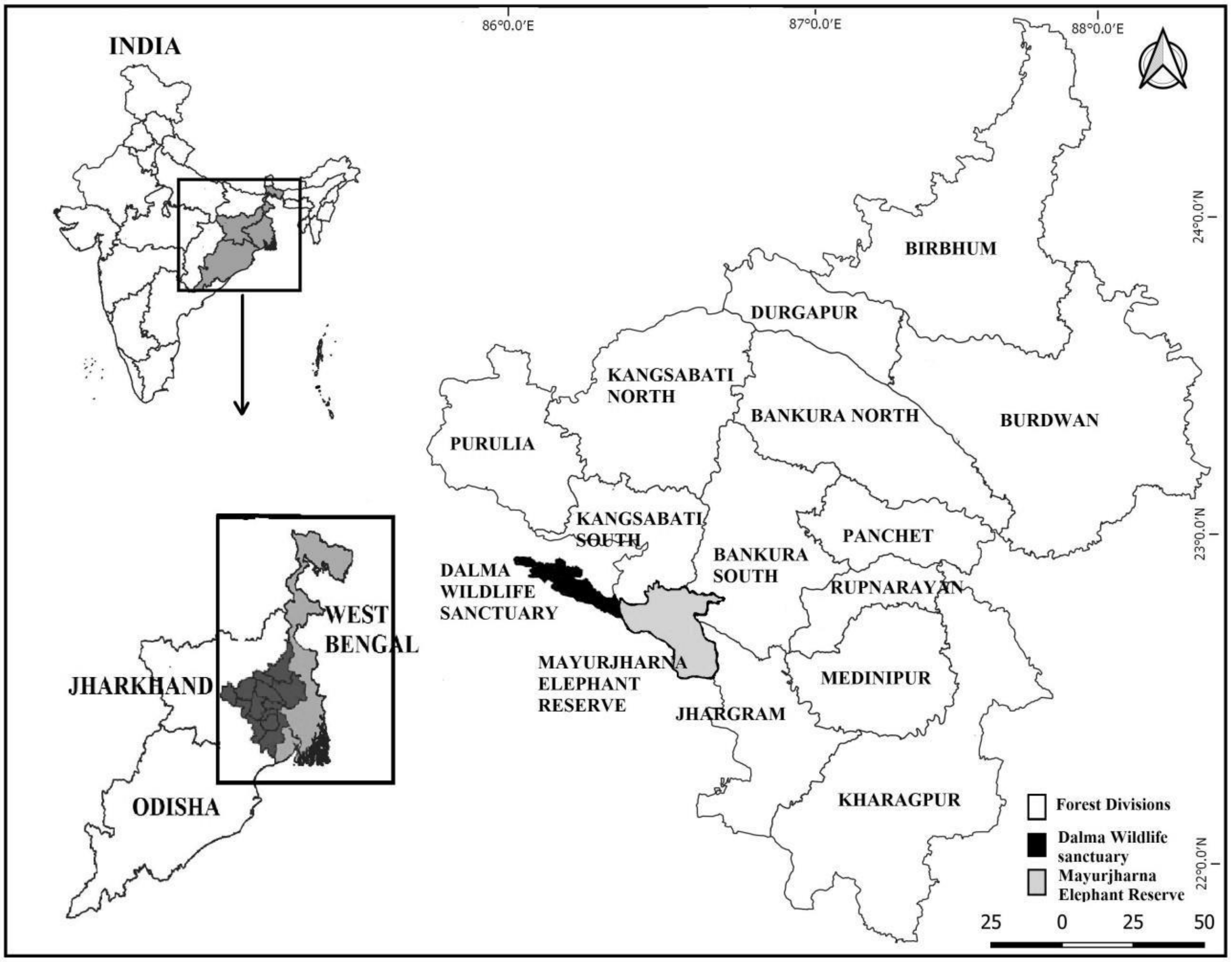

Figure 1.1 The South West Bengal with Mayurjharna Elephant Reserve the study site

Climate: There are three distinct seasons i.e., summer, monsoon, and winter. The summer is extreme and lasts from the middle of March to the middle of June with April, May, and June being the hottest months. The maximum temperature fluctuates between 42˚C and 46˚C and the minimum temperature varies between 8˚C and 13˚C. The monsoon period is from mid-June to end of the September with moderate rainfall. The average annual rainfall varies in the region with 1428 mm in Midnapore, 1271 mm in Bankura and 1180 mm in Purulia (Ghosh, 1992). The rainfall decreases from October onwards and dry winter sets in that lasts from November to February.

Vegetation: The general vegetation type is tropical dry deciduous dominated by sal *(Shorea robusta)*. According to Champion and Seth, (1968), the forests belong to category 5B of group 5 and are represented by types C1/1C, C2, DS1, E5, E7, and 2S1. Based on composition, the forest types can be divided into four broad categories i.e., sal-coppice, open scrub forests with sporadic sal and thorny bushes and plantations. The composition of forests varies from 82% sal in the western hilly tract to 95 % sal in the eastern undulating plains (Forest Survey of India, 1985). Many associate species found here include *Pterocarpus marsupium, Diospyros melanoxylon, Madhuka latifolia, Schleichera trijuga, Adina cordifolia, Terminalia tomentosa, Terminalia belerica, Soymida febrifuga, Anogeissus latifolia* (Santra *et al*., 2008).

People: The number of villages in Bankura is 3585, 2242 in Birbhum, 7600 in Paschim Medinipur, 2459 in Purulia, and 7024 in Bardhman district. Some part of the landscape is inhabited mostly by Santal, Lodha, Sabar, Kheria tribes, intermixed with local Bengali people as well as migrants from Odisha, Jharkhand, and Bihar. These districts are densely populated with 523 people/ km^2 in Bankura, 771 in Birbhum, 631 in Medinipur, 468 in Purulia and 1100 in Bardhman Districts (Chandramouli and General, 2011). Some of the villages practice farming almost throughout the year with the help of irrigation facilities; however, most of the areas still grow one crop in a year during monsoon. The major crops grown in the landscape is paddy, and some vegetables such as brinjal, bitter gourd, and potato.

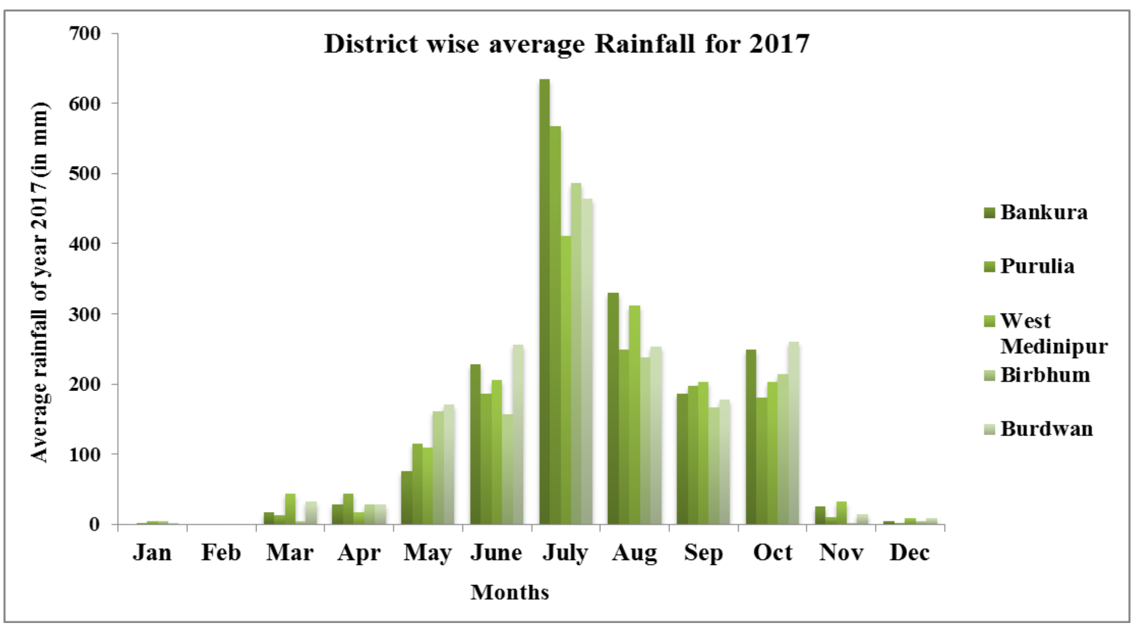

Figure 1.3 Average rainfall in different districts of South Bengal (data of the year 2017)

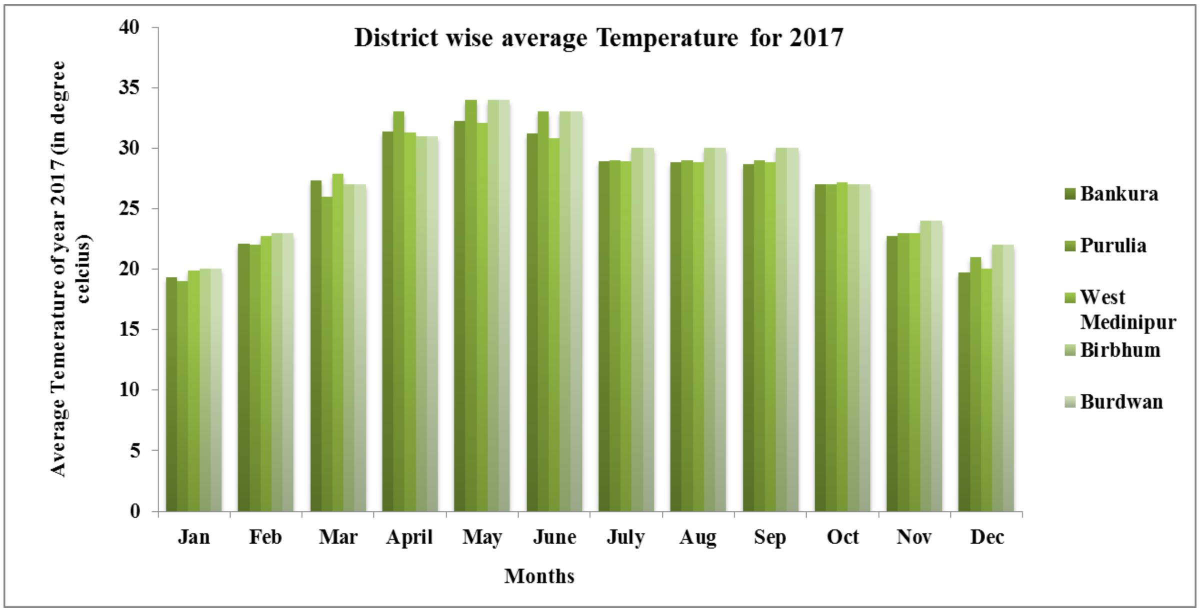

Figure 1.4 Average temperatures in different districts of South Bengal (data of the year 2017)

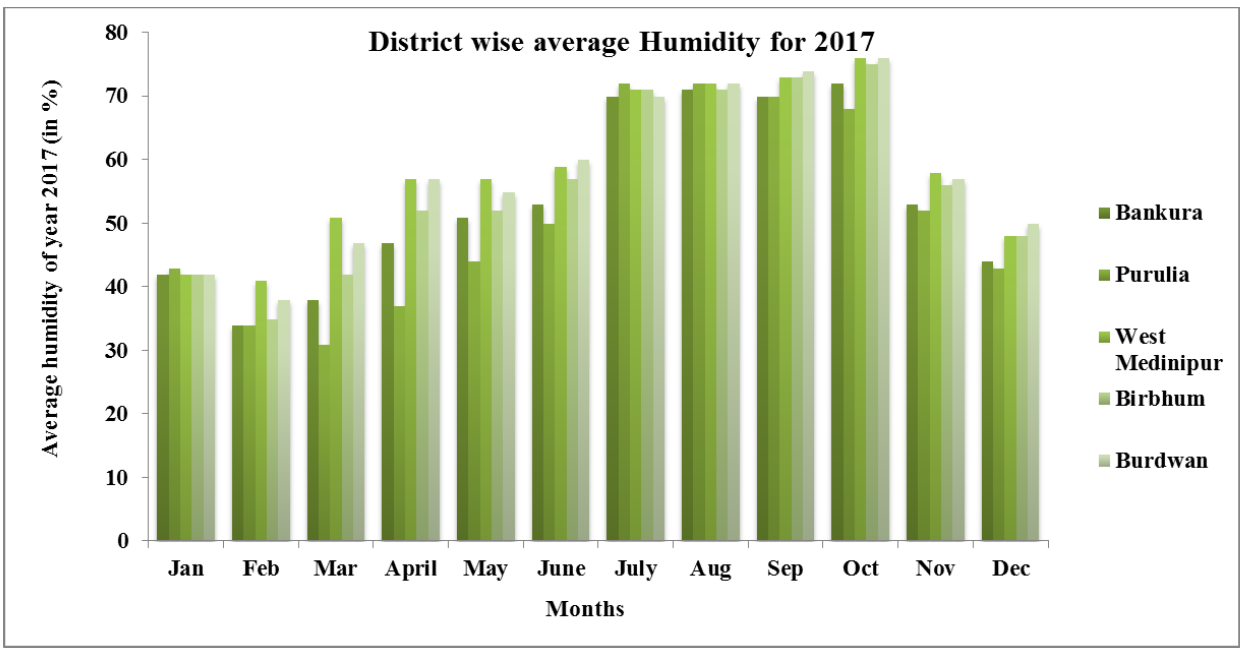

Figure 1.5 Average humidity in different districts of South Bengal (data of the year 2017)

1.3 Study Species

The Asian elephant (*Elephas maximus*) is the only living species of the genus *Elephas* and is distributed all through the Indian subcontinent and Southeast Asia, from India in the west, Nepal in the north, Sumatra in the south, and to Borneo in the east (Hussain *et al.*, 2003). Three subspecies are recognized—*E. m. maximus* from Sri Lanka, *E. m. indicus* from mainland Asia and *E. m. sumatranus* from the island of Sumatra (Schmidt and Kappelhof, 2019).

Asian elephants, once abundant from West Asia to the Indian subcontinent, South-East Asia and China spread over 9 million km^2 (Sukumar, 2003), are now extinct in West Asia, Java, and most of China. They presently occur in 13 countries, with an approximate range area of 4,86,800 km^2 (Sukumar, 2003) that include Bangladesh, Bhutan, India, Nepal and Sri Lanka in South Asia, and Cambodia, China, Indonesia, Lao PDR, Malaysia, Myanmar, Thailand and Vietnam in South-East Asia. Even within their present range, the species is declining and exists only as fragmented populations (Olivier, 1978; Sukumar, 2003; Blake and Hedges, 2004). Asian elephants are found in four distinct geographical regions in India: (a) Shivalik Hills and Terai of Uttar Pradesh, (b) North Bengal to Manipur, (c) Bihar, Jharkhand, Odisha, and south-western part of West Bengal, and (d) Karnataka, Kerala and Tamil Nadu (Baskaran *et al*., 2011). In a country like India with a population of 1.4 billion people, where the elephant population is currently estimated to be 27,000 individuals (MoEFCC, 2019) and their range is expected to be involved in frequent conflict with humans.

The Asian elephant has been listed as 'Endangered' on the IUCN Red List since 1986 as the elephant population has declined over the last 60-55 years. They are also listed in appendix 1 of Convention on International Trade of Endangered Species of Wild Fauna and Flora (CITES) and noted under Schedule-I species in the Wildlife Protection Act of India (WPA), 1972. Their ecological significance makes them a keystone and flagship species while their cultural importance and religious links attribute them as companion and revered species.

1.4 Objectives

1. ***To assess the population status and distribution of elephants in south West Bengal.***
   - **a.** What is the population size and population structure of elephants in south West Bengal?
   - **b.** How elephants are spatially distributed and what are the habitat determinants for such distribution in south West Bengal

2. ***To study the feeding ecology and movement pattern of elephants.***
   - **a.** What are the resources available and their impact on feeding ecology and movement pattern of elephants in south West Bengal?

3. ***To study the human-elephant interactions in south West Bengal.***
   - **a.** Does the intensity of human-elephant interactions spatially vary across the landscape?
   - **b.** If it is so, what are the factors influencing variation in intensity of human- elephant interactions?

1.5 Methodology

The study was conducted between 2016 and 2019. Detailed methodologies are provided in the subsequent technical chapters; here I am only providing a brief methodology followed in every technical chapter.

Distribution and population status: The ranging pattern of elephants was determined by questionnaire survey, dung count survey, transect survey and sight resight method.

Resource availability: The resource availability for elephants was determined by using vegetation surveys in all the major forest patches in South Bengal.

Feeding ecology and Movement pattern: The forage use was determined by following the feeding trails and determining the preferences for the available resources. The movement pattern was determined by following the elephant tracks.

Human Elephant Interactions: The human-elephant conflict data in form of human deaths, injuries, crop depredation and elephant deaths was collected from the forest department and ground-truthed

1.6 Organisation of the thesis

The thesis illustrates the nature of a complex social species through observations carried at the population, group, and individual levels. Chapter-1 of the thesis provides a general overview and rationale behind the study and a detailed description of the study area and study species. It is followed by objectives and research questions, and specific methods employed to achieve them. Chapter-2 is a compilation of existing knowledge available in published peer-reviewed literature. Chapters 3, 4, 5 and 6 are technical chapters addressing each objective and research question. Chapter-3 describes the population status and the ranging pattern in the study area. Chapter-4 talks about the forage availability in the area for elephants. Chapter-5 talks about the forage use by elephants and how the elephant movement is affected by the driving by the forest department and locals in the area and the availability of resources in South Bengal. Chapter-6 explores the human-elephant interactions in the area. I summarize the findings and contribution of my study to the existing knowledge of the species in Chapter-7.

Chapter 2

Review of Literature

2.1 Overview of the Genus *Elephas*

Elephants belong to the family Elephantidae, the sole remaining family within the order Proboscidea (Maglio, 1973). The Elephantidae family includes the two genera of modern elephants (*Loxodonta* and *Elephas*). The genus *Elephas* is represented by only one surviving species *Elephas maximus*, the Asian elephant (Shoshani, 2005). Asian elephants are present in 13 countries in Asia but are declining in numbers throughout their range.

2.2 Social Organization

The social organization of an Asian elephant has been studied very little as compared to their African counterparts. Studies on the Asian elephant indicate the existence of basic social units (mother and dependent offspring; McKay, 1973; Sukumar, 1989a), family groups comprising of two or more mother-offspring units (Fernando and Lande, 2000), and clans (larger associations of family groups; Sukumar, 1989b, 1994; Baskaran *et al*., 1995). Elephants live in groups of 5 to 20 animals who interact and communicate with each other as one family unit (Sukumar, 2006). Usually, the males disperse on reaching adulthood (de Silva *et al*., 2011; Eisenberg *et al*., 1990; Fernando and Lande, 2000; Vidya and Sukumar, 2005) and join the social groups only during mating. Always a division-union dynamic keeps on taking place in the social units (de Silva *et al*., 2011). There is a presence of dominance hierarchy among males, whether they are social or solitary. Dominance depends on age, size and sexual condition (Sukumar, 2003). Male elephants can be quite sociable when not competing for mates and form vast and fluid social networks (LaDue *et al*., 2022). During mating period (or in musth), male elephants are not sociable with other males and only associate with females to mate with them (Sukumar, 2003).

The formation of groups and their sizes are also influenced by the availability of forage (Jarman, 1974) and predation (Geist, 1998). Usually, elephants have huge resource requirements; hence, smaller groups are formed to avoid competition within a family unit (Sukumar, 2003). Living in small groups during foraging can be a good approach to avoid competition, especially when there is a shortage of food. The group sizes of elephants are based on strong social connections/bonds, which are influenced by factors like avoiding competition for food.

The effect of ecological elements on social structure in Asian elephant populations has not been very clear. Insignificant seasonal effect was observed on group size in Sri Lanka by McKay in 1973. Similarly, de Silva *et al*. (2011), found insignificant effect by seasonal differences on female social structure in Uda Walawe, Sri Lanka. However, Sukumar (2003) reported larger group sizes during the second wet season and dry season than in the first wet season in a southern Indian population.

2.3 Feeding Habits

Asian elephants largely depend on browse and forage, and are sometimes selective of the plant or plant part consumed (Owen-Smith and Chafota, 2012). They require large quantities of food and water for their day-to-day activities (Owen-Smith, 1988). The number of species consumed by Asian elephants varied between different areas across the elephant ranges e.g., 132 species in the dry season in North Bengal (Das *et al*., 2022), 112 plant species in Hasanur of Tamil Nadu however, 85% of their diet consisted of only 25 species (Sukumar, 1990), 18 species of flowering plants in the Manas National Park in the dry season (Lahkar *et al*., 2007), 50 species in Rajaji National Park that includes 74% trees, 14% grass, 8% shrubs and 4% climbers (Joshi and Singh, 2008), 71 species including 56% tress in Central India (Mohapatra *et al*., 2013), 22 plant species in West Medinipur, Purulia and Bankura districts of West Bengal (Santra *et al.*, 2008), 106 species in the Shangyong National Natural Reserve in China (Chen *et al*., 2006), 57 species in Nepal (Koirala *et al*., 2016), and 26 species in Vietnam (Varma *et al*., 2008).

Elephants are mixed feeders, and the food selection varies seasonally (Sukumar, 1989a). The proportion of dicot and monocot species in the elephant diet differs across their home ranges. Elephants profoundly depend on grasses in the wet season and almost exclusively on woody plants during the dry season in southern India (Sukumar, 2006). Similarly, Pradhan *et al*. (2007) reported identical seasonal variations in Bardia National Park in Nepal. Grasses dominated the diet of elephants in all seasons while browsed material was an important portion of their diet during the dry season in Nilgiri Biosphere Reserve (Baskaran *et al*., 2010). Browsing makes up for the majority of diet in dry season in the foothills of the Himalayas (Lahkar *et al*., 2007).

Although, the diet is highly diverse across their range and reflects that there is high diversity and a huge difference in the nutrient content and the secondary compounds of the plants available in the landscape that they inhabit.

Crop raiding by elephants is affected by proximity of crop field, density, seasonal availability of crops, and the seasonal differences in nutrient concentration of wild and cultivated plants (Naughton- Treves, 1998; Sitati *et al*., 2005; Chiyo, 2000; Dudley *et al*., 1992; Nyhus *et al*., 2000; Sukumar, 1989a). Food crops are generally high in energy, easily digestible, and low in secondary compounds (Rode *et al*., 2006) and may also provide secondary health benefits such as lower parasite loads (Finch, 2013) which make them attractive to the elephants (Jachmann, 1989; Omondi, 1995; Sukumar, 1989a). Conversely, forest food was found to be lower in protein and minerals than crops (Osborn, 1998; Sukumar, 1989a).

2.4 Habitat Use

Studies show that elephants showed an inclination towards mixed forests and areas surrounding the agricultural land in Indonesia (Rood *et al*., 2010), India (Sukumar, 1989a; Desai and Baskaran, 1996; Areendran *et al*., 2011), Sri Lanka (Fernando *et al*., 2008) and China (Zhang *et al*., 2015). Elephants largely use marginal areas with forests and agricultural land nearby, suggested by studies from Nepal (Steinheim *et al*., 2005; Pradhan and Wegge, 2007), India (Sukumar, 1989a, 1990), and China (Zhang and Wang, 2003). Marginal areas are generally rich in elephant feed (Sukumar, 1989a, 1990; Zhang and Wang, 2003) and are close to the crop fields owing to their high nutritional values compared to other vegetation types (Anderson and Briske, 1995; Steinheim *et al*., 2005). Elephants retreat to forests for cover and/or shade when not feeding on grasses, and/or may travel through these areas while searching for food or for avoiding an encounter with humans while traveling. The sal forest provides low-quality food (Steinheim *et al.*, 2005) and elephants use sal vegetation considerably less compared to other vegetation types in India (Williams *et al*., 2008).

2.5 Conflict

The biggest threat to the existence of elephants is the human-elephant conflict, particularly in the agricultural rural regions (Sitati *et al*., 2003). Alterations of the landscape by humans have impelled humans and elephants to live in closer proximity which leads to even more conflict issues (Shaffer *et al*., 2018). Habitat fragmentation further fuels this human-elephant conflict as the roads and the agricultural land surrounding the feeding grounds are often more susceptible to conflict (Fernando *et al*., 2005) and often lead to fatal results (Shaffer *et al*., 2019). The most common form of conflict comprises elephants foraging in the agricultural fields to meet their dietary requirements (Sukumar, 1990; Williams *et al*., 2001; Sitati *et al*., 2003; Graham *et al*., 2010; Sitienei *et al*., 2014; Goswami *et al*., 2015; Liu *et al*., 2016). The elephant crop-raiding pattern has been documented in Asia and Africa (Sukumar, 1989a; Damiba and Ables, 1993; Hoare, 1995; Kiiru, 1995; O'Connell *et al*., 2000), and attempts have been made to estimate the costs of the crop damage (Bell and McShane-Caluzi, 1986; O'Connell *et al*., 2000). Crop raiding often peaks near harvest time threatening the survival of farming households due to high crop losses (Chen *et al*., 2006; Graham *et al*., 2010; Webber *et al*., 2011; Gubbi, 2012). Crop raiding by elephants has been documented to coincide with the harvesting seasons in Africa and Asia (Sitati *et al*., 2003; Chen *et al*., 2016; Naha *et al*., 2020). As a result, elephants often stimulate fear and anger in rural communities (Sitati, 2003; Parker *et al*., 2007), often leading to retaliatory killings of elephants by these farmers (Parker *et al*., 2007).

India documented around 500 human deaths from 2010- 2020 along with 150 elephant deaths due to conflict annually (MoEFCC, 2021). In Africa, Kenya reported deaths of around 200 people in human-elephant conflict between 2010 and 2017 (Mariki *et al*., 2015). Similar numbers are found in the entire range of Asian and African elephants (Saaban *et al*., 2011; Webber *et al*., 2011; Tchamba and Foguekem, 2012; Chen *et al*., 2013; Mariki *et al*., 2015; Sarker *et al*., 2015; Acharya *et al*., 2016; Pant *et al*., 2016). Although crop raiding and human and elephant casualties are often most commonly reported, hidden costs of conflict like the psychosocial well-being and disrupted social activities of people in the conflict prone areas remain unstated in any report (Jadhav and Barua, 2012; Barua *et al*., 2013). These emotional and unseen costs make it difficult for people to appreciate and tolerate elephants existing in their community. Human–elephant conflict thus challenges the support for elephant conservation and impend the future of elephant populations across their range.

Conflicts occur largely outside the forests, especially along their movement paths (Choudhury, 2004; Nath *et al*., 2009; Das *et al*., 2012; Gubbi *et al*., 2014; Prakash *et al*., 2020). Asian elephant is a forest-edge species (Fernando, 2015). Asian elephants substantially spend time in human-dominated landscapes where the high number of conflict have been reported, such as high ecological overlap between elephants and people in Malaysia (de la Torre *et al*., 2021), and a higher number of elephant attacks on humans in Nepal in close proximity to the forest (Ram *et al*., 2021a). Elephants spend more time in closed canopy habitat during the day than at night, which is probably due to thermal regulation and the shade provided by the closed canopy during the day, but they come to the edge area more at night (Sitompul *et al*., 2013). The continued habitat loss and fragmentation have most likely fragmented elephant populations over the last century (Ram *et al*., 2021b). Elephants move more in ranges with higher percentages of agricultural area (Chan *et al*., 2022). The proximity of elephants to human-dominated areas for their dietary requirements (Graham *et al*., 2010; Webber *et al*., 2011; Gubbi, 2012) has become a matter of concern from the management perspective too. Similarly, Goswami *et al*. (2015) reported the availability of crops is a major driver of elephant occupancy and crop depredation in the Garo Hills in Meghalaya.

Chapter 3

Distribution and Population Status of Elephants in South West Bengal

3.1 Introduction

The changes in the geographic range of species are a natural phenomenon; however, most of these changes during the last century have been caused by human actions (Ripple *et al*., 2014). Understanding the underlying causes of such changes is crucial for managing species and maintaining biodiversity (Lalibetre and Ripple, 2004). Apart from their habits, many environmental and anthropogenic factors can impact the shift in the range (Wang *et al.*, 2021). Anthropogenic factors frequently cause shrinkage in the range of a species, particularly in large-bodied animals e.g., 24 species of the 43 species evaluated had lost their geographic range, however, 17 of them showed expansion of their range while three species remained unchanged in their range, further the species showed range expansion was relatively with smaller body size in North America (Lalibetre and Ripple, 2004). The range expansion and range shift by a large-bodied animal like the African elephant (*Loxodonta africana*) is well-documented (Buechner *et al*., 1963; White, 1994). African elephants expanded their ranges to include pastoral lands in Kenya to meet their nutritional requirements (Graham *et al*., 2009), as well as they showed varying intensities of seasonal home range shifts (Shannon *et al*., 2006). They shifted their ranges due to the changes in land cover, such as the conversion of large areas of woodland and forest to grassland in Uganda (Buechner *et al*., 1963) or the transformation of the land for agriculture in the Sebungwe region of north-west Zimbabwe (Hoare, 1999). Whereas the Asian elephant is an endangered species that survives in human-dominated habitats with high human densities. The current populations are restricted to only a small proportion of their historical range (Choudhury *et al*., 2004; Sukumar, 2006) and are under threat from land use changes due to the continuous conversion of their habitat to agriculture, urbanization, transportation, and industry (Kanagaraj *et al*., 2019; Williams *et al*., 2020). Such changes in range by elephants are attributed to vegetation types and local availability of high-quality food resources due to their dietary requirements (White, 1994). Often, animal populations expand their ranges to acquire sufficient food resources and shelter because their survival depends on the spatial distribution of suitable habitats. Changes in the range of a species are also controlled by competition for ecological resources (Sexton *et al*., 2009).

Elephants became rare in large areas of South Bengal in the 18th century due to forest degradation and poor areal coverage of coppice sal forests (Palit, 1991; Malhotra, 1995; Panda, 1996). The elephants have eventually expanded their distribution in South Bengal from neighboring province of Jharkhand since 1950 (Shahi, 1980; Dey, 1991; Palit, 1991; Malhotra, 1995; Panda, 1996; Singh and Chowdhury, 1999). Estimating the number of elephants in these forests is indispensable for monitoring and assessing the elephant population in this area. The commonly used methodologies include line-transect surveys direct detections (Caughley and Goddard, 1975; Jathanna *et al*., 2015; Kumara *et al*., 2012), dung count techniques (Baskaran *et al*., 2013; Madhusudan *et al.*, 2015), mark-recapture method (Goswami *et al.*, 2007), waterhole count (Jennifer *et al*., 2010), and use of acoustic sensors (Thompson *et al*., 2009; Thompson *et al.*, 2010).

In addition to an estimate of population, understanding of their social organization is crucial to know the viability of the population. The social organization of an Asian elephant has been studied very little as compared to their African counterparts. There have been many long-term studies on African elephants (Douglas-Hamilton, 1972; Moss and Poole, 1983; Moss, 1988; Moss, 2001) where their multi-tiered social organization has been studied and defined. Studies on the Asian elephant show the existence of basic social units (mother and dependent offspring; McKay, 1973; Sukumar, 1989a), family groups comprising two or more mother-offspring units (Fernando and Lande, 2000), and clans (larger associations of family groups; Sukumar, 1989a, 1994; Baskaran *et al*., 1995). Usually, the males disperse on reaching adulthood (de Silva *et al*., 2011; Eisenberg *et al*., 1990; Fernando and Lande, 2000; Vidya and Sukumar, 2005) and join the social groups only during mating. Always a division-union dynamic keeps on taking place in the social units (de Silva *et al*., 2011).

Proper understanding of the pattern of range expansion, the probability of elephants using the habitat and how many elephants use this area is quintessential in the management and retention of these elephants in a human-dominated agricultural landscape.

3.2 Methods

Geographical range over the study period

The home range estimates of an Asian elephant vary from 105 km^2 to over 500 km^2 (Sukumar, 1989a; Baskaran *et al*., 1995; Fernando *et al*., 2008). Thus, I considered a minimum home range size of 100 km^2 as the smallest unit for sampling and overlaid 10 x 10 km (100 km^2) grid cells on the map of the study area of South Bengal on the QGIS platform (v 2.18) that provided 455 grid cells (QGIS Development Team, 2009; Lamichhane *et al*., 2018).

When there is an absolute lack of information, the local people knowledge helps in constructing the history of the focal issue, that will help in re-create the baseline information (McClenachan *et al*., 2012). Recent studies have shown how historical data can be integrated into conservation and management frameworks using scientific methods (Hassall and Thompson, 2010; Johnson *et al*., 2016). Considering the availability of discrete or lack of information on elephant range information, and since it is of recent 70 years, and still many old people available in the landscape having experience with the elephants, I opted to interview the local people to elucidate the presence of elephants at different time intervals and these sightings were used to build the variations in the presence or abundance of a species over a period (Pan *et al*., 2016; Nash *et al*., 2016). In each grid cell, people ≥50 years of age were identified, owing to their experience and familiarity with the area by having experience of working with the forest department or as practicing hunters or native people who were dependent on the forest resources. The selected individuals were interviewed between January 2018 and February 2019 using an open-ended questionnaire after obtaining their consent. I interviewed five individuals for each grid cell (N = 2275).

Considering the initial sightings of elephants in the South Bengal, I considered six intervals of the time period beginning in 1950 (i.e., 1950–60, 1960–70, 1970–80, 1980–90, 1990–2000, 2000–2010, and 2011–18). I initiated an informal interaction with each respondent. The respondents were questioned about their first memory of an encounter with elephants, any accounts of elephants, the frequency of sightings, movement patterns, and conflicts, in association with their age. That helped me to group the data according to the time period. I also collated the information on elephants in the archival records of the forest department and published literature. I obtained data on elephant sightings on a daily basis from the forest department from 2000 to 2018. All locations of elephant records were visited and recorded the geo-coordinates using a handheld global position system (Garmin GPSMap 64s). A similar study was done keeping Mayurjharna Elephant Reserve as the center with grid size was reduced to 2X2 km (4km^2).

The positive response to elephant sightings from each interview was considered as a record of elephant occurrences for the specific grid cell for the fixed time interval. The geo-coordinates of all the elephant records (sighting/crop raiding) for each decade was overlaid on the grid cells to obtain grid-wise occurrences by the elephants (Lamichhane *et al*., 2018). The sum of all the grid cells that the elephants entered in each decade was multiplied by 100 km^2 to obtain the range occupied in that decade. I mapped the same to depict the range used by elephants for each decade.

Probability of using a grid cell

In the present context, I define occupancy as the probability of using a grid cell by elephants for the 2011-2018 interval. I modeled the probability of using a grid cell using the observations of elephants made by timber concession workers along with local people (Brittain *et al*., 2018). Similarly, the probability of using a grid cell of mammal species was modeled using interviews with concerned people in various contexts (Karanth *et al*., 2010; Pillay *et al*., 2011). I considered the data on sighting records of elephants by interviews for the 2011–2018 interval, and modeled the probability of using a grid cell by elephants for the current decade. The number of individuals interviewed in each grid cell was considered as replicates (Karanth *et al*., 2010; Pillay *et al*., 2011; Srivathsa *et al*., 2019). Based on the predicted probability of grid cell use, the modeling was stratified by spatial habitat factors, with expected elephant occurrence ranging from low to high. I obtained the classified vegetation map of the South Bengal landscape from the Forest Department and extracted habitat variables. I correlated the closely related variables and retained the independent variables for further analysis. That includes areas with forests, waterbody, barren land, settlements, and agriculture, and the Shannon index of them and the edge of the forest as habitat covariates, while the age of a respondent as a covariate for the probability of providing the proper response (Table 3.1).

Table 3.1. The variables considered and their importance to the elephant to model the probability of elephants using a grid cell

Variable	Importance of the variable to the elephants
Area with forest (FA) **Area with water body (WA)** **Area with barren land (BA)** **Area under settlements (SA)**	Elephants require large quantities of forage, including grass, and water (Sukumar, 1989a), their availability in the grid cell was considered as important covariates, viz. area with forest (FA), an area with water body (WA), and area with barren land (BA). I considered the area under settlements (SA) as another covariate that may negatively influence the elephant's presence.
Area of agriculture (AG)	About half of the elephant habitat in Asia is fragmented and heavily impacted by humans (Leimgruber *et al*., 2003), perhaps they live in heterogeneous habitats leading to high human-elephant conflict (Sukumar, 2003). In such habitat conditions, the reduction of natural habitat, degradation of habitat, and high palatability and nutritional value of crops increase the crop-raiding by elephants (Sukumar, 1990). Thus, the area of agriculture in a grid was considered as one of the covariates.
Shannon index (SHA)	I calculated the Shannon index using the presence of FA, AG, WA, SA, and BA and their areas as representative of the heterogeneity of the habitat.
Edge of the Forest (FOREDG)	I calculated the edge of the forest by summing the perimeter of all the forest patches in each grid cell, which is represented as a length.
Age of a respondent (RA)	I considered the age of a respondent might influence their knowledge of elephants because their memories last longer as they age. Thus, I considered the age of a respondent as a covariate for the probability of providing the proper response.

I treated the responses of each respondent as a replication and constructed the matrix of detection history as '1' detected the elephants, '0' no detection of elephants from the five replications of the 2010–18 data. I estimated the detection probability (p) and the probability of using a grid cell ($\widehat{\psi}$) using single-season occupancy modeling (MacKenzie *et al*., 2002) in the program PRESENCE 12.9 (MacKenzie *et al*., 2017). I evaluated the effect of covariates on model parameters on detection probability, and probability of using a grid cell using logistic models with a logit link and binomial error. I used the potential covariate respondent age (RA) of a respondent for detection probability and built the model to investigate its influence on the estimate of the probability of using a grid cell by an elephant. I built a null model and another model with RA for the detection probability. Since RA did not influence the *p*, I built the subsequent models without covariates for the detection probability. The models were ranked using Akaike's information criterion (AIC) (Akaike, 1973; Burnham and Anderson, 1998). I built a constant model for the probability of using a grid cell and estimated the naïve occupancy (the proportion of sampled grids with elephant detections). The naïve estimate was determined by elephant detection in the number of grid cells divided by the number of grid cells sampled. I built a balanced model set using the selected covariates having each variable at least in the five models. The models were ranked using AIC and the lowest AIC value indicated the best-fit model for the data. For each model, an estimate of the probability of using a grid cell and the associated standard error were averaged across the grid cells that provided the estimate of the probability of using a grid cell and associated standard error. If the top model had a weight > 0.9, then it is considered as parsimonious model. The model-averaged coefficient to estimate the probability of using each grid cell (Burnham and Anderson, 1998) was calculated by averaging all the candidate models with ΔAIC <=2. The computed model weights were summed from all the models having the particular covariate to infer the relative influence of each covariate on the probability of using the grid cells by the elephants. I used the beta coefficient of each covariate to infer their relative influence of them on the probability of using a grid cell in the top models. I plotted each grid cell to show the probability of using a grid cell by elephants from the top model for visual depiction.

Year-round spatial use of habitat by elephants in 2018

The daily records of elephant occurrence location and the number of individuals were collected from the information network created by the elephant cell of the West Bengal Forest Department for the year 2018. I obtained 2367 occurrence locations of elephants in the 365 days of 2018 for South Bengal. For the analysis, I considered 2082 locations that were independent (considering the occurrence of elephants only once a day in a grid cell). I mapped all the locations on a map that was overlaid with 100 km^2 grid cells. I counted grid cells with locations in a month and provided a total number of grid cells with the occurrence of elephants. The total number of grid cells entered by elephants in each month was compared using the chi-square goodness of fit test. The day-wise number of grid cells used was extracted and the mean number of days in a month was compared between the months using one-way ANOVA in the IBM SPSS 16 package (SPSS, 2007. Version 16.0. Chicago, SPSS Inc.).

Estimating the population status

- Dung count survey

  Dung count technique involves the estimation of three factors, i.e., the estimate of the dung decay rate, dung density, and defecation rate.

  Dung Decay Rate: To determine the dung density, I first determined the dung decay rate in the landscape. The dung decay rate is the rate at which the dung disappears under natural conditions (Fig. 3.1). The decay rates can highly vary between different sites due to differences in climatic conditions, especially rainfall. Inter-site differences in rainfall regime, weather conditions, elephant diet, and vegetation type have major implications for dung-based surveys, and thus the decay rate from other sites may not be used. It is preferred to estimate the decay rate for each site while determining elephant densities. I adopted categorization of the decay stages as defined by Dawson (1990) since insects like termites etc. attack the boli from within; thus, the breakdown of each bolus is not readily evident. These stages are defined below:

  A: Boli intact, very fresh (<1 day old); moist with odour.

  B: Insect activity commenced from beneath (detected by the fact that dung was cemented to the substrate), but all boli still intact.

  Cl: Less than 50% of the boli is consumed by termites.

  C2: More than 50% of the boli consumed by the termites

  D: All boli disintegrated as a result of termite activity, but not necessarily tuned into a flat amorphous mass.

  E: Only mud left (in the shape of boli); no dung left except for a few fibers.

  To determine the dung decay rate, in total 28 fresh dung piles were selected and marked in Goaltore range in the Rupnarayan division. The GPS locations were taken for each dung pile. Visits were made once in every seven days to check the piles for decomposition and the decay stages were recorded. The visits were made until the dung piles fully decomposed.

To calculate the decay rate, the survival method was adopted (Dawson, 1990). It derives the "life expectancy" of a dung pile from a life table of dung surviving at the end of each week (Amitage and Berry, 1987). In this method, dung piles are monitored until the last dung pile disappears and the mean expected survival time is calculated. The reciprocal of this survival time gives the decay rate (r). This means that: $r = 1 / T$, where T is the mean survival time per dung pile.

STAGE A

STAGE B

STAGE C1

STAGE C2

Figure 3.1 Different dung stages for scoring to estimate the dung decay rate

Belt transect for elephant dung count: In total 25 belt transects were laid in Rupnarayan and Medinipur forest divisions (Fig. 3.2) and 28 belt transects in Mayurjharna ER (Fig. 3.3). The length of transects varied between 1 km to 3 km adding to 42.3 km (42300 m) in Rupnarayan and Medinipur forest divisions and 51.7 km (51700 m) in Mayurjharna spatially representing the larger landscape by covering all major forest areas.

For counting the dung piles, a transect belt width of 4 m (2 m on each side) was considered. The belt transects were walked and all dung piles observed within 2 m on both sides of the transect were recorded (Fig. 3.4). The assumption was that all the dung piles within 4 m of the belt are detected. On sighting dung piles, the GPS readings and dung stages were recorded.

It requires estimates of three variables, i.e., dung-pile abundance on the ground, defecation rate and dung decay rate that gives the dung density which is then converted into elephant density using the formula (Baskaran *et al.*, 2013; Varman *et al.*, 1995) given below.

$$E = Y \times r / D$$

Where E is the density of elephants, Y is dung density, r is the decay rate, and D is the number of dung piles deposited (defecation rate) per elephant per day.

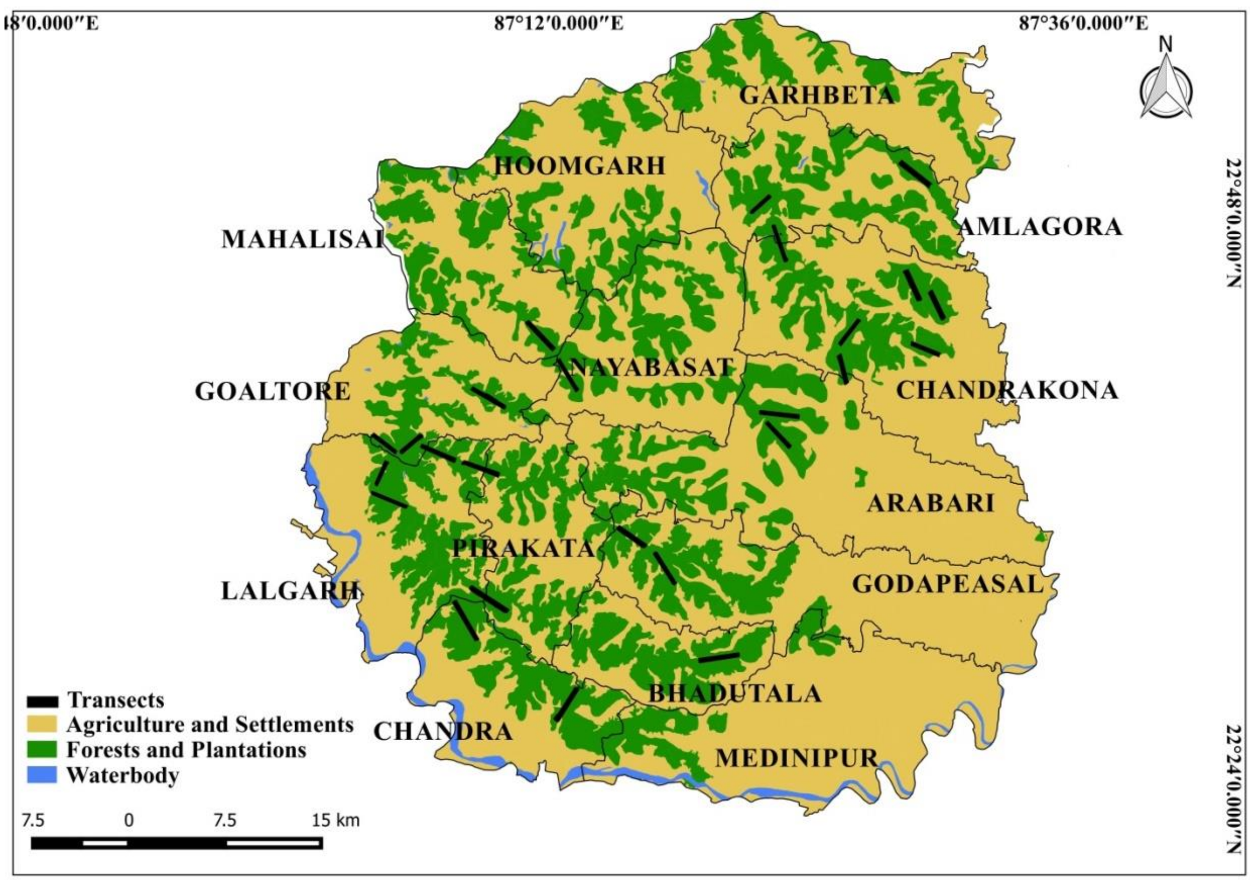

Figure 3.2 Belt transects in Rupnarayan and Medinipur Forest Divisions

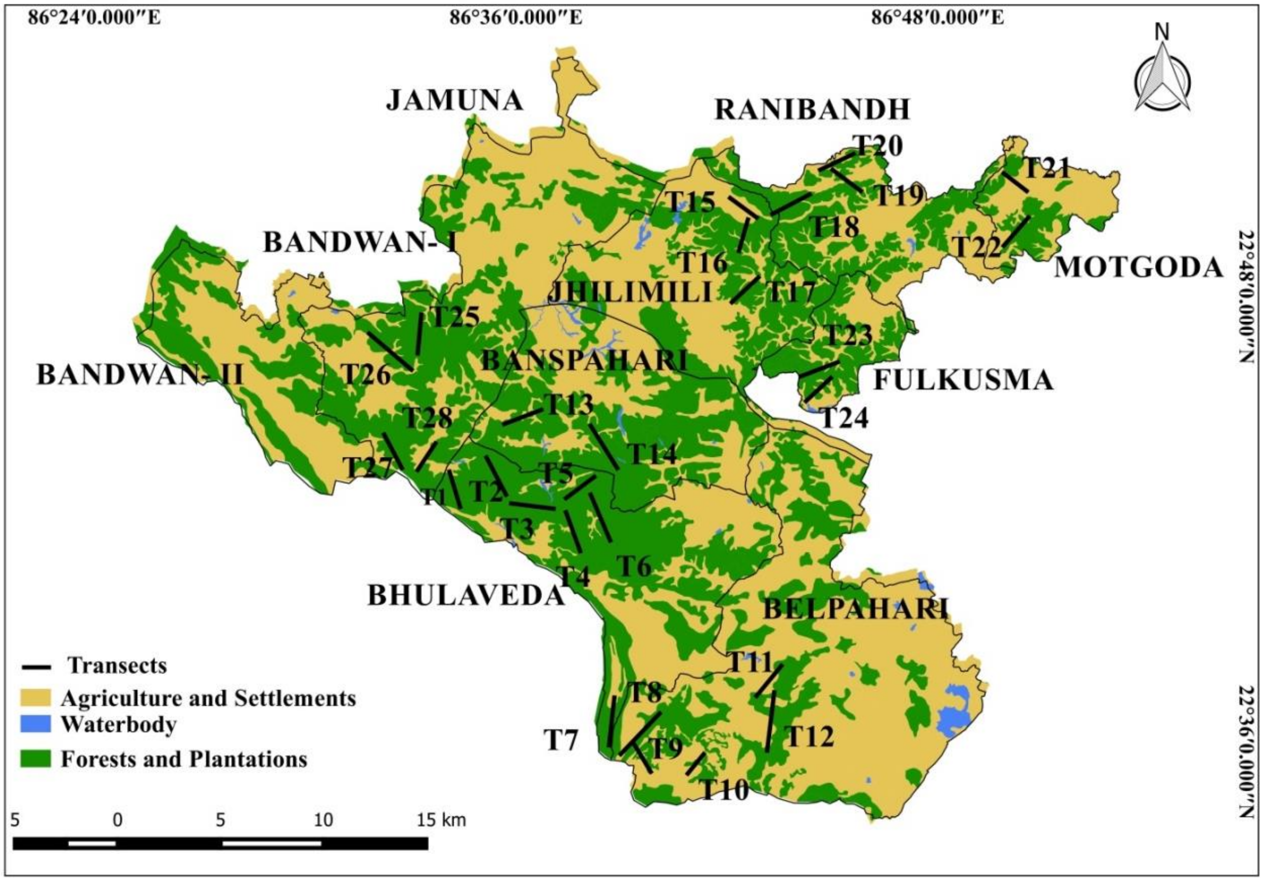

Figure 3.3 Transect line/belts in Mayurjharna ER

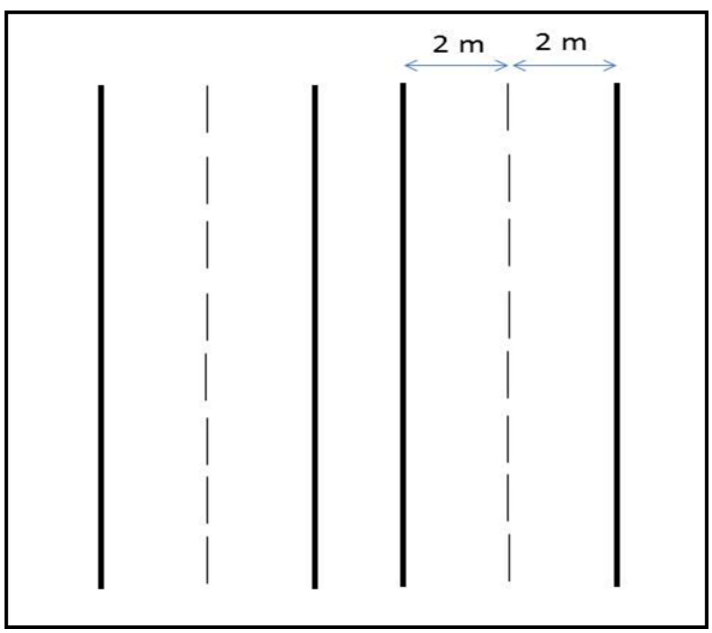

Figure 3.4 Belt transect for dung count

- Line transect for direct detection of elephants

  Line transects were laid only in Mayurjharna ER and not in other areas due to the continuous movement of elephant populations from those areas. A total of 28 transect lines were laid in Mayurjharna ER (Fig. 3.3). Initially, each transects lines were determined on ground and mapped using handheld global position system (Garmin eTrex). The transect length varied between 1 km and 3 km, maintaining a minimum gap of one kilometer between each transect line. All the transect lines spatially represented the entire landscape and major forest types of Mayurjharna ER.

  Each transect line was walked 12 times in the morning between 0600 and 1130 hrs between December 2016 and March 2017. Thus, in total 620.4 km of transect walk was made. The date and time at the start and end point of the transect walk were recorded.

Social Organization

Elephant herds were photographed whenever possible; videos and photographs of elephants were also collected from the villagers and the forest staff on a regular basis. By comparing various photographs and videos, herds were identified and the number of elephants in each herd was counted. The elephants were then categorized into different age-sex classes following the figure description in Varma *et al.* (2012). The elephants were also classified into various age-sex categories based on relative height and morphological characteristics (McKay, 1973; Daniel *et al.*, 1987; Sukumar, 1989a). Younger elephants (<15 years) were classified by comparing their height to the oldest adult female in the group. The elephants were grouped as calves (<5 year), juveniles (5-15 years) and adults (>15 years).

3.3 Results

Range dynamics of elephants

A few elephants entered South Bengal in the 1950s through Mayurjharna Reserve via the Kankrajhore region from Dalma Wildlife Sanctuary in Jharkhand. Elephants were confined to ~1200 km^2 (Table 3.2) area of Ajodhya Hills and Mayurjharna Reserve in Purulia during the 1950s and 60s (Fig. 3.5). Although elephants were primarily confined to the Ajodhya Hills and the Mayurjharna Reserve, a few expanded their range to ~1600 km^2 of the northern periphery of the Mayurjharna Reserve during the 1960–70s (Fig. 3.6). By the 1970–80s, elephants expanded their range to ~2100 km^2, and ~3800 km^2 by the 1980–90s, yet the range was confined to in-and-around the Ajodhya Hills and the Mayurjharna Reserve (Fig. 3.7, 3.8). During the 1990–2000s, elephants increased their range to ~17400 km^2 by moving to the southern part of South Bengal (Fig. 3.9). In the following decade, the range had increased to 18500 km^2 by 2000–10s (Fig. 3.10). However, the range has shrunk, especially in the northern region of their earlier range to ~13200 km^2 during 2010–18 (Fig. 3.11).

Few elephants started to enter through Kankrajhore to Mayurjharna during 1950-60 (Fig. 3.12); they used to cover *ca*. 80 km^2 (Table 3.2). During 1960-1970, elephants extended their range to 260 km^2 and started to use the northern periphery of the Mayurjharna ER (Fig. 3.13); yet the major activity was confined to the reserve. In the next decade (1970-1980), the use of the area increased to 376 km^2 (Fig. 3.14). In the subsequent decades (1980-1990 and 1990-2000), use of area became more extensive and was about 448 km^2 and 572 km^2 respectively (Fig. 3.15 and 3.16). During this time (between 1980-1990), the elephants started moving out of Mayurjharna and started exploring parts of Medinipur beyond Kangsabati River (Fig. 3.15). In the subsequent decades, the usage of area decreased, and during 2000-2010 (Fig. 3.17) elephants were limited to 208 km^2. The current usage is about 144 km^2 of the Mayurjharna ER (Fig. 3.18).

Table 3.2 Area used by elephants and their entry and exit locations in Mayurjharna ER

	South Bengal		**Mayurjharna ER**	
Period	**Total number of grids used**	**The area used (km^2)**	**Total number of grids used**	**The area used (km^2)**
1950 - 1960	12	1200	20	80
1960 - 1970	16	1600	65	260
1970 – 1980	21	2100	94	376
1980 – 1990	38	3800	112	448
1990 – 2000	174	17400	143	572
2000 – 2010	185	18500	52	208
2011 - 2018	132	13200	36	144

Probability of using a grid cell by the elephants

I recorded the presence of elephants in 163 grid cells in 2011-2018 of the 455 sampled grid. I built a null model and another model with a covariate 'age of a respondent' for the detection probability, where the null model emerged as the top model with w_i = 0.86.

Therefore, I built the subsequent model for the probability of using a grid cell without any covariates for the detection probability. The estimate of the detection probability of elephants was $0.74 \pm 0.01_{SE}$, and the naïve occupancy was 0.36. I built 26 models for the probability of using a grid cell by considering the logical composition of various covariates (Table 3.3). The top model had a model weight (w_i) of 0.27. The averaged probability of using a grid cell and the associated standard error across the model set was $0.36 \pm 0.03_{SE.}$ The summed model weights and β co-efficient indicate that the forest edge (0.80), area of forest (0.29), area of agriculture (0.27), and barren area (0.10) in the grid cell influenced the probability of elephants using the grid cells (Table 3.4).

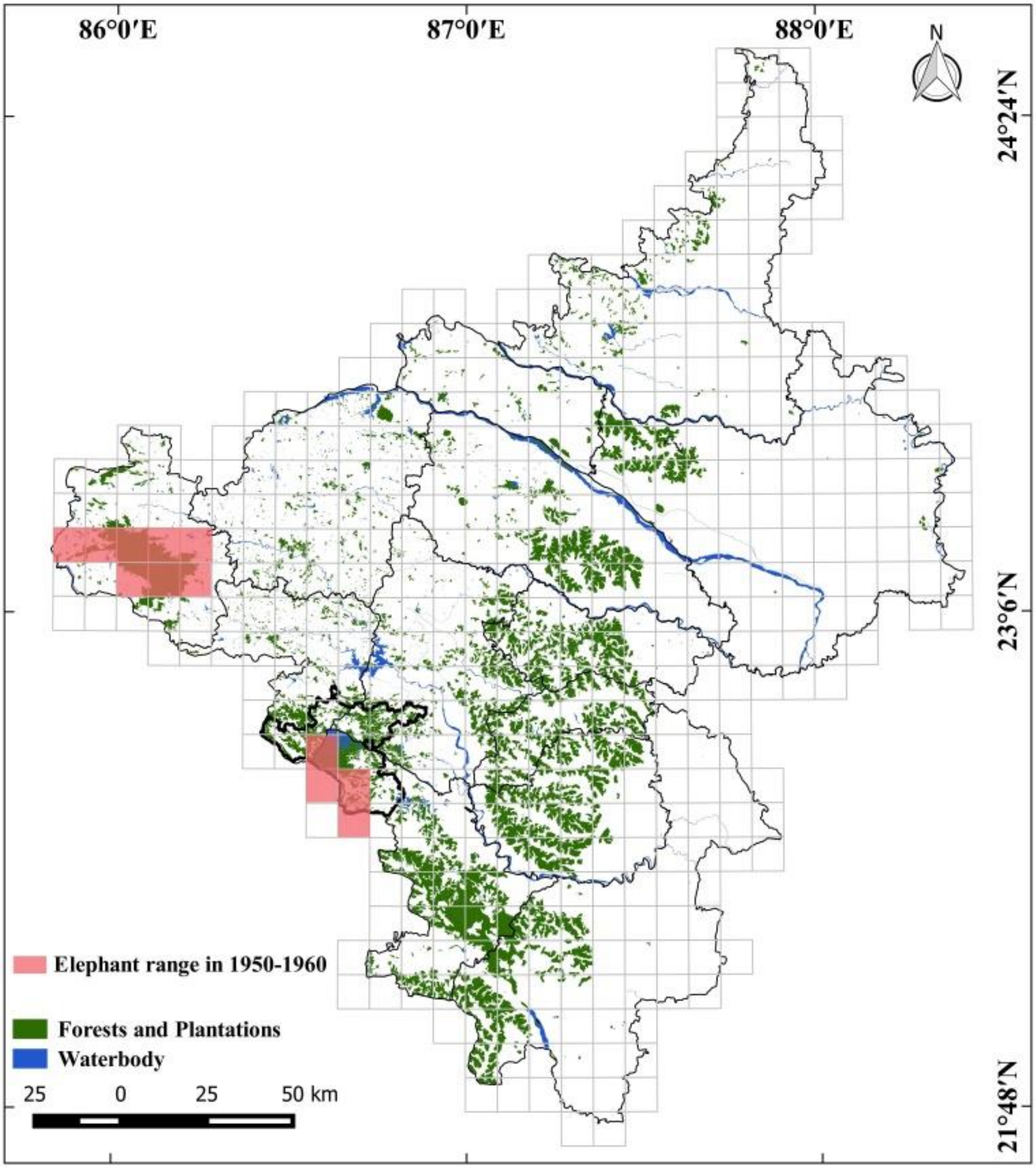

Figure 3.5 Area used by elephants in South Bengal between 1950 and 1960

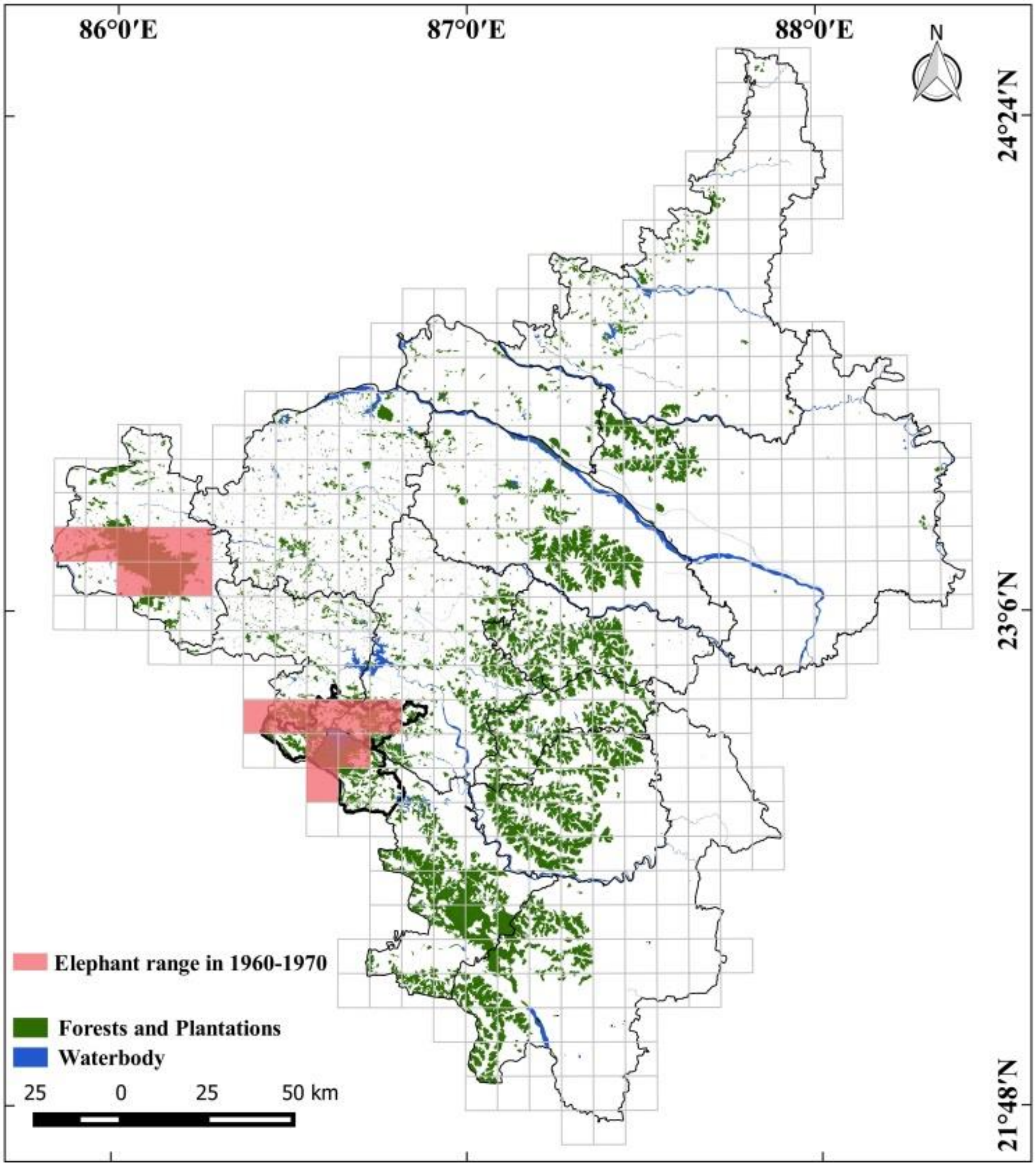

Figure 3.6 Area used by elephants in South Bengal between 1960 and 1970

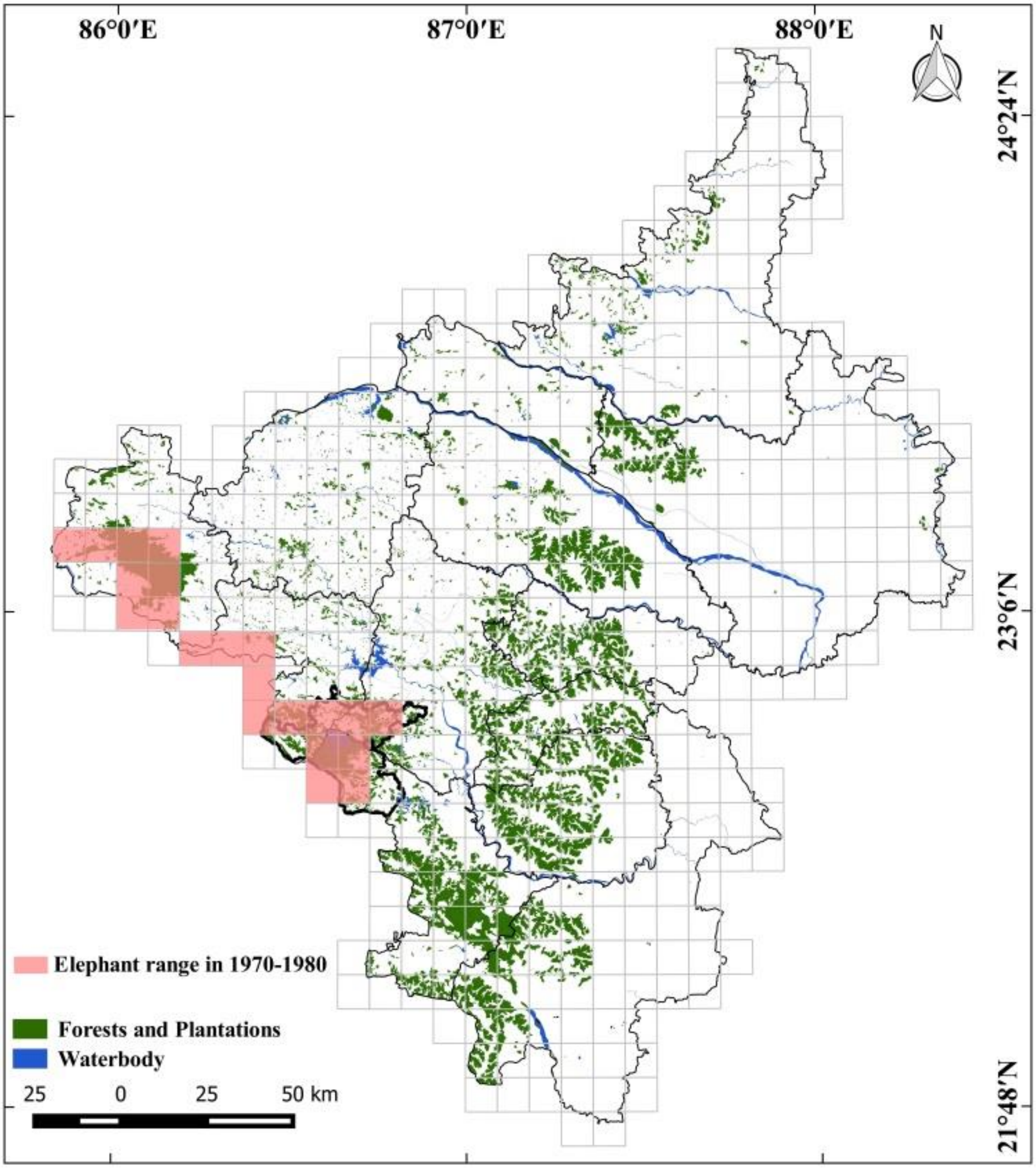

Figure 3.7 Area used by elephants in South Bengal between 1970 and 1980

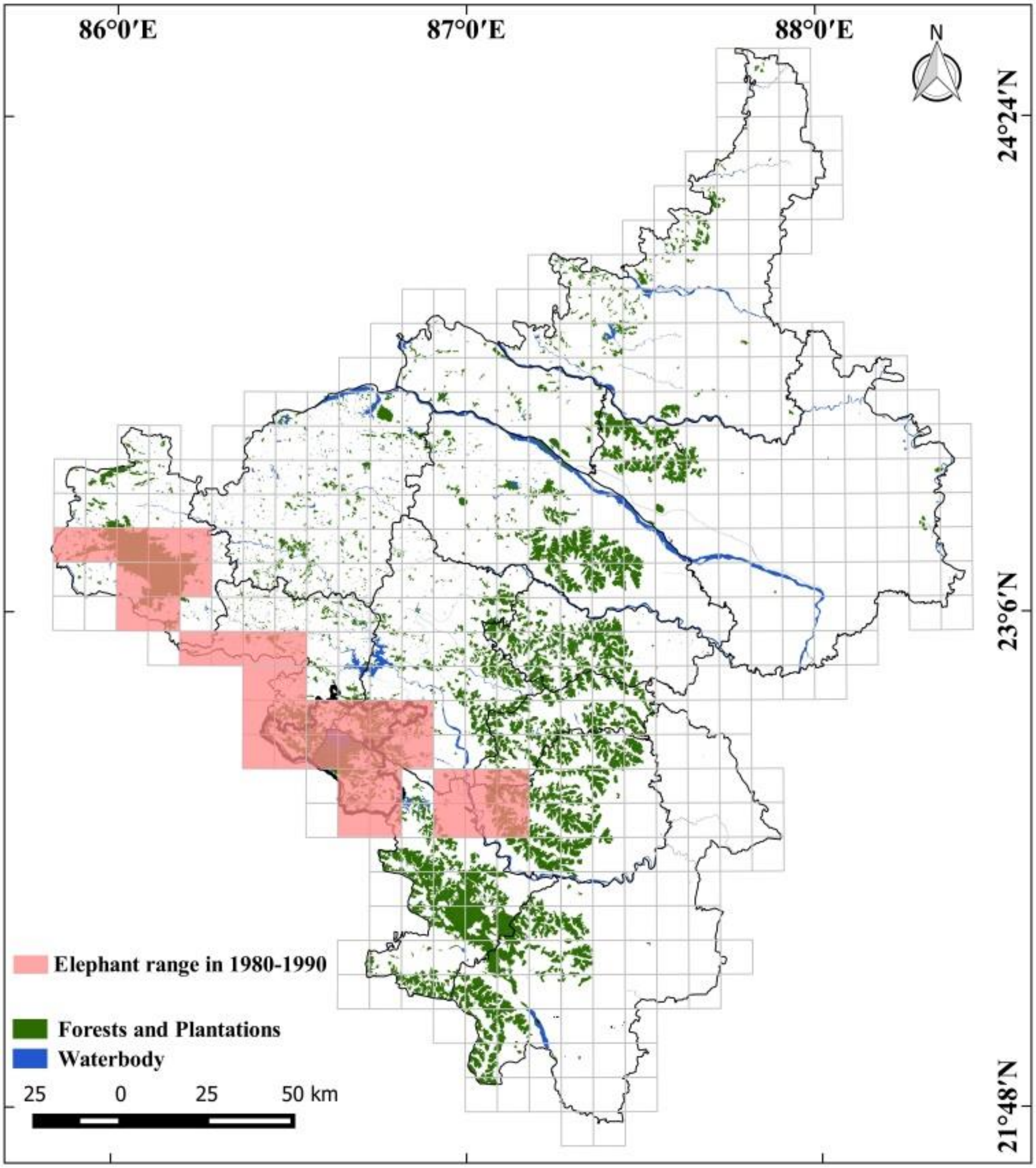

Figure 3.8 Area used by elephants in South Bengal between 1980 and 1990

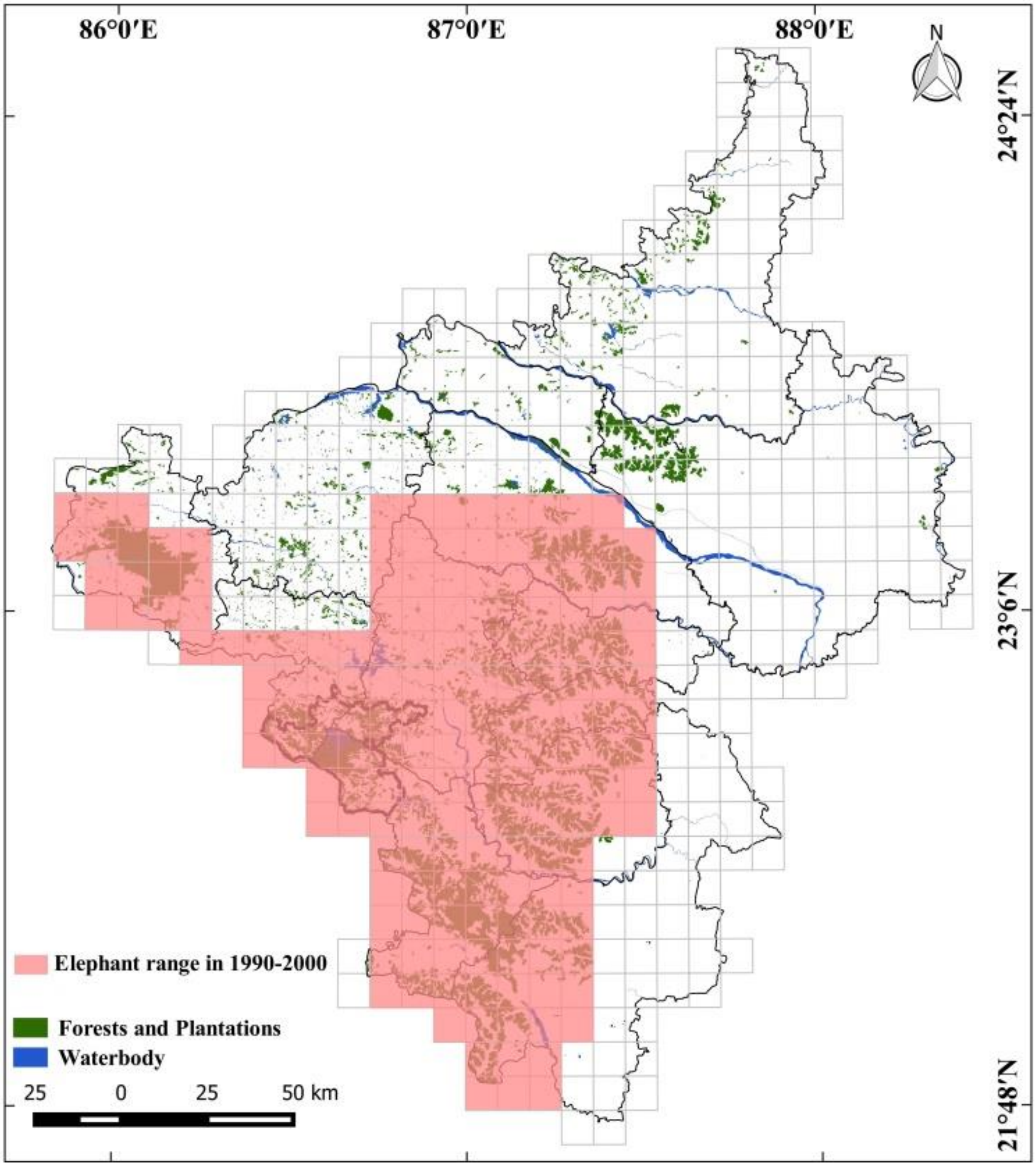

Figure 3.9 Area used by elephants in South Bengal between 1990 and 2000

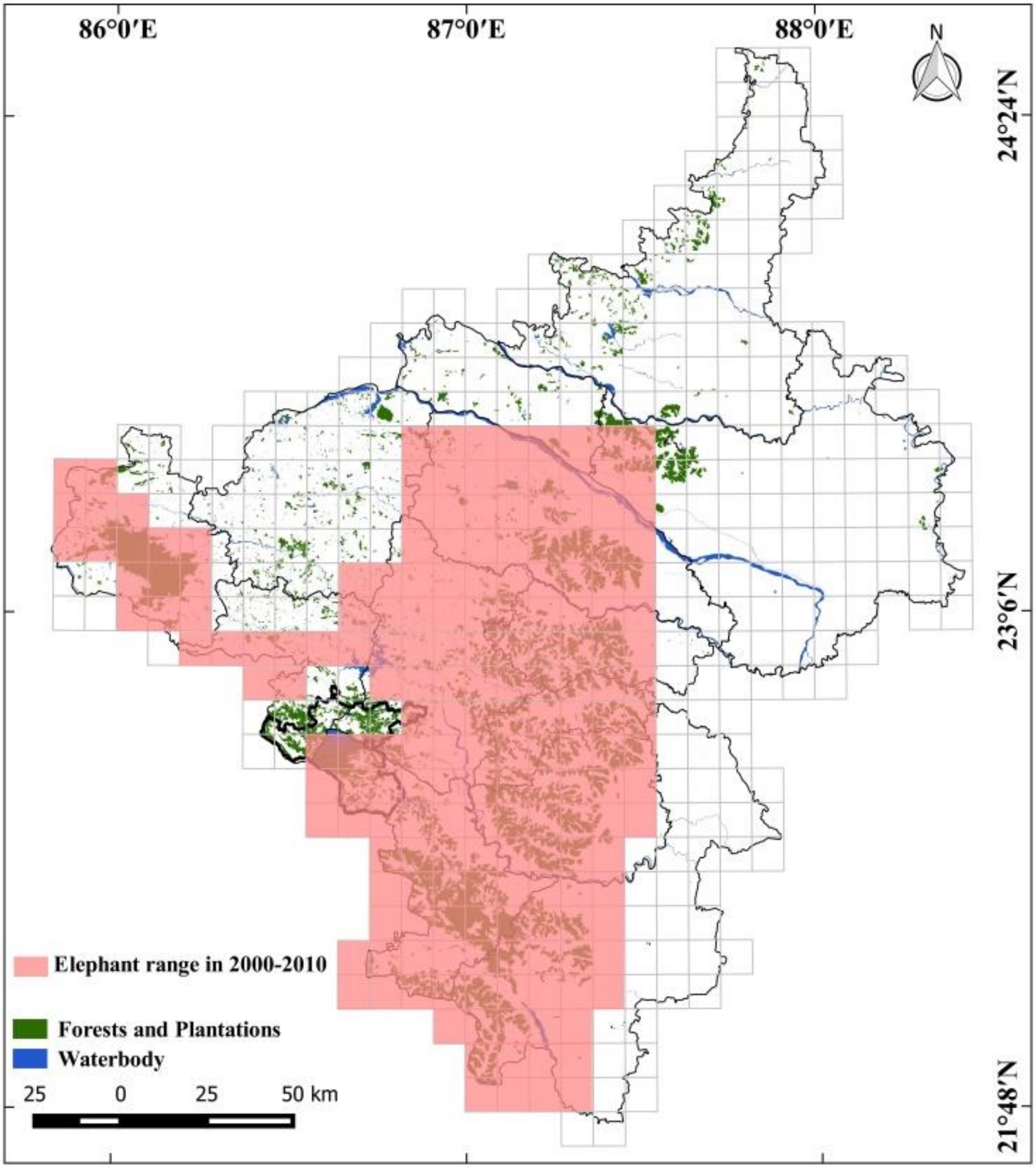

Figure 3.10 Area used by elephants in South Bengal between 2000 and 2010

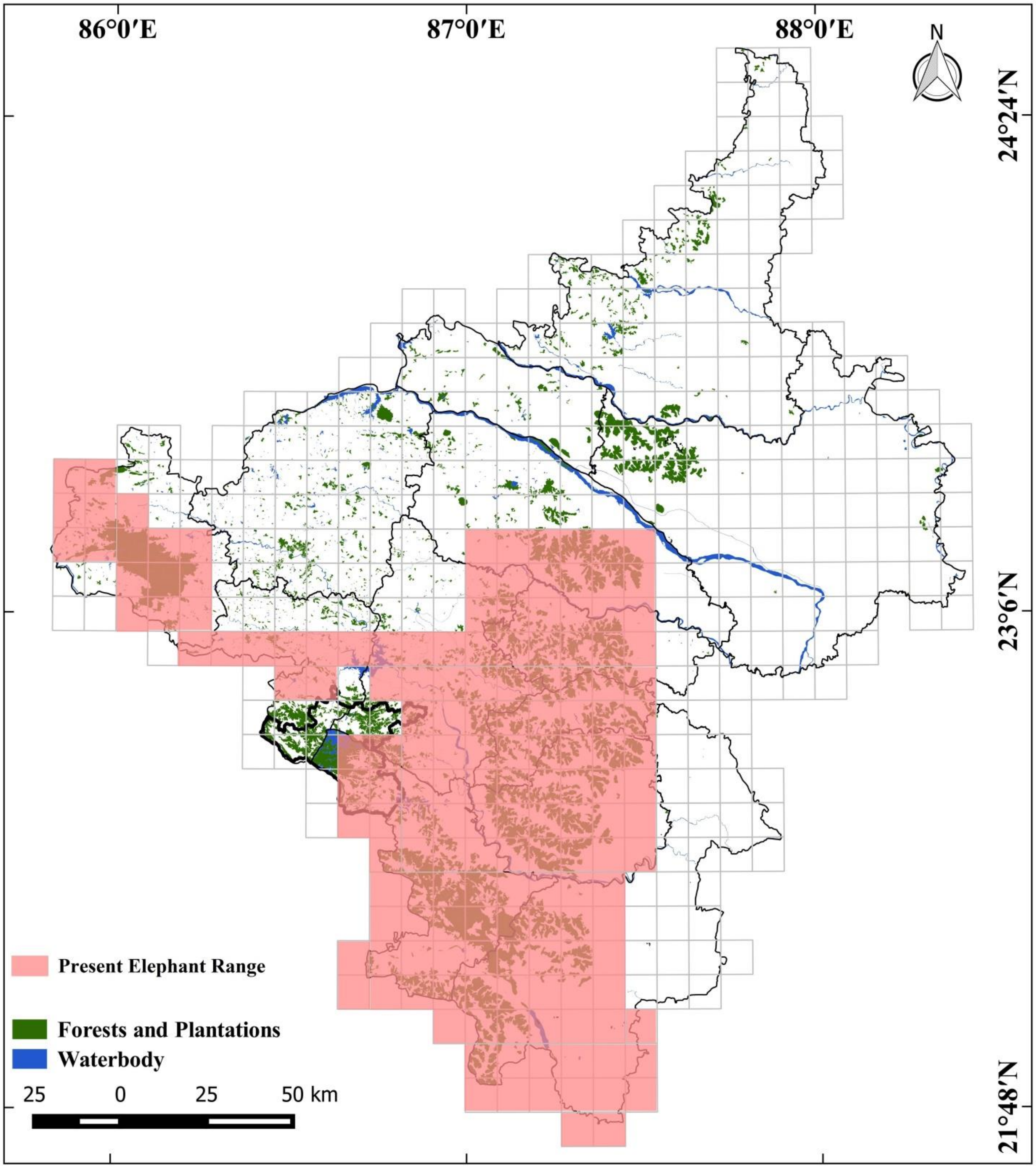

Figure 3.11 Area used by elephants in South Bengal between 2010 and 2018

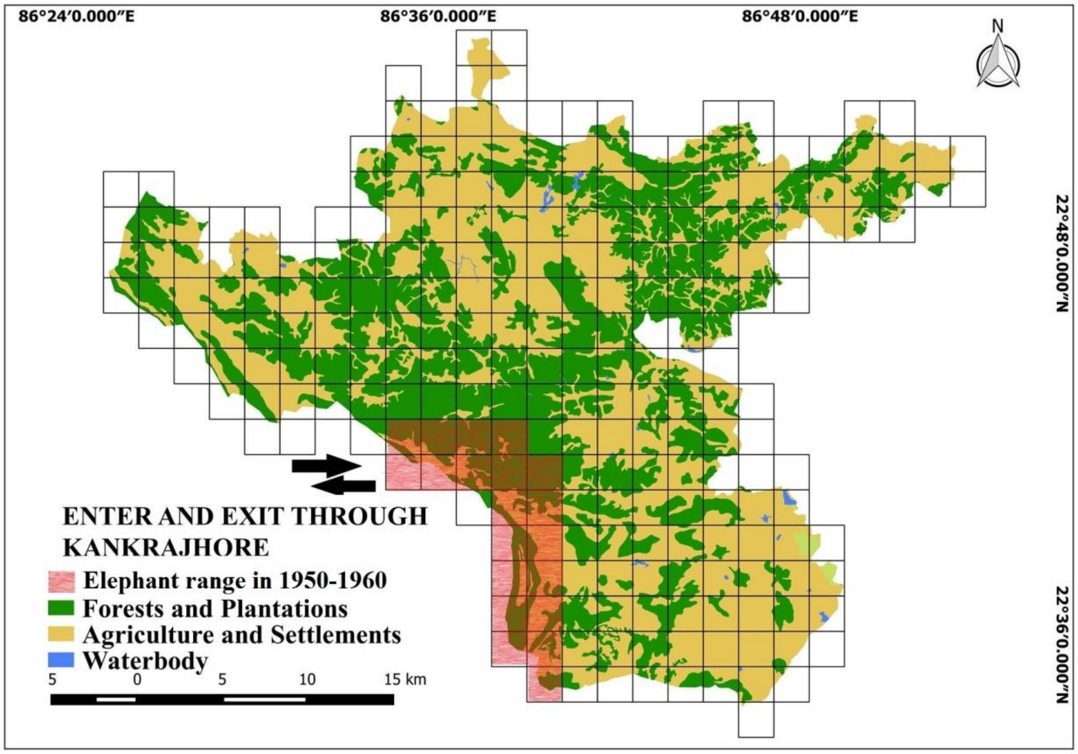

Figure 3.12 Area used by elephants in Mayurjharna ER between 1950 and 60

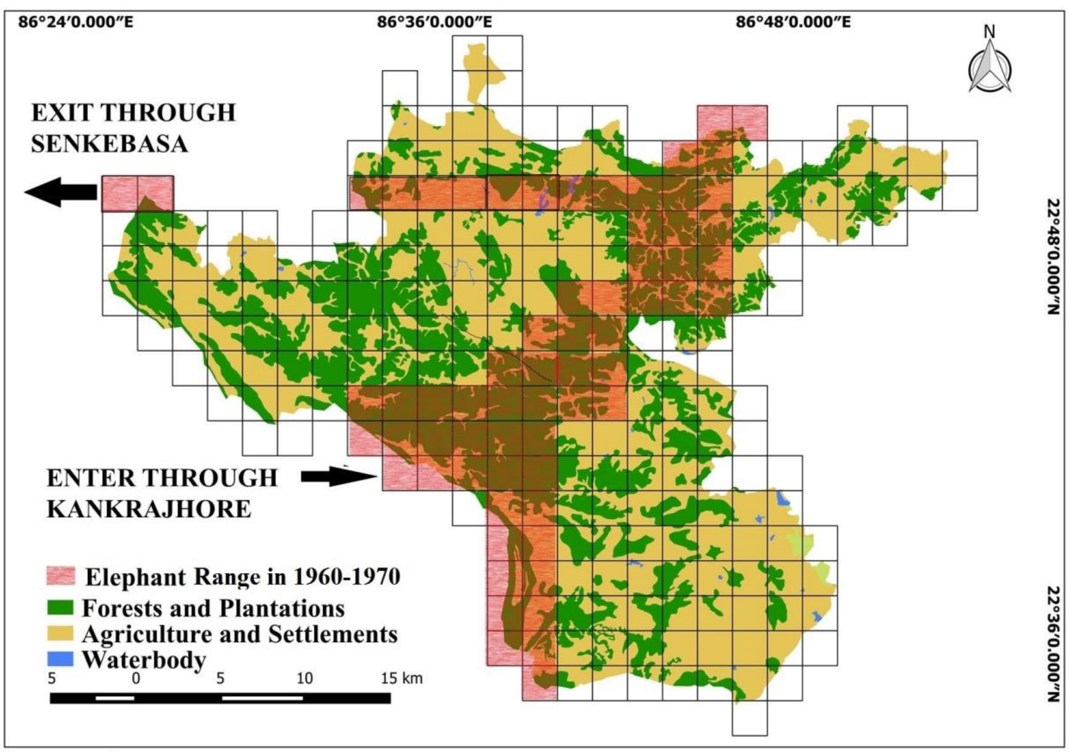

Figure 3.13 Area used by elephants in Mayurjharna ER between 1960 and 70

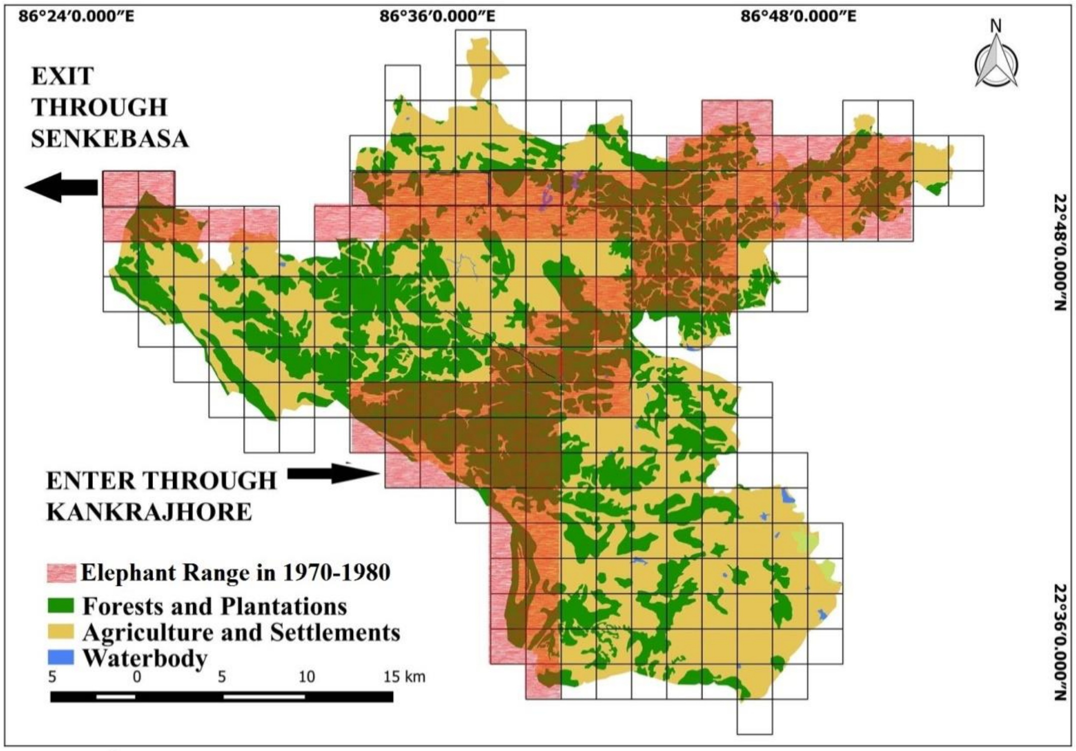

Figure 3.14 Area used by elephants in Mayurjharna ER between 1970 and 80

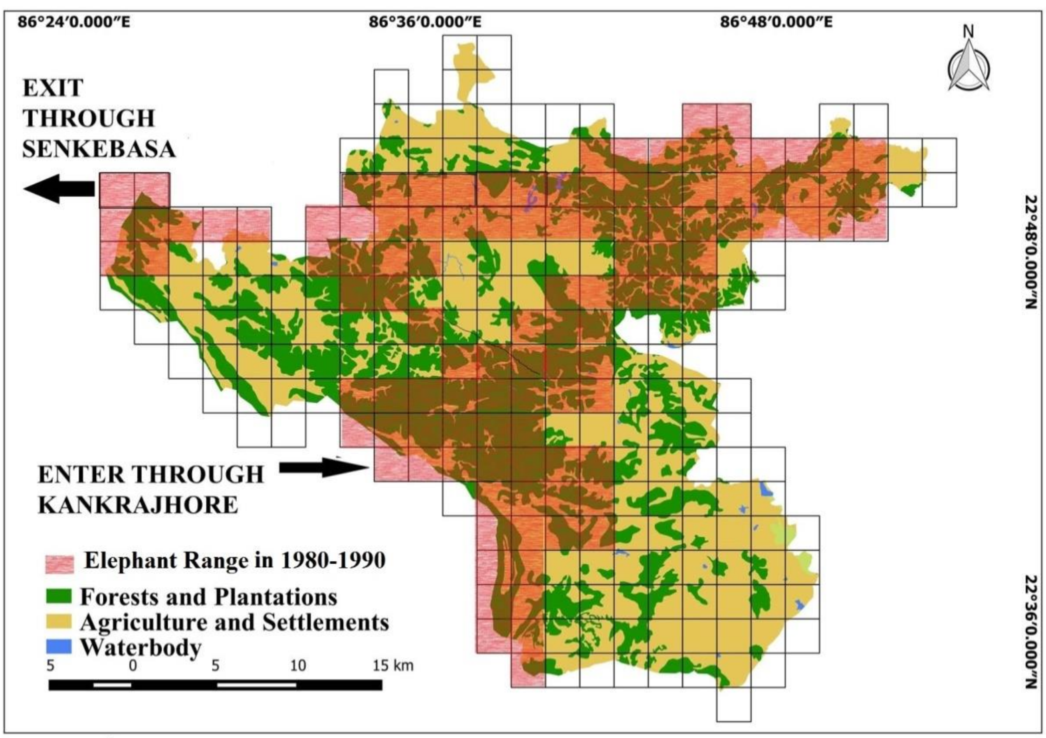

Figure 3.15 Area used by elephants in Mayurjharna ER between 1980 and 90

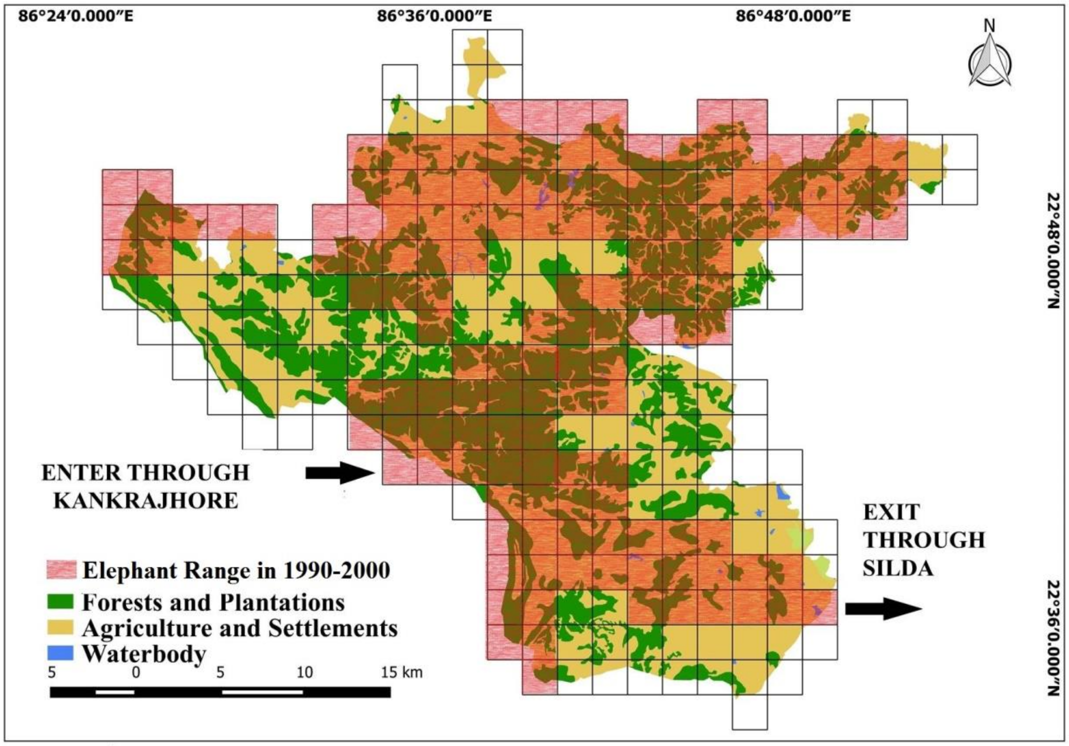

Figure 3.16 Area used by elephants in Mayurjharna ER between 1990 and 2000

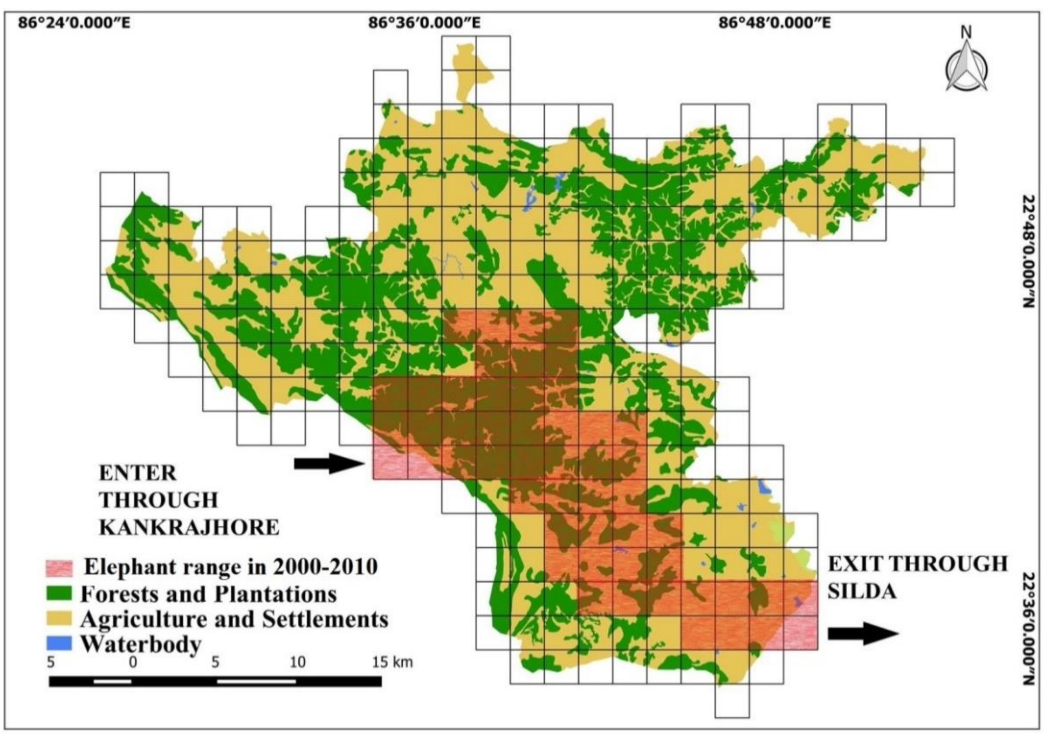

Figure 3.17 Area used by elephants in Mayurjharna ER between 2000 and 2010

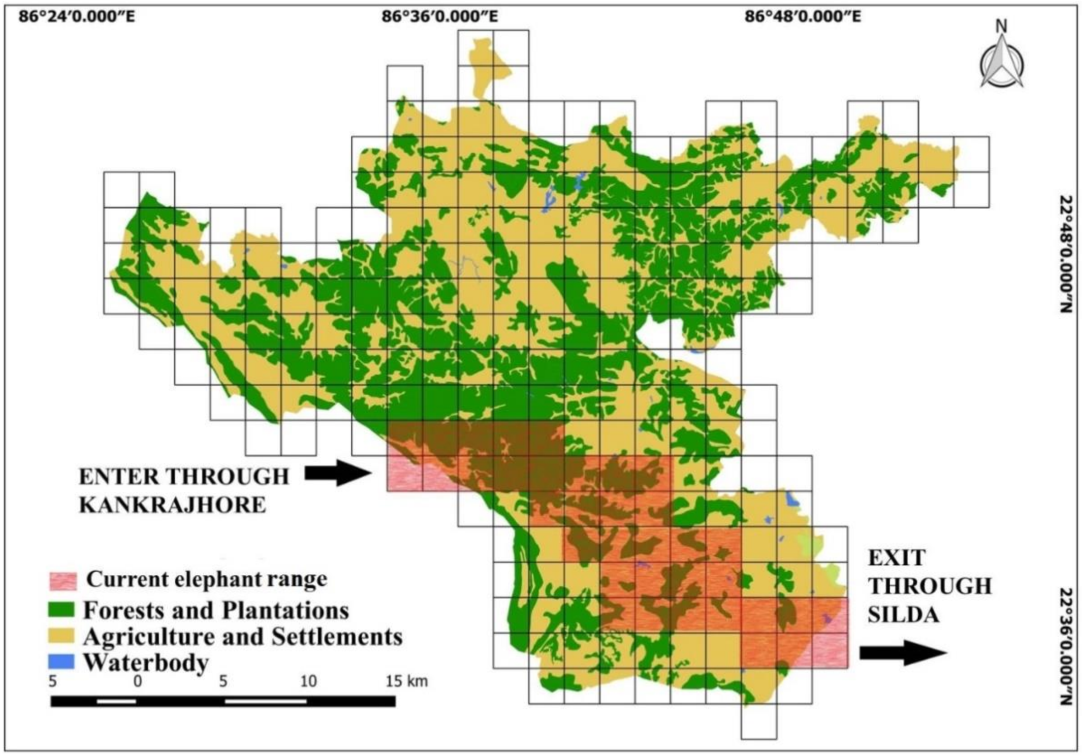

Figure 3.18 Area used by elephants in Mayurjharna ER between 2010 and 2018

The elephants using grid cells in the study area increased as the forest edge (β = 1.51 ± 0.16_{SE}), area of forest (β = 0.14 ± 0.11_{SE}), area of agricultural (β = 0.12 ± 0.11_{SE}) and barren area (β = 0.01 ± 0.13_{SE}) increased. The estimates of predicted probability of using a grid cell were classified as very low ($\widehat{\psi}$ = <0.20), low ($\widehat{\psi}$ = 0.21–0.40), medium ($\widehat{\psi}$ = 0.41–0.60), high ($\widehat{\psi}$ = 0.61–0.80), and very high ($\widehat{\psi}$ = >0.81), and the same was mapped (Fig. 3.19). This shows that 59 out of 455 grid cells have a high probability, while 37 grid cells show relatively less probability of elephants using the grid cells.

Table 3.3 All the models for the probability of using a grid cell by elephants in South Bengal

Model	$\hat{\psi}$	(SÊ)	AIC	Δ AIC	AIC w_i	Model Likelihood	K	-2*LogLike
ψ (FOREDG), p(.)	0.36	0.03	1375.55	0.00	0.27	1.00	3	1369.55
ψ (FOREDG+FA), p(.)	0.36	0.03	1376.64	1.09	0.16	0.58	4	1368.64
ψ (FOREDG+AG), p(.)	0.36	0.03	1376.90	1.35	0.14	0.51	4	1368.90
ψ (FOREDG+AG+FA), p(.)	0.36	0.04	1377.06	1.51	0.13	0.47	5	1367.06
ψ (FOREDG+BA), p(.)	0.36	0.04	1377.54	1.99	0.10	0.37	4	1369.54
ψ (FOREDG+AG+BA+FA), p(.)	0.36	0.03	1377.72	2.17	0.09	0.34	6	1365.72
ψ (FOREDG+BA+FA), p(.)	0.36	0.03	1378.55	3.00	0.06	0.22	5	1368.55
ψ (FOREDG+BA+AG), p(.)	0.36	0.04	1378.71	3.16	0.06	0.21	5	1368.71
ψ (FA+AG+SA+SHA), p(.)	0.36	0.03	1461.41	85.86	0.00	0.00	6	1449.41
ψ (SA+SHA), p(.)	0.36	0.03	1467.31	91.76	0.00	0.00	4	1459.31
ψ (FA+SHA+AG), p(.)	0.36	0.03	1485.76	110.21	0.00	0.00	5	1475.76
ψ (FA+AG+WA+SA+BA), p(.)	0.36	0.05	1488.25	112.70	0.00	0.00	7	1474.25
ψ (WA+FA+SA+BA), p(.)	0.36	0.05	1489.69	114.14	0.00	0.00	6	1477.69
ψ (AG+SHA), p(.)	0.36	0.03	1490.16	114.61	0.00	0.00	4	1482.16
ψ (BA), p(.)	0.36	0.03	1490.78	115.23	0.00	0.00	3	1484.78
ψ (BA+AG), p(.)	0.36	0.04	1492.44	116.89	0.00	0.00	4	1484.44
ψ (SHA), p(.)	0.36	0.03	1502.19	126.64	0.00	0.00	3	1496.19
ψ (SA), p(.)	0.36	0.03	1503.25	127.70	0.00	0.00	3	1497.25
ψ (FA+SA), p(.)	0.36	0.03	1504.73	129.18	0.00	0.00	4	1496.73
ψ (FA+AG+SA), p(.)	0.36	0.03	1506.10	130.55	0.00	0.00	5	1496.10
ψ (AG), p(.)	0.36	0.03	1519.77	144.22	0.00	0.00	3	1513.77
ψ (WA+AG), p(.)	0.36	0.03	1521.54	145.99	0.00	0.00	3	1513.54
ψ (.), p(.)	0.36	0.001	1522.00	146.45	0.00	0.00	2	1518.00
ψ (FA+AG+WA), p(.)	0.36	0.02	1523.10	147.55	0.00	0.00	5	1513.10
ψ (WA), p(.)	0.36	0.03	1523.33	147.78	0.00	0.00	3	1517.33
ψ (FA), p(.)	0.36	0.03	1524.00	148.45	0.00	0.00	3	1518.00

ψ: Estimated occupancy parameter; SÊ: Associated standard error; AIC: Akaike Information Criterion; Δ AIC: Difference in AIC values between each model and the model with the lowest AIC; AIC w_i: AIC model weight; K: Number of parameters estimated by the model; FOREDG: Forest Edge Density; AG: Agriculture area, BA: Barren area; FA: Forest area; WA: Water body; SA: Settlement; SHA: Shannon Diversity Index

Table 3.4 Covariates influencing probability of using the grid cells by elephants ranked using the summed model weights, with averaged β co-efficient (SE)

Covariate	Summed AIC weights	*β* co-efficient ± SE
FOREDG	0.80	1.51 ± 0.16
FA	0.29	0.14 ± 0.11
AG	0.27	0.12 ± 0.11
BA	0.10	0.01 ± 0.13

FOREDG: Forest Edge Density; FA: Forest Area; AG: Agriculture area; BA: Barren area

Space use by elephants in 2018

The number of grid cells wherein elephant was detected varied between 16 in November to 36 in April (Fig. 3.20) with an average of 26 grid cells per month, but the number of grid cells with elephant detection did not differ between the months (χ^2 = 16.709, df = 11, p = 0.117). The mean number of grid cells with elephant detection in a month (5.70 ± 2.34 $_{SD}$) differed between the months ($F_{11,353}$ = 64.896, $p < 0.001$) (Fig.3.21). The mean number of grid cells with elephant detection remained low between August and November, but it was very high in January.

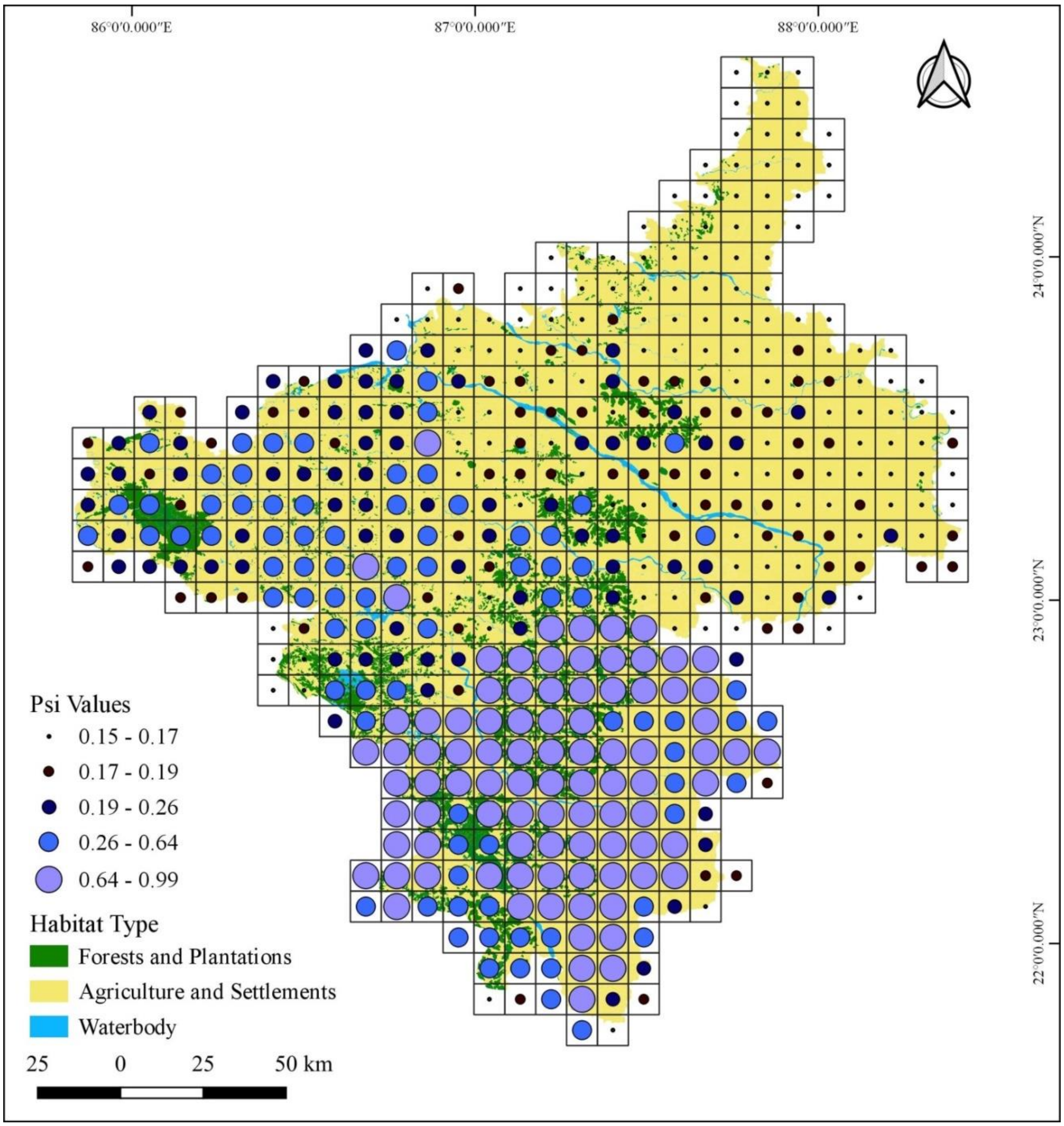

Figure 3.19 Probability of using a grid cell by the elephants in South West Bengal (2018)

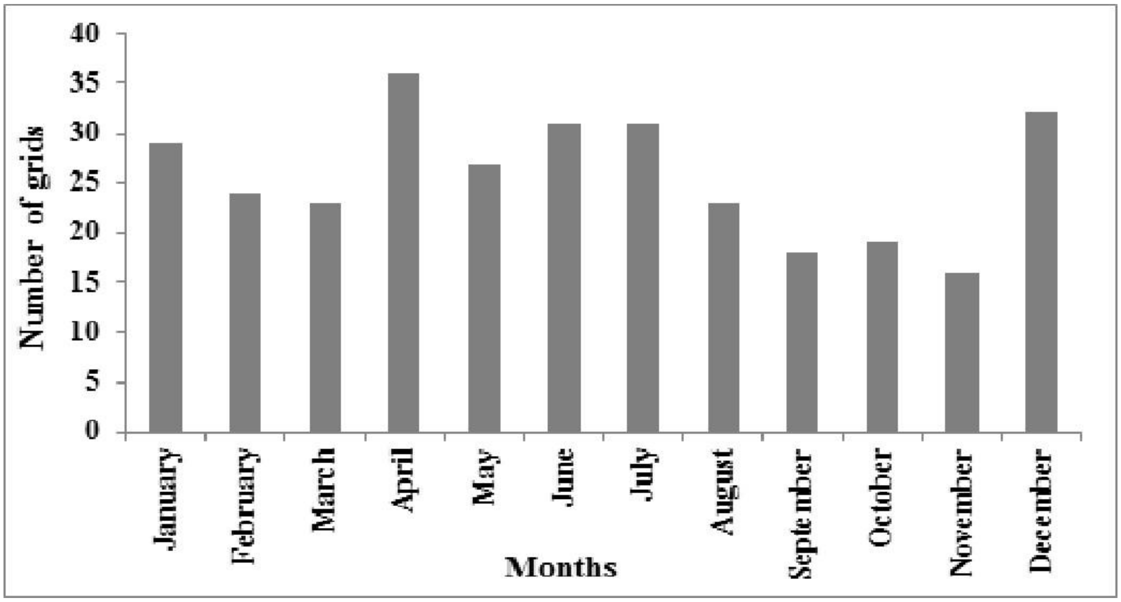

Figure 3.20. Grid cell wise distribution of elephants in different months of the year-2018 in South West Bengal

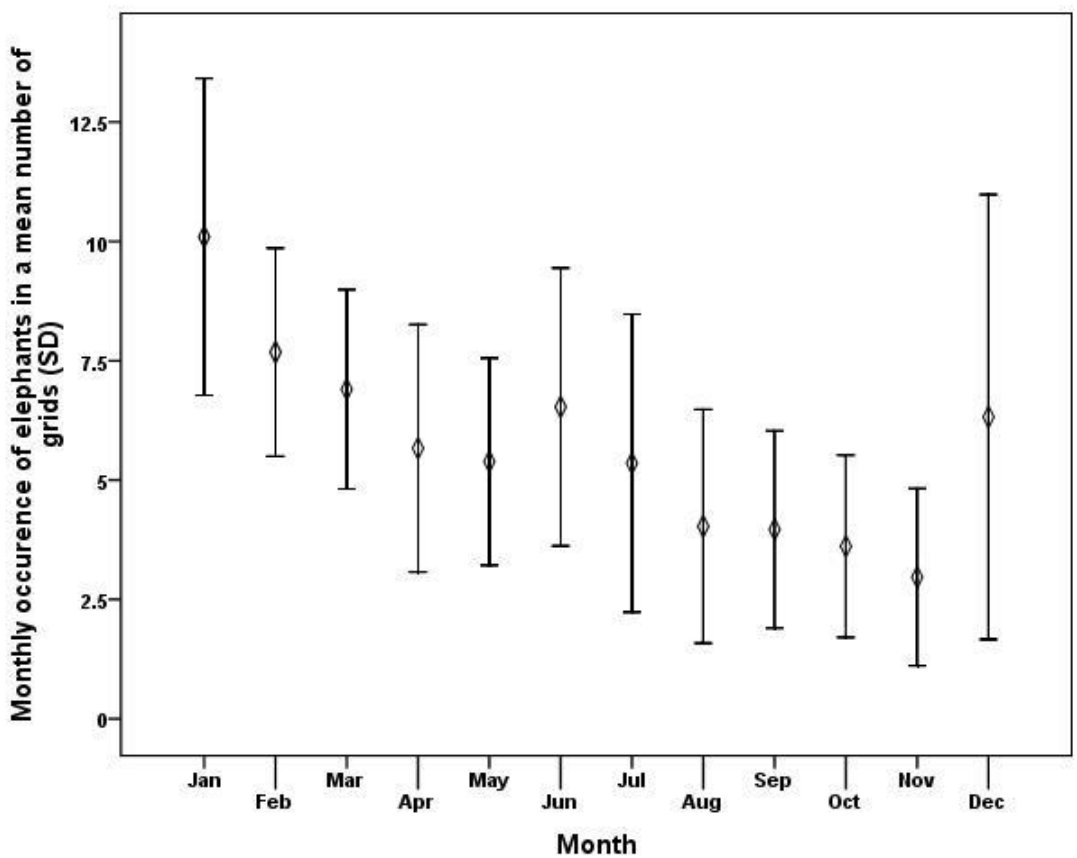

Figure 3.21. Mean number of grid cells with elephants in a month in South West Bengal (2018)

Estimating the population status

In Rupnarayan and Medinipur forest divisions, 72 dung piles were recorded on the belt transects (Table 3.5). The total area of sampling was 0.17 km^2. That gives a dung density of 423.53 dungs/ km^2. Similarly, in Mayurjharna ER, in the total area of 2.07 km^2 sampled 5 dung piles were recorded giving a dung density of 2.42 dungs/ km^2.

Dung decay rate: It took 49 days for 20 dung piles to decompose and 56 days to the rest of 8 dung piles to decompose.

For Decay rate: Mean time (T) = [(20*49) + (8*56)] / 28 = 51 days, therefore, Decay rate (r) = 1/T = 1/51= 0.0196. The decay rate was estimated to be **0.0196 per dung per day.**

The defecation rate (D) in Indian conditions was taken as 16.33 dungs per day.

Therefore, elephant density in Rupnarayan and Medinipur forest divisions (E) = Y× r / D

= 423.53 *0.0196 / 16.33 = **0.52** elephants/ km^2

Elephant density in Mayurjharna ER (E) = 2.42 *0.0196 / 16.33 = **0.003** elephants/ km^2

The estimated elephant density in Rupnarayan and Medinipur forest divisions was 0.52 (Table 3.5). If the area of the two divisions taken together is 2697 km^2, then the minimum population size of elephants is 1348 elephants. Similarly, the estimated elephant density in Mayurjharna ER was 0.003 elephants/ km^2. If the area of the reserve is 414 km^2, then the minimum population size of elephants in Mayurjharna ER is 1.2 elephants.

Detection of elephants on line transect: A total of 620.40 km of transect walk was carried out Mayurjharna ER (Table 3.6) with no elephant detection. Hence, the density could not be computed.

Table 3.5 Estimates of elephant density using dung count method for Rupnarayan and Medinipur forest divisions and Mayurjharna ER

Area	No. of Transects	Dung piles found	Area (km^2)	Density (elephants/ km^2)
Rupnarayan and Medinipur	25	72	0.17	0.518
Mayurjharna ER	28	5	2.07	0.003

Table 3.6 Sampling effort and detection of elephants in Mayurjharna ER

Forest Range	No. of transect lines	The total distance of transect lines (km)	Number of replications	No. of detections
Bhulaveda	7	15.2	12	0
Belpahari	5	6.8	12	0
Banspahari	2	4.4	12	0
Jhilimili	3	4.4	12	0
Ranibandh	3	6.3	12	0
Motgoda	2	3.8	12	0
Fulkusma	2	3.4	12	0
Jamuna	4	7.4	12	0

Social organization: I have identified seven herds in South West Bengal from which demographic data on five herds with a total sum of 97 individuals have been collected. The herds were classified in different age-sex classes (Table 3.7). The mean group size was 17 animals; the adult female: calf ratio was 1:0.51 while adult male: adult female ratio was 1:0.4.

Table 3.7 Details of the elephant herds in South West Bengal

Herd ID	Adult Male	Adult Female	Juvenile	Calf	Unidentified	Total
1	2	6	1	1	0	10
2	2	11	1	3	0	17
4	5	11	6	4	0	26
6	3	4	0	2	3	12
7	7	15	3	0	0	25
						97

3.4 Discussion

The elephants expanded their range from ~1200 km^2 in the 1950s to ~13200 km^2 by 2010–18. One of the major hypotheses for such a greater expansion by elephants is the disturbance caused in the Dalma Wildlife Sanctuary and adjoining areas in the Singhbhum district of Jharkhand. The iron ore mining in the adjoining Dalma Wildlife Sanctuary caused perilous disturbances to the ecological conditions (Négrel *et al.*, 2007; Giri *et al.*, 2017) that disrupted the ecological balance in the forest (Singh and Chowdhury, 1999; Lohani *et al*., 2008; Guha and Guha, 2014). This resulted in habitat degradation, deterioration in the quality of drinking water, and loss of refuge cover for the elephants (Guha and Guha, 2014) that forced the elephants to move towards Mayurjharna in South Bengal (Chatterjee, 2016). Elephants from the Dalma range started moving towards Mayurjharna between October and December due to the availability of the paddy crop, but their movement was limited to the west of the Kangsabati river (Dey, 1991). By the mid-1970s, elephants started moving into Purulia district up to Sindhri (Shahi, 1980), where they stayed for 20 days. Shahi (1980) reported the movement of elephants in September and some incidences of crop damage in Paschim Medinipur during that time.

The first long-distance movement by elephants from the Dalma to Purba Medinipur district beyond the Kangsabati river was recorded in 1987 (Dey, 1991, 1993; Datye and Bhagwat, 1995) where a herd of 50 elephants from Dalma moved to West Bengal after the wet season and stayed through the winter season. It can be attributed to the success of the forestry projects (Datye and Bhagwat, 1995) that converted a few patches of degraded land into forests which were surrounded by agricultural land and water (Chatterjee, 2016). This provided a corridor for movement and shelter for the elephants (Singh *et al*., 2002; Chatterjee, 2016). The vast croplands and no competition from other wild animals might have been a reason for the elephants to increase their range in the landscape. Another major reason for the change in the movement was the forest degradation in the Mayurjharna ER (Mandal and Chatterjee, 2021). Apart from this, the movement of elephants outside the Mayurjharna area is largely affected by the degradation and conversion of the forest area into agricultural land. The degradation started with large-scale deforestation of forest lands following the arrival of the British; forest-dwelling people were forced to take up settled agriculture in the hilly landscape of the Mayurjharna-Dalma areas (Gupta, 2014). The natural vegetation of Mayurjharna ER progressively degraded due to 'Babui' grass (*E. binate*) cultivation, NTFP collection, and agriculture (Datta and Sarkar, 2012; Shit and Pati, 2012; Chatterjee and Mandal, 2020). The alteration and overexploitation of the forest in Mayurjharna ER led to less availability of forage; meanwhile, the ample nutritional crops in the agricultural fields outside the reserve attracted the elephants. This would have driven the elephants to raid the agricultural crops (Datye and Bhagwat, 1996), consequently, the elephants started visiting crop fields outside the reserve. Since then, the elephants enter Mayurjharna ER from Dalma WLS, use the reserve for a shorter duration, and exit to move towards other areas. The reserve, therefore, appears to have served just as a gateway for elephants to other parts of the landscape in recent times. This demonstrates how anthropogenic activities have influenced the range expansion of elephants to an agricultural landscape.

The proximity of crop fields to the forest edge provides a greater crop depredation opportunity for elephants (Goswami *et al*., 2015), thus increasing edge density of forests and the presence of elephants in those areas is evident. The presence and density of crop fields adjacent to forests can also be anticipated to increase as the village density is high in landscapes like South Bengal, primarily for agricultural purposes. The barren fragments of land also influenced the probability of using a grid cell by the elephants because they act as corridors, allowing elephants to disperse and move between the fragments (Johnsingh and Williams, 1999). However, this leads to an increase in interactions between elephants and humans, leading to conflicts (Johnsingh and Williams, 1999). The barren areas having a scarcity of grasses or areas without any grass, and the presence of closed-canopy forests of sal along with peripheral agricultural land, become reasons for seeking crops in lieu of wild grasses (Santra *et al*., 2008).

All year-round presence of elephants could be attributed to a change in the agriculture pattern from rain-dependent cropping to irrigated cropping (Santra *et al*., 2008). The Kangsabati Reservoir Project along with various irrigation schemes provided the facilities for irrigation that has increased cropping intensity by 19.59 % in South Bengal (Saxena, 2012), resulting in the availability of food in almost all months. However, a peak in the numbers of grid cells with elephants was observed in the month of January due to the harvesting season of major cash crops like potato and rice in the area (Adhikari *et al*., 2011), leading to high forage availability.

I also attempted to estimate the elephant density using direct detection on line transects and dung count on belt transects. The elephants were not detected on line transects, despite 620.4 km of walk-on spatially representing line transects in Mayurjharna ER. During the dung count survey, 72 dung piles were detected in 0.17 km^2 sampling in Lalgarh and Medinipur forest divisions and five dung piles in 2.07 km^2 sampling in Mayurjharna ER. Thus, I could estimate the density of elephants only from the belt transect sampling, i.e. 0.51 elephants/ km^2 in Lalgarh and Medinipur forest divisions and 0.003 elephants/ km^2 in Mayurjharna ER.

A minimum of 40 detections is required to use DISTANCE software to compute the density of an animal using line-transect technique (Buckland *et al*., 1993), otherwise causing bias due to the high confidence interval. To use detection-based estimation using DISTANCE program, there should be some resident and evenly distributed minimum population of a species to obtain minimum required detections to estimate the density. However, that was not the case in the current study and hence estimation could not be made. There are many factors that affect elephant densities, such as the defecation rate and other spatial and temporal factors. One basic assumption of dung survey is that all the elephants in a habitat defecate at the same rate, which, however, is not true. According to Wanghongsa, (2004), there is a substantial difference in the defecation rate between ages and sexes of elephants. Elephants are also known to defecate more in humid zones (Sivaganesan and Kumar, 1995), than elephants in a dry zone. The deterioration rate also acts as a major variable. Nchanji and Plumptre, (2001) found that the deterioration rate was faster in the wet season than in the dry season that may be due to the higher activity of insects in the wet season, which accelerates the deterioration process of dung piles.

An estimate of densities using similar field techniques was available for several protected areas and landscapes in South Asia (Table 3.8). In Sri Lanka, the population density was estimated to be between 0.10 and 0.46 elephants/ km^2 (Eisenberg and Lockhart, 1972). Sukumar, (1989a) reported 0.56 elephants/ km^2 in the deciduous forests of Chamarajanagar, Kollegal and Satyamangalam Forest Divisions in South India. Population densities as high as 3.10 elephants/ km^2 in Mudumalai Tiger Reserve (Tamil Nadu Forest Department, 2010), 2.60 elephants/ km^2 in Kaziranga National Park, 2.40 elephants/ km^2 in Nagarhole Tiger Reserve, 2.10 elephants/ km^2 in Bandipur National Park (Jathanna *et al*., 2015), 1.75 elephants/ km^2 in Wayanad Wildlife Sanctuary (Kerala Forest Research Institute, 2007), 1.70 elephants/ km^2 in Biligiri Rangaswamy Temple Tiger Reserve (Kumara *et al*., 2012) were reported based on dung count/transect surveys. Varman *et al*. (1995) reported 1.54 elephants/ km^2 for Mudumalai Wildlife Sanctuary and Baskaran *et al*., (2007) reported a density of 1.10 elephants/ km^2 for Anamalai Hills. These estimates indicate that line transects and dung surveys have provided robust estimates. On comparing the estimates with the other areas in the country, the density of elephants in Mayurjharna ER is insignificant while in the forest divisions of Rupnarayan and Medinipur is comparable but questionable. Making direct comparisons of density estimates may not be appropriate because elephants in South Bengal appear to be a moving population. At any given point of time, one or two herds would be present in the landscape; however, their movement pattern is unnatural due to regular driving of them for long distances. Thus, determining the density using line-transect technique using direct detections of the animal from transect walk or through dung count would be difficult. In the absence of a resident population, the possibility of zero detection was obvious in Mayurjharna ER. Even, very low detection of fresh dungs during the dung count made it difficult to estimate their density using dung count method. Presence of a few herds of elephants in the entire landscape of South Bengal, and herds always being driven from one forest patch to the other, results in elephants venturing into new areas, making it more complicated to estimate the area of suitable habitat for elephants in the study area. Thus, estimating the population size for the entire landscape including Mayurjharna ER would be biased if the dung count method or line transect method is followed.

Table 3.8 Estimate of Asian elephant density from other parts of the country

Area	Elephants/ km^2	Method	Source
Mudumalai WLS	1.54	Dung count	Varman *et al*., 1995
Buxa TR	0.35		Sukumar *et al*., 2003
Wayanad WLS	1.75	Dung count	Kerala Forest Research Institute, 2007
Kalakad–Mundanthurai TR	0.10- 0.20	Dung count	Varma, 2008
Bannerghatta NP	0.70	Dung count	Varma *et al*., 2009
Mudumalai TR	3.10	Dung count	Tamil Nadu Forest Department, 2010
Nilgiri North	0.50	Dung count	Tamil Nadu Forest Department, 2010
Satyamangalam TR	0.30	Dung count	Tamil Nadu Forest Department, 2010
Biligiri Rangaswamy Temple TR	1.70	Distance sampling	Kumara *et al*., 2012
Anamalai Hills	1.10	Dung count	Baskaran *et al*., 2013b
Bandipur NP	2.10	Distance sampling	Jathanna *et al*., 2015
Bhadra TR	0.30	Distance sampling	Jathanna *et al*., 2015
Kaziranga NP	2.60	Distance sampling	Jathanna *et al*., 2015
Nagarahole TR	2.40	Distance sampling	Jathanna *et al*., 2015
Mayurjharna ER	0.0029 and 0.50	Dung count	Current study

The formation of groups and their sizes are highly influenced by the availability of forage (Jarman, 1974) and predation (Geist, 1998). Usually, the elephants have huge resource requirements; hence, smaller groups are formed to avoid competition within a family unit (Sukumar, 2003). Living in small groups during foraging can be a good approach to avoid competition, especially when there is a shortage of food or food availability is patchy. The group sizes of elephant are based on strong social connections/bonds, which are influenced by factors like avoiding competition for food. Elephants live in groups of 5 to 20 animals who interact and communicate with each other as one family unit (Sukumar, 2006). Similar observation was made in the present study too where group sizes of 12 to 20 elephants were recorded. Similar mean herd sizes have been observed in other parts of the country too (Table 3.9).

The ratio of female to calves in a herd is an important parameter that influences the population growth rate of elephants (Ramesh *et al*., 2012). The high number of calves and juveniles shows the tremendous reproductive health in the elephant females in South Bengal. The reported adult male to female ratio is comparable to other areas in the country (Table 3.9) which could be attributed to the lack of competition among males for mating and hence, the survival of males becomes easy.

Table 3.9 Herd size and age-sex ratios of Asian elephants from protected areas in India.

Area	Mean herd size	Adult female: calf ratio	Adult female: adult male ratio	Source
Mudumalai, India	4.6	1:0.26	1:0.11	Ramesh *et al*., 2012
Bandipur	7.8	1:0.37	1:0.40	Johnsingh, 1983
Nagarhole	3.5	1:0.20	1:0.18	Arivazhagan, 2005
Hasanur- Biligiri Ranga Hills	7.6	1:0.20	1:0.20	Sukumar, 1985
Periyar	-	1:0.16	1:0.02	Arivazhagan, 2005
Parambikulum	7.9	1:0.32	1:0.14	Easa and Balakrishnan, 1995
Rajaji	6.8	1:0.41	1:0.54	Williams *et al*., 2007
South West Bengal	17	1:0.51	1:0.31	Present study

The study unfolded the pattern of range expansion of elephants in the agricultural landscape of South Bengal despite the dearth of continuous forests. The presence of ample agricultural land to feed elephants has enticed them to the region, increasing their stay to almost all-around the year. However, estimating their numbers has been a challenge, all attempts to guess their numbers have proven to be inadequate. Considering the highly dynamic situation of elephant movement, continuous monitoring of the elephant population would help in a better understanding of the scenario.

Chapter 4

Resource availability for elephants in South West Bengal

4.1 Introduction

Quantitative analysis on tree species diversity in the forest ecosystem provides a better understanding of its floristic status and distribution pattern which helps in the conservation and management of biodiversity (Pradhan and Rahaman, 2015). The characteristics of vegetation play an important role in determining the distribution and diversity of animals in a particular habitat (MacArthur, 1972). The herbivore population is known to affect the forest composition of an area (Nuttle *et al*., 2013). Herbivores influence plant community structure and may promote the domination of certain species (Wardle *et al*., 2002). The forest ecosystem of any area in turn influences the herbivore population and their dependency on the local flora (Gordon *et al*., 2004), and any change in the forests affects its herbivore community. The increasing human activity in and around forests changed the biodiversity of the region (Swaine *et al*., 1987; Abdulhadi *et al*., 1987; Vitousek, 1994; Hooper *et al*., 2005). The effective management of dynamic plant communities requires an understanding of the basic processes involved in vegetation change (Niering, 1987). A sound understanding of the species diversity is necessary for the appropriate conservation and restoration of biological diversity.

South Bengal, had uncontrolled forest destruction during the expansion of the Bengal Nagpur railway line in 1889 followed by the railway tracks through the Medinipur district in 1903 (Palit, 1991; Malhotra, 1995). Such massive destruction of forests pressed the government to establish a committee in 1938, which led to the Bengal Private Forest Act of 1945 mandating the landowners to plant and restore the forests that were felled. In 1981, under the joint forest management (JFM) programme, the Social Forestry Project was launched with an objective of planting fast-growing tree species on public and private lands to meet the fuel demands of the local people (Malhotra and Poffenberger, 1989) e.g., *Eucalyptus* sp., akashmoni (*Acacia auriculiformis*), and mahua (*M. longifolia*). However, these regenerated forests of sal and other fast-growing species replaced the indigenous plant species of lateritic tracts. Thus, within the last one and a half century, the forests were modified due to the replacement of the indigenous species by largely exotic species.

Elephants are generalist feeders and need about 108 kg fresh (27 kg dry) to 150 kg plant fodder per day owing to its enormous size (Sukumar, 1986). Due to this, elephants deplete the small forest patches very fast and need to move to the next. They can alter the plant community of a landscape structure at a high rate.

To understand the food resource requirements of elephants and habitat quality, it was essential to study the vegetation in detail. In this chapter, I discuss the diversity and stand structure of trees that form natural food sources for elephants and food availability from major cultivated crops.

4.2 Methodology

Vegetation assessment: 708 quadrats of size 10 x 10 m were placed randomly to sample the woody plants in the study site (Fig. 4.1). From each quadrat, the stems with GBH (Girth at Breast Height) >10 cm were designated as woody plants (Hall and Okali, 1979).Although elephants feed on plants with less than 10 cm GBH and also grasses but I have not considered that in my work due to many field constraints. Each stem in the sampling plot was recorded with the name of the species and GBH. Plant species were initially identified by their vernacular names (Bengali and Hindi) with the help of field assistant or other Forest Department personnel who accompanied the researcher. Scientific names of the plant species were later ascertained using existing literature (Santra *et al*., 2008; Basu, 2009) and online portals like 'Flowers of India' (http://www.flowersofindia.net/) and 'Indian Biodiversity Portal' (https://indiabiodiversity.org/).

The occurrence matrix of plant species in each quadrant was developed. The adequacy of the plant species sampled was checked using the species accumulation curve by plotting the cumulative number of plant species recorded against the cumulative number of plots sampled in Estimate S ver. 9 (Colwell,1994-2014). Quantitative community characteristics (Table 4.1) including frequency, density, abundance, relative frequency, relative density, relative abundance, relative dominance, Importance Value Index (IVI), Simpson's Index (SI), Shannon diversity index (H) and composition of plant communities were computed following Curtis and McIntosh, (1950), Philips, (1959), Muller-Dombois and Ellenberg, (1974), and Mori *et al*.,(1983).

Data on the crops cultivated in South Bengal was collected from the Agricultural Department of all the districts in South Bengal for the period of 2016–17. The total area under cultivation and the yearly production of major crops was collected through the annual reports of the department (Agricultural Statistics at a Glance, 2017). Cropping pattern was observed during the field visits and details such as species, variety, and area under cultivation were recorded.

Table 4.1 Calculating quantitative structure and composition of plant communities

Parameters	Formula
Frequency (%)	(No. of quadrats in which a species occurred /total no. of quadrats examined) X 100
Abundance	Total number of individuals of a species /no. of quadrats in which the species occurred
Density	Total no. of individuals of a given species/total no. of quadrats examined
Relative density	(No. of individuals/no. of individuals of all Species) X 100
Relative abundance	(Abundance of species X 100) /sum of all abundances
Relative frequency	(Number of quadrats occurring /total no. of quadrats) X 100
Basal area	$(\text{GBH in m})^2/4\pi$
Relative basal area	(Total basal area of individuals /total basal area of all species) X 100
Importance Value Index (IVI)	Relative density + relative dominance + relative frequency
Simpson Index (SI)	$D = \Sigma (n_i /N)^2$ (where, n_i = IVI; N = total IVI of all species)
Shannon–Wiener's Index	$H' = \Sigma(n_i/N) \ln(n_i/N)$
Species Occurrence Rate	Species richness/ species density, where species richness is no. of species in each group

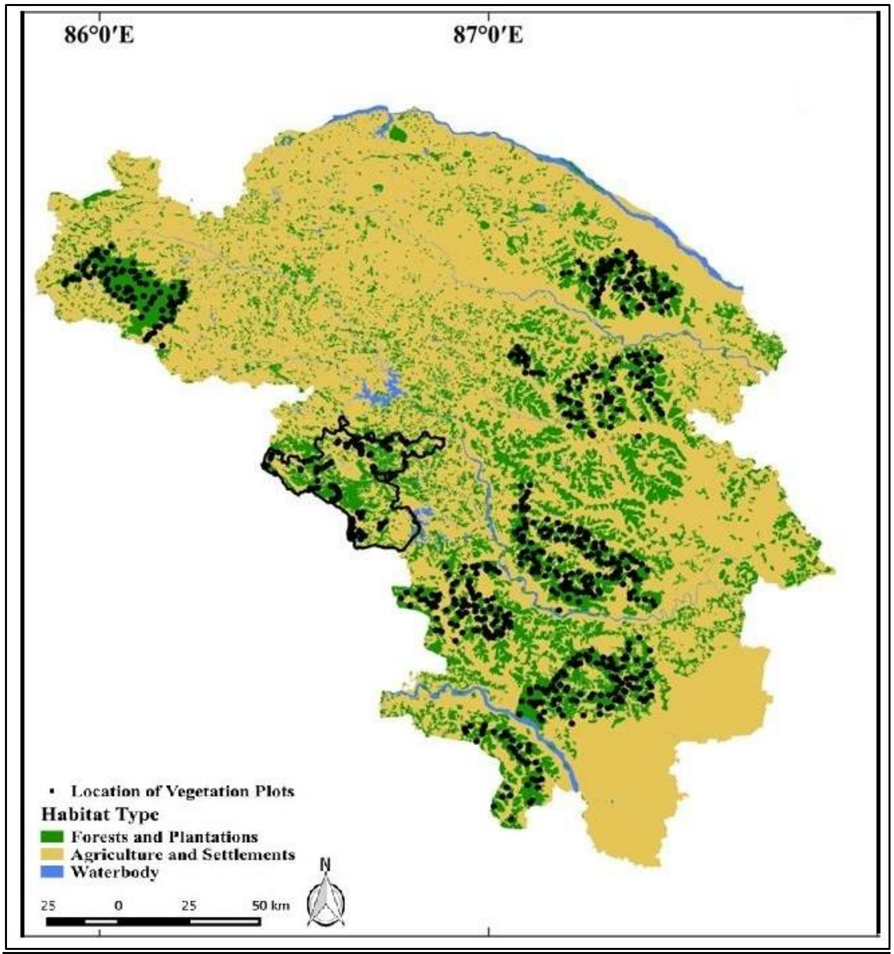

Fig 4.1 Location of sampling plots for vegetation assessment in South West Bengal

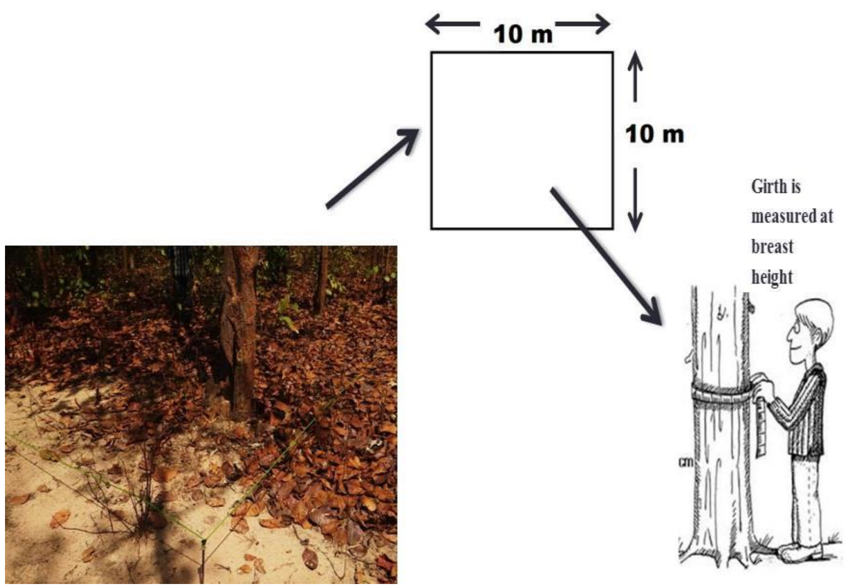

Figure 4.2 Field methods for vegetation sampling

4.3 Results

Vegetation Assessment: A total of 12151 trees belonging to 70 species (Table 4.2) were recorded in 708 quadrats (7.08 hectares) in South West Bengal. The species accumulation curve was estimated using Chao-2 providing a least biased estimate of species richness (Fig. 4.3), which depicts an almost reaching asymptote as the expected number of species was 71 while, the observed number of species was 70. Among them, *S. robusta* accounted for the highest number of individuals (75.75%, n= 9206), followed by *Madhuca longifolia* (n=521), *Buchanania cochinchinensis* (n=231), *D. melanoxylon* (n=203), *Semecarpus anacardium* (n=185) and *Cleistanthus collinus* (n= 142). *S. robusta* (IVI= 151.78, SDI= -0.34) was the most dominant species followed by *M. longifolia* (IVI=21.768, SDI= -0.19), *Gardenia gummifera* (IVI= 19.50, SDI= -0.18), *D. melanoxylon* (IVI=13.31, SDI= -0.14) and *B. cochinchinensis* (IVI=10.72, SDI= -0.12). The Shannon diversity index of the tree species in the study area was -2.24, and the Simpson index of diversity was 0.27, the stand density was 1716.38 individuals ha^{-1} and the mean basal area was 5.76 m^2 ha^{-1} (Table 4.3).

The stand density decreased as the girth class increased, with a maximum density of 1147 trees ha^{-1} in girth class of 10-29 cm and the lowest density of 2 trees ha^{-1} in the girth class of 150—169 cm (Table 4.4). The highest tree species richness (50) was found in the girth classes of 10-29 cm GBH followed by 30-49 cm GBH (27) and lowest in 150-169 cm GBH (3); also, the girth class 30 - 49 cm GBH contributed to the highest basal area (Fig. 4.4). Similarly, the occurrence rate of species decreased as girth class increased (Table 4.4).

Familial Composition: The number of tree families in the sampled area was 27 (Fig. 4.5). Among them, Fabaceae was represented by seven species dominating the forest woody trees followed by Combretaceae (6 species), Anacardiaceae (5species), Rubiaceae (5 species) and Euphorbiaceae (4 species). Based on the density, family Dipterocarpaceae (n=9206) represents the highest number followed by Anacardiaceae (n=566) and Sapotaceae (n= 521).

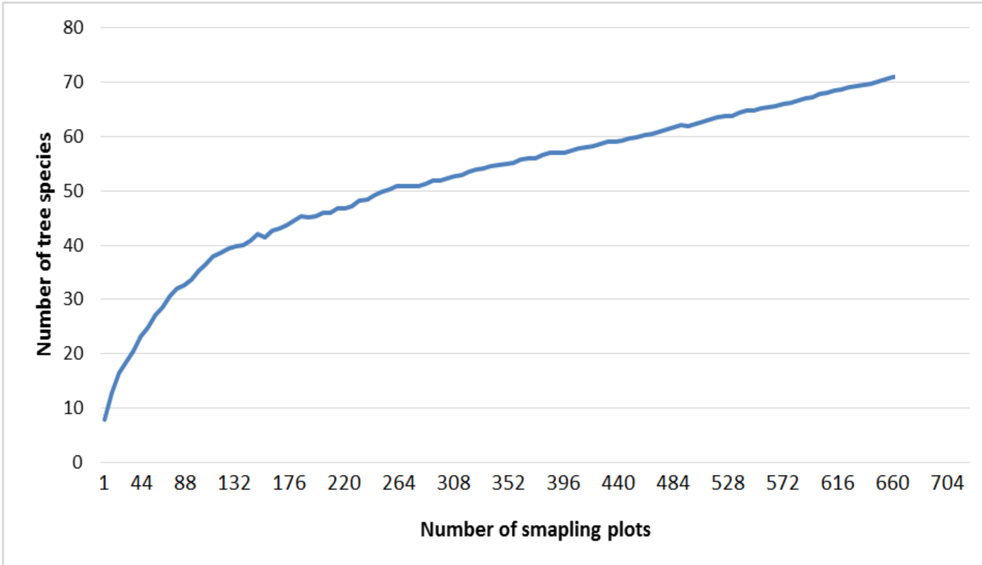

Figure 4.3. The species accumulation curve using Chao-2

Table 4.2. Important Value Index of tree species in South West Bengal

S.No.	Tree species	Family	TI	D	Freq.	BA	IVI	SI	SDI
1	*Acacia auriculiformis*	Fabaceae	1	0.001	0.14	0.014	0.040	0.000	-0.001
2	*Acalypha Indica*	Euphorbiaceae	2	0.003	0.28	0.024	0.079	0.000	-0.002
3	*Aegle marmelos*	Rutaceae	58	0.082	7.34	3.877	2.910	0.000	-0.045
4	*Alangium salvifolium*	Cornaceae	1	0.001	0.14	0.010	0.039	0.000	-0.001
5	*Albizia lebbeck*	Fabaceae	9	0.013	1.27	0.323	0.409	0.000	-0.009
6	*Anacardium occidentale*	Anacardiaceae	4	0.006	0.42	0.131	0.150	0.000	-0.004
7	*Annona squamosa*	Annonaceae	72	0.102	9.60	7.216	4.306	0.000	-0.061
8	*Anogeissus latifolia*	Combretaceae	72	0.102	9.89	2.784	3.264	0.000	-0.049
9	*Artocarpus heterophyllus*	Moraceae	98	0.138	13.84	4.835	4.779	0.000	-0.066
10	*Bauhinia Purpurea*	Fabaceae	1	0.001	0.14	0.060	0.051	0.000	-0.001
11	*Bombax ceiba*	Bombacaceae	1	0.001	0.14	0.066	0.053	0.000	-0.002
12	*Buchanania cochinchinensis*	*Anacardiaceae*	231	0.326	32.06	9.662	10.721	0.001	-0.119
13	*Butea monosperma*	Fabaceae	12	0.017	1.69	0.388	0.534	0.000	-0.011
14	*Casearia tomentosa*	Salicaceae	48	0.068	6.64	1.304	2.049	0.000	-0.034
15	*Cassia Fistula*	Fabaceae	4	0.006	0.42	0.122	0.148	0.000	-0.004
16	*Ceriscoides turgida*	Rubiaceae	1	0.001	0.14	0.094	0.060	0.000	-0.002
17	*Cleistanthus collinus*	Phyllanthaceae	142	0.201	19.35	3.863	6.004	0.000	-0.078
18	*Cochlospermum religiosum*	Bixaceae	1	0.001	0.14	0.033	0.045	0.000	-0.001

19	*Croton persimilis*	Euphorbiaceae	9	0.013	1.13	0.131	0.333	0.000	-0.008
20	*Desmodium oojeinense*	Fabaceae	2	0.003	0.14	0.026	0.051	0.000	-0.001
21	*Diospyros exsculpata*	Ebenaceae	4	0.006	0.42	0.096	0.142	0.000	-0.004
22	*Diospyros melanoxylon*	Ebenaceae	203	0.287	28.39	24.026	13.315	0.002	-0.138
23	*Eucalyptus tereticornis*	Myrtaceae	54	0.076	7.06	7.176	3.638	0.000	-0.054
24	*Ficus racemosa*	Moraceae	1	0.001	0.14	0.056	0.050	0.000	-0.001
25	*Ficus religiosa*	Moraceae	1	0.001	0.14	0.029	0.044	0.000	-0.001
26	*Flacourtia indica*	Salicaceae	1	0.001	0.14	0.013	0.040	0.000	-0.001
27	*Gardenia Gummifera*	Rubiaceae	126	0.178	17.37	60.446	19.501	0.004	-0.178
28	*Gymnema sylvestre*	Asclepiadaceae	5	0.007	0.56	0.103	0.180	0.000	-0.004
29	*Haldinia cordifolia*	Rubiaceae	12	0.017	1.69	0.262	0.503	0.000	-0.011
30	*Holarrhena antidysenterica*	Apocynaceae	22	0.031	2.82	0.318	0.826	0.000	-0.016
31	*Holoptelea integrifolia*	Ulmaceae	2	0.003	0.28	0.035	0.082	0.000	-0.002
32	*Joannesia princeps*	Euphorbiaceae	9	0.013	0.99	0.238	0.331	0.000	-0.008
33	*Kydia calycina*	Malvaceae	18	0.025	2.40	0.341	0.714	0.000	-0.014
34	*Lannea coromandelica*	Anacardiaceae	38	0.054	4.94	1.410	1.653	0.000	-0.029
35	*Lannea grandis*	Anacardiaceae	108	0.153	14.97	1.191	3.928	0.000	-0.057
36	*Madhuca longifolia*	Sapotaceae	521	0.736	72.46	11.944	21.768	0.005	-0.190
37	*Mallotus nudiflorus*	Euphorbiaceae	4	0.006	0.56	0.045	0.157	0.000	-0.004
38	*Mitragyna parvifolia*	Rubiaceae	11	0.016	1.27	0.355	0.433	0.000	-0.009
39	*Myristica fragrans*	Myristicaceae	1	0.001	0.14	0.030	0.044	0.000	-0.001
40	*Neolamarckia cadamba*	Rubiaceae	65	0.092	8.62	2.379	2.851	0.000	-0.044
41	*Nyctanthes arbor-tristis*	Oleaceae	3	0.004	0.42	0.033	0.118	0.000	-0.003
42	*Phyllanthus acidus*	Phyllanthaceae	6	0.008	0.71	0.099	0.215	0.000	-0.005
43	*Phyllanthus emblica*	Phyllanthaceae	2	0.003	0.28	0.023	0.079	0.000	-0.002
44	*Pterocarpus marsupium*	Fabaceae	72	0.102	9.89	1.194	2.870	0.000	-0.044
45	*Sapindus emarginatus*	Sapindaceae	1	0.001	0.14	0.011	0.039	0.000	-0.001
46	*Sapindus mukorossi*	Sapindaceae	8	0.011	1.13	0.123	0.323	0.000	-0.007
47	*Schleichera oleosa*	Sapindaceae	42	0.059	5.08	2.394	1.958	0.000	-0.033
48	*Semecarpus anacardium*	Anacardiaceae	185	0.261	25.99	4.987	7.967	0.001	-0.096
49	*Shorea robusta*	Dipterocarpaceae	9206	13.003	97.32	228.033	151.781	0.256	-0.345
50	*Streblus asper*	Moraceae	2	0.003	0.28	0.045	0.084	0.000	-0.002
51	*Strychnos nuxvomica*	Loganiaceae	1	0.001	0.14	0.011	0.039	0.000	-0.001
52	*Symplocos racemosa*	Symplocaceae	3	0.004	0.28	0.049	0.094	0.000	-0.003
53	*Syzygium cumini*	Myrtaceae	106	0.150	14.27	5.892	5.191	0.000	-0.070
54	*Tectona grandis*	Lamiaceae	92	0.130	12.85	3.807	4.276	0.000	-0.061
55	*Terminalia alata*	Combretaceae	121	0.171	16.67	3.319	5.158	0.000	-0.070

56	*Terminalia arjuna*	Combretaceae	4	0.006	0.56	0.047	0.158	0.000	-0.004
57	*Terminalia bellirica*	Combretaceae	50	0.071	6.50	4.478	2.823	0.000	-0.044
58	*Terminalia chebula*	Combretaceae	10	0.014	1.41	0.189	0.412	0.000	-0.009
59	*Terminalia elliptica*	Combretaceae	108	0.153	14.55	1.853	4.263	0.000	-0.060
60	Antar		46	0.065	6.36	0.439	1.761	0.000	-0.030
61	Bodha		29	0.041	3.81	0.668	1.169	0.000	-0.022
62	Goti		2	0.003	0.14	0.031	0.052	0.000	-0.002
63	Ladan lata		1	0.001	0.14	0.074	0.055	0.000	-0.002
64	Lepsi		1	0.001	0.14	0.025	0.043	0.000	-0.001
65	Lulajhangri		1	0.001	0.14	0.013	0.040	0.000	-0.001
66	Merai		1	0.001	0.14	0.011	0.039	0.000	-0.001
67	Rakta dohora		56	0.079	7.06	0.936	2.108	0.000	-0.035
68	Tetalia		2	0.003	0.28	0.020	0.078	0.000	-0.002
69	Tilai		15	0.021	1.84	0.202	0.541	0.000	-0.011
70	Valnk sukti		1	0.001	0.14	0.014	0.040	0.000	-0.001

TI= total individuals, D= density, F= Frequency, BA= basal area, IVI= importance value index, SDI= Shannon Diversity Index, SI= Simpson Index

Table 4.3. Community structure of woody trees in South West Bengal

Species composition variables	**Value**
No. of species	70
No. of family	27
Stand density (Individuals/ ha)	1716.38
Basal area (m^2 ha^{-1})	5.76 m^2 ha^{-1}
Shannon Diversity Index	-2.24
Simpson Dominance Index	0.27

Table 4.4. Stand density, species richness and basal area under various girth classes of trees in South West Bengal

Girth class (cm)	Stand density (stems ha^{-1})	Species richness	Basal area (m^2ha^{-1})	Species occurrence rate
10-29 cm	1147	51	50.65	0.04
30-49 cm	336	27	26.64	0.08
50-69 cm	129	14	12.63	0.11
70-89 cm	59	15	5.38	0.25
90-109 cm	35	10	1.90	0.28
110-129 cm	4	8	1.60	1.89
130- 149 cm	3	6	0.90	1.77
150-169 cm	2	3	0.30	1.77

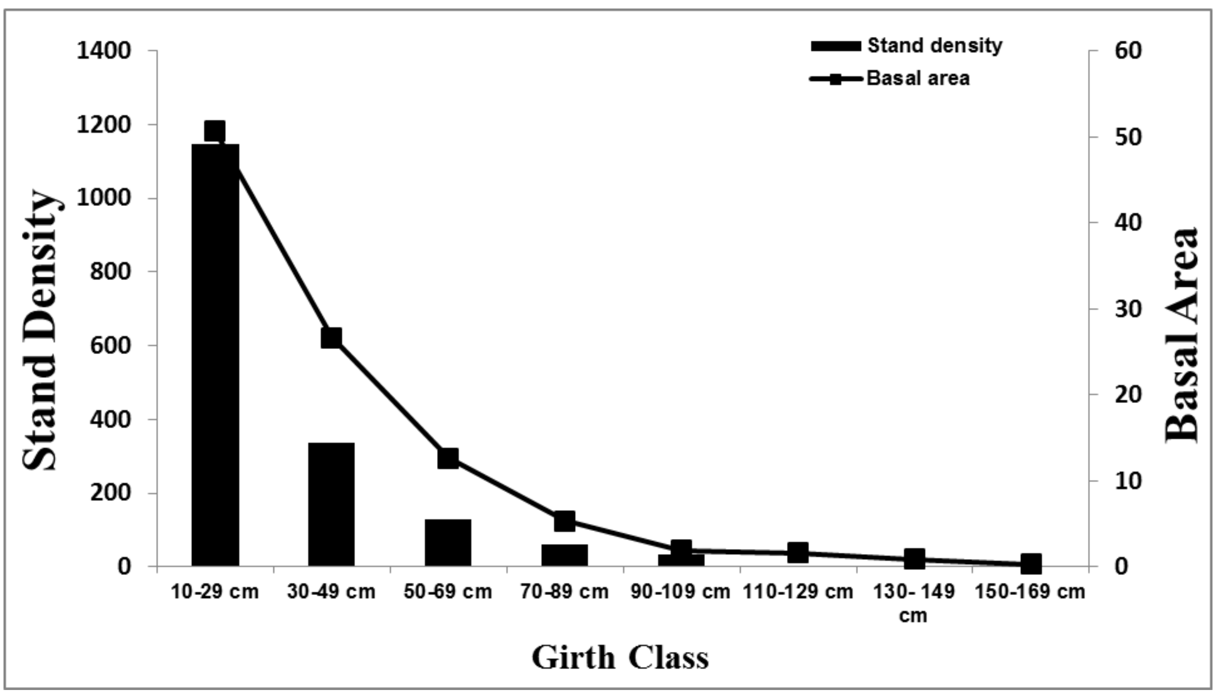

Figure 4.4. Comparison of stand density (stems per ha) and basal area in different girth class of tree species in South West Bengal

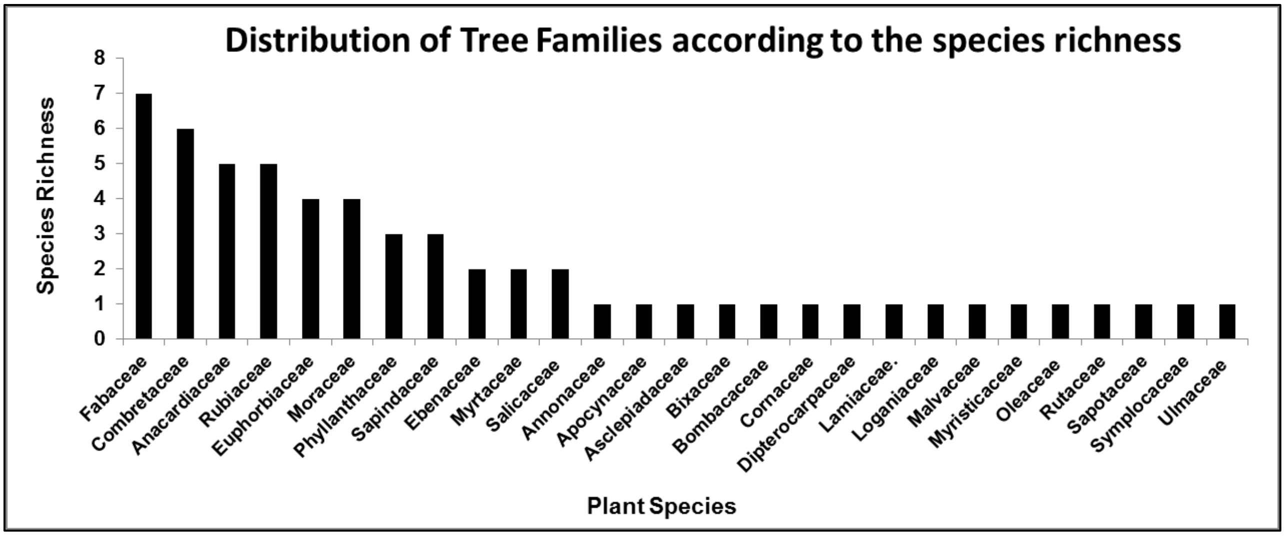

Figure 1.5. Distribution of tree families in South West Bengal

Crops cultivated: In South West Bengal, the total area under cultivation is 21,91,599 hectares wherein ~ 67,50,564 tons of paddy, 9,80,821 tons of sugarcane, 64,47,297 tons of potato and 37,17,815 tons of vegetables are grown (Table 4.5). There was a presence of paddy all around the year while vegetables prevailed for about eight months of the year (Fig 4). Potato and sugarcane were present for nearly four months of the year (Fig 4.6).

Table 1.5. Details of the total cultivated area and the crop productions across the districts of South West Bengal

District	Area under cultivation (in hectares)	Crop production in tons			
		Paddy	Sugarcane	Potato	Vegetables
Birbhum	320610	1261884	60810	272600	613500
Bardhaman (Purba and Paschim)	466630	1896032	113754	1235000	764849
Bankura	490447	984156	393	2943097	893270
Purulia	318702	599421	16250	477000	533080
Paschim Medinipur	595210	2009071	789614	1519600	913116
Total	2191599	6750564	980821	6447297	3717815

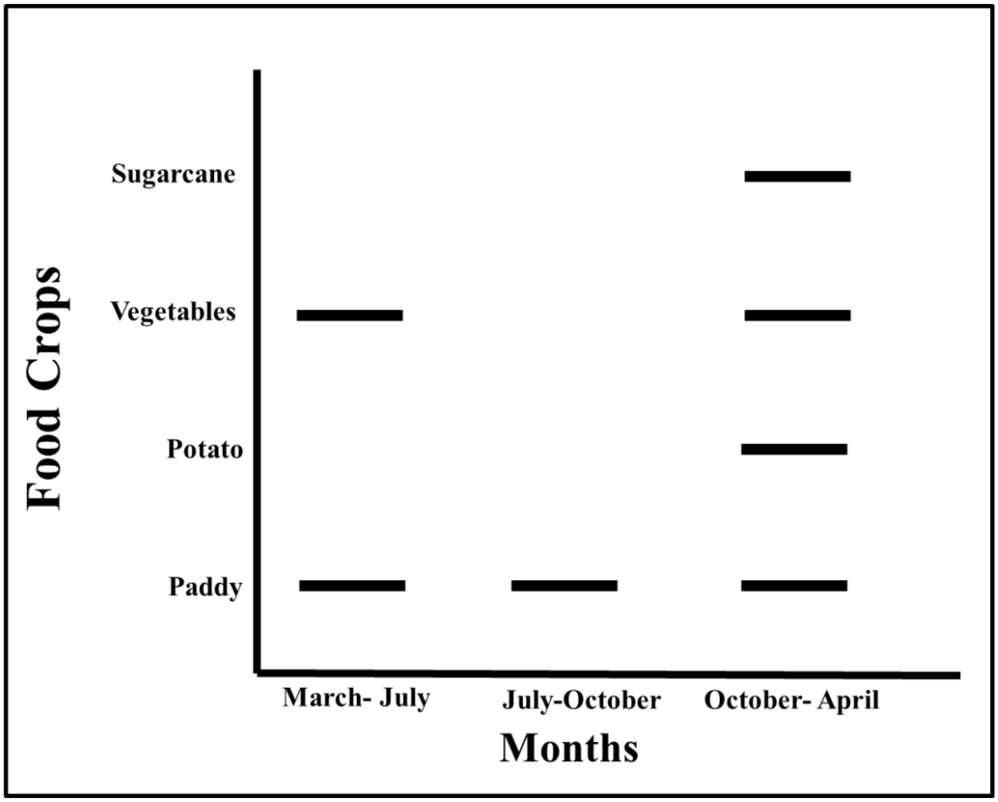

Figure 4.6. Food crop availability for elephants around the year

4.4 Discussion

The study provides quantification of stand structure and tree species composition for entire South Bengal. The area has 70 species belonging to 27 families dominated by the Fabaceae family. The stand density was 1716.38 trees $ha^{-1}$and the basal area of tress was 5.76 m^2 ha^{-1}. *S.robusta* dominates the landscape (14.7 individuals ha^{-2}, 88% of the tree density). Shannon-Weiner Index of -2.24 indicates that the landscape although has high species richness, it is dominated by few species. This is further corroborated by IVI values with *S. robusta* having the highest of 151.781, while the next most dominant species was *M. longifolia* (21.786) and *G. gummifera* (19.501).

Although the stand structure or species composition is not available for the entire South Bengal, 139 species of angiosperms belonging to 51 families was reported from 25 sacred groves (SG) covering an area of 60,500 m^2 in Paschim Medinipur (Pandit, 2011). Similarly, 114 species were reported from 26 SG covering an area of 83167 m^2 in Bankura district (Basu, 2009) and reported *S. robusta* to be the dominant species these sacred grooves. 52 species were reported from 6000 sq. m. in West Midnapur, Bankura and Purulia districts also recorded *S. robusta* to be the dominant species (Santra *et al*., 2008). Although during my study, *S. robusta* was found to be most dominant like previous studies, next most dominant species reported were *M. longifolia* and *G. gummifera*. *B. monosperma* were not found to be dominant. This may be due to anthropogenic disturbances and *B. monosperma* not being able to regenerate at the rate of its destruction. Due to economic importance of *M. longifolia*, it survived the selective logging and are now second most dominant.

The overall distribution of trees on GBH size classes suggests that the forests consist mostly of stands with relatively young ages. Most of the woody plants fall into the 10-29 cm GBH which can be attributed mostly to the selective felling of trees for timber and firewood by local inhabitants (Borchsenius *et al*., 2004). The species richness 58 species in the study site is closer to the species richness of the Bhadra Wildlife Sanctuary (46 species, Krishnamurthy *et al*., 2010) and forests in Puerto Rico (50 species, Murphy and Lugo, 1986) and SW Denmark (23 woody species, Borchsenius *et al*., 2004). The species richness of a forest area is highly dependent on factors like severe disturbances in the area or temporary conversions of these areas into arable land in the past (Jacquemyn *et al*., 2001). In the study area, a plantation drive for planting fast-growing species replaced the local flora (Chatterjee, 2016). The lower basal area is indicative of the small number of larger sized individuals (Gonzalez and Zak, 1996), as the large sized trees are often felled by the locals for their personal uses or are extracted by the forest department for timber.

The presence of crops all-round the year is favored by the rich alluvial soil along with Kangsabati canal as major irrigation source. There has been an alteration in the agriculture pattern in south Bengal which steered the rain-dependent cropping to irrigation based cropping (Santra *et al*., 2008). The Kangsabati Reservoir Project along with various other irrigation schemes facilitated extended irrigation that helped increasing the cropping intensity by 19.59 % in South Bengal (Saxena, 2012). Paddy being the major food crop for the locals (Samaddar, 2006) is grown all-round the year with major production in Nov- June (Boro paddy; Mondal *et al*., 2020). Potato and sugarcane though major cash crops are grown only in the Rabi season. Vegetables are grown in most of the months but largely for self-consumption by the farmers and not as a major commercial crop (Dasgupta and Paul, 2011).

The forests are being incessantly degraded by the frequent visits by people from the nearby villages for their daily requirement of fuel wood and other non-timber forest produce. This has led to the fragmentation of the forests, thereby causing damage to plant diversity. The replacement of many local flora species by the fast growing species have also affected the species richness in this area leading to dominance of sal forests.

Chapter 5

Feeding ecology and Movement pattern (Habitat utilization) of elephants in South West Bengal

5.1 Introduction

Understanding the way in which the animal uses its environment, unambiguously the type of food it consumes, or the variety of habitat it occupies is vital to understand the ecology of the animal (Johnson, 1980). For any migrating population, the availability of resources, predation risks, habitat conditions, and the risk of interactions with humans play an important role in determining their feeding grounds (Hunter, 2007). The seasonal variation in the availability of resources, the spatial dispersion of forage, and level of risks influences the size of large mammalian populations (Dunham, 1994) and their movement as well (Viswanathan *et al*., 1999; Bartumeus *et al*., 2005). The effort any animal population take to adjust their movement, diet, and other necessities to the changing habitat conditions, regulate the survival of their population and reproductive success (Morales *et al*., 2010). Resource availability especially the food resources in an area, plays an important role for the survival of an animal that too for large herbivores (Traill, 2003). A homogeneous plant species composition in forest patches with depleting food resources can be a factor that determines the population size of the animal species (May, 1976). A habitat with diverse and palatable food resources and an understanding of the movement pattern is a prerequisite for a population of herbivore species to flourish (Bolger *et al*., 2008; Harris *et al*., 2009).

Large herbivores like elephants cover a great distance to satisfy their dietary needs (Sukumar, 1989b), utilize an array of plant species, and are generalized feeders (Sukumar, 1990). They have strong selection for areas offering high foraging opportunities (Bastille-Rousseau *et al*., 2020), and consume up to 150 kg of plant matter per day (McKay, 1973). Asian elephants (largely depend on browse and forage, and are sometimes selective of the plant or plant part consumed (Owen-Smith and Chafota, 2012). The decrease in the availability of palatable food resources owing to habitat loss has led to unavoidable challenges for elephant survival (Sukumar, 1990). Such decrease in natural food resources has led to a crop-raiding by elephants for high nutrient content (Sukumar, 1990; Osborn, 2004; Rode *et al*., 2006). This in turn results in human-elephant conflict (De Boer and Baquete, 1998), especially in areas at the interface of cultivated lands and forests. South West Bengal is one such landscape where elephants recolonized in the recent past where the landscape is dominated by the agricultural field with little forest (Chatterjee, 2016).

South Bengal had very few small highly degraded forest patches in the past (Chatterjee, 2016). In the last six-seven decades, under the joint forest management (JFM) program, fast-growing tree species e.g., Eucalyptus sp., akashmoni (*A. auriculiformis*), sal (*S. robusta*), and mahua (*M. longifolia*) were planted in and around of the remnant forest patches and also at public and private lands to meet the fuel demands of the local people under the Social Forestry Project (Malhotra and Poffenberger, 1989). In the last one and a half-century, the forests got dominated with these planted species and have been classified as sal dominant deciduous forests (Champion and Seth, 1968).

The recolonization of this predominantly agricultural landscape having remnant sal dominated forest patches by elephants poses various constraints for the animal to adapt to such a landscape and also results in various management issues due to high human-elephant conflict. Therefore, understanding their movement patterns, habitat use and their feeding habits is crucial to assist the conservation and management of elephants in the human-dominated landscape of South Bengal.

5.2 Methodology

Forage Use

Direct observation to collect the data on resources that were feeding by elephant during the follow was not possible due to the aggressive nature of the elephants in the study area (Singh *et al*., 2023a). Thus, observation on the feeding trail method was used to collect the data on forage use by elephants (English *et al*., 2014; Koirala *et al*., 2016). Two herds of elephants among the seven herds identified in the study site were selected for sampling for forage use (Fig 5.1). The sampling was done between January 2017 and December 2018. I built an information network of local people including farmers, people who work for the forest department including the ‘elephant driving team’, and forest department personnel in the entire landscape. The information about the presence of elephants and their movement was informed to the observer by informers whenever elephants were located in their region. I visited the site and established the identity of the herd with the known identified individuals. Once the identity of the herd was established and if the herd was of the focal study, the herd was monitored from distance for as many days as possible. Meanwhile, the trail of the herd was recorded by walking using a handheld global position system (using Gramin Etrex 30s). While walking with the elephants, I recorded the plant species and the part eaten by them. The plant species with clear signs of feeding like chewed vegetation, debarked, broken twigs and branches were recorded (White, 1994; Demeke and Bekele, 2000; Shoshani *et al*., 2004; Chen *et al*., 2006; Owen-Smith and Chafota, 2012).

The preference of food species was computed using the relative frequency of different plant species observed in the diet, and their relative abundance in the study area using the formula Preference Index (PI) = u/ab (De Boer *et al*., 2000; Fritz *et al*., 1996; Kassa *et al*., 2007; Parker *et al*., 2003; Roux, 2006; Uresk, 1984), where, u is the relative frequency of a food item in diet, and ab is the relative frequency of plant species in the study area.

PI score >1 indicates that the plant was utilized more than its occurrence in the environment which means the plant is less available but highly used, and PI score <1 indicates that the plant was used less than its presence in the habitat which means that the plant is abundant in the number but less utilized (Uresk, 1984). For any species where the abundance was not available, the relative abundance value of the least abundant species present in the observations was considered the value for the unavailable species, and PI was calculated (Uresk, 1984).

In case of feeding from the cropland, the focal herd was followed to every cropland they raided. The crop being fed by the elephants was noted. The area of the crop depredated was recorded by fixing the 10 x 10 m grid cells (Fig 5.1) using ropes on the area of depredated and counted the number of depredated grids and the per cent of crop depredated in each grid was recorded. The production of each crop per hectare for the region was obtained from the official site of the Agricultural Department of India (https://agricoop.nic.in/en). A total of 348 instances of elephant feeding on crops were observed in the area between January 2017 and December 2018.

For quantification of crops fed by the elephants, since quantifying the exact quantity of the crops ingested by elephants was difficult, an approximation was done in order to get the proportion of each crop consumed by elephants per day. As the quantity of food consumed per day by Asian elephants is ~150 kg (Sukumar 2003), accordingly their contribution in the diet was calculated.

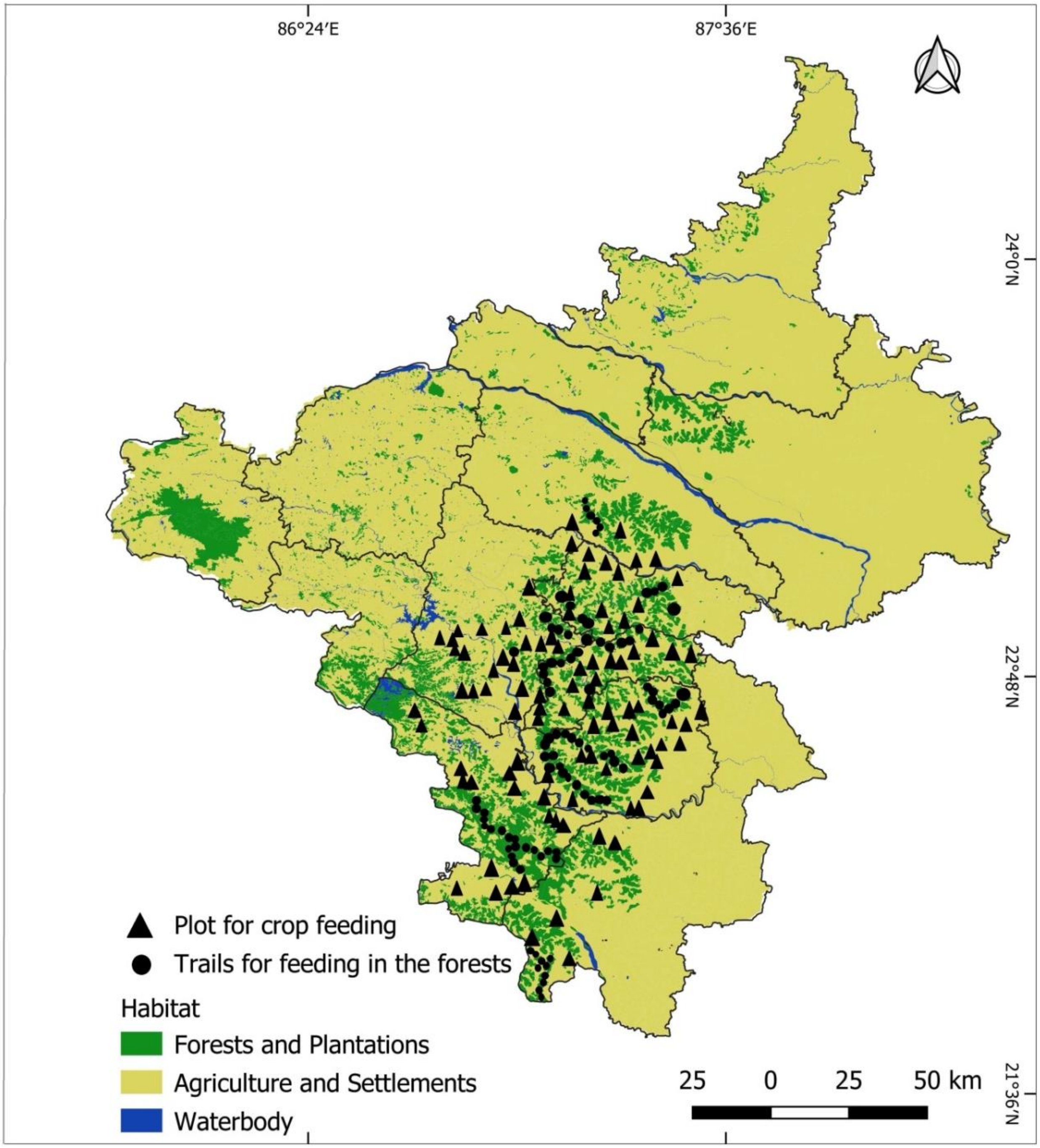

Figure 5.1. Location of the crop feeding plots along with the feeding plots on trails in the forest in South West Bengal

Habitat use by two selected herds of elephants

The data on elephant movement was collected between August 2017 and December 2018. To study the habitat use, two herds, Herd 1 (10 individuals) and Herd 7 (25 individuals) were selected. The herds were recognized based on few key individuals identified by their body characters, tail shape, body wounds, nature of tail length and any cuts on the body. Possible attempts were made to follow the herds both in the day and night hours. Since the *hula* drive is a common practice in the landscape, I accompanied them on many such occasions. The elephants are usually agitated due to continuous driving and tend to become aggressive. Thus, maintaining the distance from the herd, I followed the track and collected the data on movement pattern using handheld global position system. The geo-coordinates were recorded at every 100 m of the path taken by the focal herd.

The selected sites of the two herds were overlaid with 2 x 2 km grids on QGIS platform (v 2.18, QGIS Development Team, 2009). The geo-coordinates obtained were plotted on the gridded select sites on QGIS platform. The number of geo-coordinates falling into each grid is considered as an indicator of the intensity of the habitat use. The extent of usage of each grid in different divisions was depicted by color gradients, greater was the usage where darker the color.

Path length

The daily movement of the herd was recorded along with the data on herd size, and driving type i.e. *hula* drive conducted either by the forest department or by the local villagers. The day-wise data on 24 hr scale was segregated and loaded into Ranges 7 Software to compute the path length (PL) of the animals. The movement records for less than six hours were not considered for analysis.

5.3 Results

Forage use

Elephants were observed to feed on 13 wild plant species belonging to 12 families. Elephants showed a positive preference score for nine of the 13 utilized plant species (Table 5.1). Plant species that had relatively high preference scores ranged from 1.28 to 2.93. The strongest preference was for *L. grandis* (PI= 2.93), *P. marsupium Roxb* (PI= 2.67) and *G.Gummifera* (PI= 2.56). Percent availability of highly preferred species like *L. grandis, P. marsupium Roxb,* and *G. Gummifera* was 2 while that of *T.elliptica* and *D. melanoxylon* was 3. However, percent availability of *S. robusta* was 25 while its preference score was 1.57.

Preference for *A. marmelos* (PI=1.57), *S. cumini* (PI=1.56), and *T. elliptica* (3.13) increased during the pre-monsoon period (Table 5.2), while consumption of *S. robusta* (PI=1.86) increased during the monsoon. However, consumption for *A. heterophyllus* (PI=1.05), *B. cochinchinensis* (PI=0.74), and *D. melanoxylon* (PI=1.85) were highest in the post-monsoon.

The total area depredated for paddy was 81.59 ha (Table 5.3) with a total consumption of ~220500 kg. Similarly, for potatoes, the total area depredated was 44.63 ha with a total consumption of ~1338900 kg. In the case of vegetables, the total area depredated was 13.86 ha with a total consumption of ~249500 kg, and for sugarcane, the total area depredated was 1.96 ha with a total consumption of ~160950 kg.

As the average requirement of food for elephants is around 150 kg, paddy makes around 66.66 % of their diet when in season and rest is fulfilled by forest produce. While potato makes around 40% of the diet when it is available and rest of the diet comprises of forest produce. Vegetables account for 43.3% of diet when available and sugarcane makes around 33% of their diet when available. On and average crops makes up about 45% of the diet when in season and the rest is fulfilled by the forest produce.

The time spent on crop raiding by elephants was not significantly related either to the number of elephants that raided the crop (r_s = -0.058, n = 347, p = 0.279) or the crop area that they depleted (r_s = 0.032, n = 347, p = 0.550). However, the crop area that they depleted increased with the increased number of elephants (r_s = 0.183, n = 347, p < 0.001). Although the number of elephants raided the crop varied between 1 and 27, but the mean number of elephants raided the crop was not different between the crops (paddy: $9.61 \pm 4.72_{SD}$; potato: $9.61 \pm 4.72_{SD}$; sugarcane: $9.61 \pm 4.72_{SD}$; vegetables: $9.61 \pm 4.72_{SD}$) ($F_{3,343}$ = 0.170, p = 0.917). Similarly, the mean time spent on each crop by elephants for each visit (paddy: $54.72 \pm 17.56_{SD}$; potato: $53.42 \pm 17.70_{SD}$; sugarcane: $53.24 \pm 19.84_{SD}$; vegetables: $55.98 \pm 17.97_{SD}$) also did not vary ($F_{3,343}$ = 0.277, p = 0.842). However, the depletion of paddy ($0.45 \pm 0.43_{SD}$) and potatoes ($0.46 \pm 0.38_{SD}$) was more than vegetables ($0.27 \pm 0.23_{SD}$) and sugarcane ($0.12 \pm 0.10_{SD}$) ($F_{3,343}$ = 6.825, p < 0.001).

Table 1.1. Preference indices (PI) for the most important species in the diet of elephants

Species	Plant Part Consumed	Relative Frequency (% Utilization)	Relative Abundance (% Availability)	PI
Aegle marmelos	Fruit	2.56	2	1.28
Artocarpus heterophyllus	Fruit	2.24	3	0.75
Buchanania cochinchinensis	Foliage	6.18	10	0.62
Diospyros melanoxylon	Foliage and fruit	5.01	3	1.67
Gardenia gummifera	Foliage	5.12	2	2.56
Lannea grandis	Foliage	5.86	2	2.93
Madhuca longifolia	Flowers	10.23	6	1.71
Pterocarpus marsupium Roxb	Foliage	5.33	2	2.67
Phoenix sylvestris	Pith and fruits	2.13	1	0.21
Syzygium cumini	Fruit	2.67	2	1.33
Terminalia bellirica	Foliage and fruit	7.68	17	0.45
Terminalia elliptica	Foliage	5.65	3	1.88

Table5.2. Preference Index (PI) for the important species in the diet of elephants according to different seasons

	Relative Frequency (% Utilization)			Relative Abundance	PI		
Tree species	**Pre Monsoon**	**Monsoon**	**Post Monsoon**	**(% Availability)**	**Pre Monsoon**	**Monsoon**	**Post Monsoon**
Aegle marmelos	0.02	-	0.03	0.02	1.57	-	0.78
Artocarpus heterophyllus	0.00	0.01	0.03	0.03	0.00	0.40	1.05
Buchanania cochinchinensis	0.06	0.04	0.07	0.1	0.63	0.44	0.74
Diospyros melanoxylon	0.03	0.05	0.06	0.03	1.04	1.57	1.85
Gardenia gummifera	0.06	0.06	0.04	0.02	3.13	3.01	2.21
Lannea grandis	0.05	0.06	0.06	0.02	2.34	3.14	2.95
Madhuca longifolia	0.11	0.10	0.11	0.06	1.82	1.61	1.75
Phoenix sylvestris	0.02	0.02	0.02				
Pterocarpus marsupium Roxb.	0.06	0.05	0.05	0.02	3.13	2.56	2.68
Shorea robusta	0.36	0.47	0.37	0.25	1.44	1.86	1.46
Syzygium cumini	0.03	-	-	0.02	1.56	-	-
Terminalia bellirica	0.11	0.07	0.08	0.17	0.64	0.41	0.47
Terminalia elliptica	0.09	0.06	0.05	0.03	3.13	2.01	1.66

Table 5.3. Total Estimated crop damage by elephants according to seasons in the study area

Parameters	Season	Paddy	Potato	Vegetables	Sugarcane
	Pre-Monsoon	19	0	20	15
	Monsoon	50	0	0	0
No of feeding sites	Post Monsoon	112	99	31	2
Total		**181**	**99**	**51**	**17**
	Pre-Monsoon	19	0	19	31
	Monsoon	27	0	0	0
Average crop % consumed	Post Monsoon	28	28	19	25
Total		**24.66**	**28**	**19**	**28**
	Pre-Monsoon	6.6	0	4.65	1.09
	Monsoon	23.33	0	0	0
Total Area depredated (in ha)	Post Monsoon	51.66	44.63	9.21	0.87
Total area		**81.59**	**44.63**	**13.86**	**1.96**
Average production (kg per ha)		2700	40000	18000	82000
	Pre-Monsoon	18000	0	83800	89800
	Monsoon	63000	0	0	0
Estimated quantity of crop consumed (kg per ha)	Post Monsoon	139500	1785400	165700	71150
Total		**220500**	**1785400**	**249500**	**160950**

Habitat use: 1268 grids of 2 x 2 kilometers were laid in Kharagpur Division, 533 grids in Medinipur and 268 grids in Rupnarayan Forest Division. Of these, 92 grids were utilized by the elephants in Medinipur, 64 in Kharagpur and 22 in Rupnarayan Forest Divisions (Table 5.4). Most of the used grids are found on the margins of the forest area close to agricultural fields (Fig. 5.2 to 5.11)

Table 5.4 Number of days focal herds were followed and the grids utilized by them in Rupnarayan, Medinipur and Kharagpur forest divisions

Habitat use	Rupnarayan Forest Division	Medinipur Forest Division	Kharagpur Forest Division	No of days followed
No. of grids utilized by Herd 1	22	53	24	170
No. of grids utilized by Herd 7		30	64	82
Total no. of grids utilized by all herds combined	22	56	64	

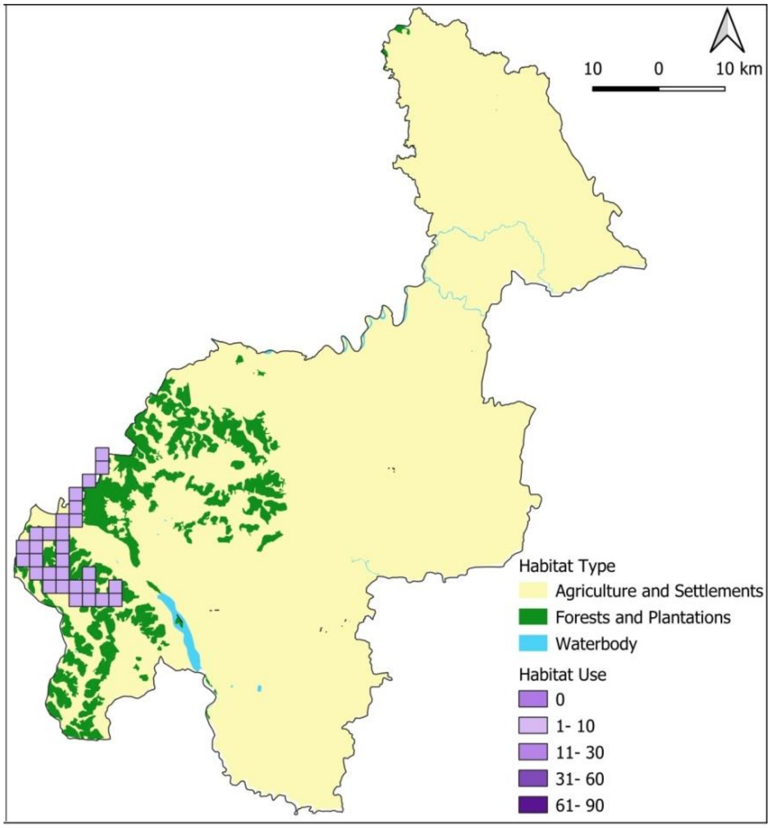

Figure 5.2 Intensity of habitat use by elephant herd-1 in Kharagpur Forest Division

Path length: Day-wise movement by the elephants was calculated in terms of daily path length for the duration of 224 days (Fig 5.12). The path length of the elephants was negatively related to their herd size (r_s =-0.171, N= 190, $p < 0.05$; Fig. 5.13). Although the mean path length varied between 5.52± 2.52 $_{SD}$ and 9.59 ± 3.35 $_{SD}$ (Fig. 5.14), that did not differ across the months ($F_{10, 179}$ = 0.690, p =0.733). However, mean path length was significantly higher during the *hula* drive (9.47 ± 4.30 $_{SD}$; Fig. 5.15) ($F_{2, 187}$ = 21.776, $p < 0.001$) than the drives by the local people (4.93 ± 2.22 $_{SD}$) or natural movement (6.86 ± 5.32 $_{SD}$).

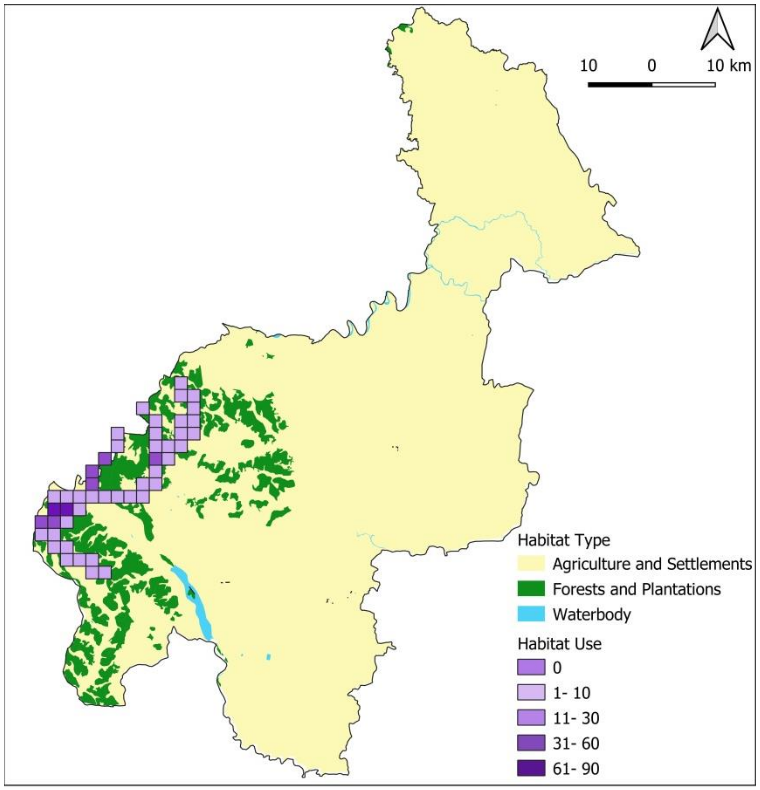

Figure 5.3 Intensity of habitat use by elephant herd-7 in Kharagpur Forest Division

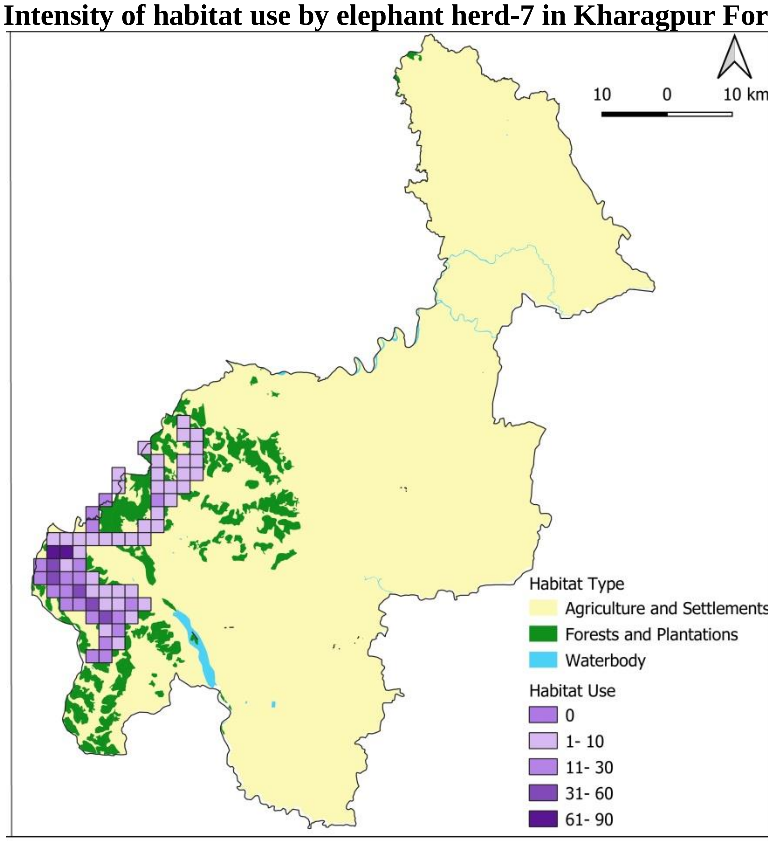

Figure 5.4 Overall intensity of habitat use by the elephant herds in Kharagpur Forest Division

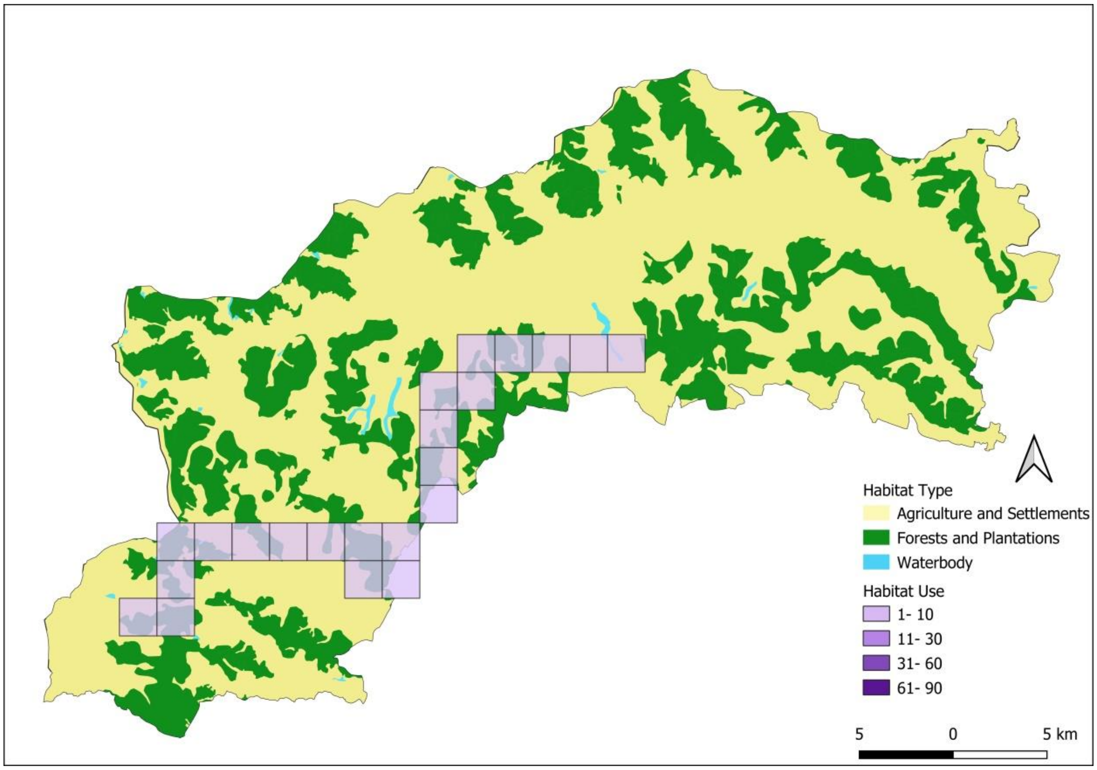

Figure 5.5 Intensity of habitat use by elephants in the Rupnarayan Forest Division

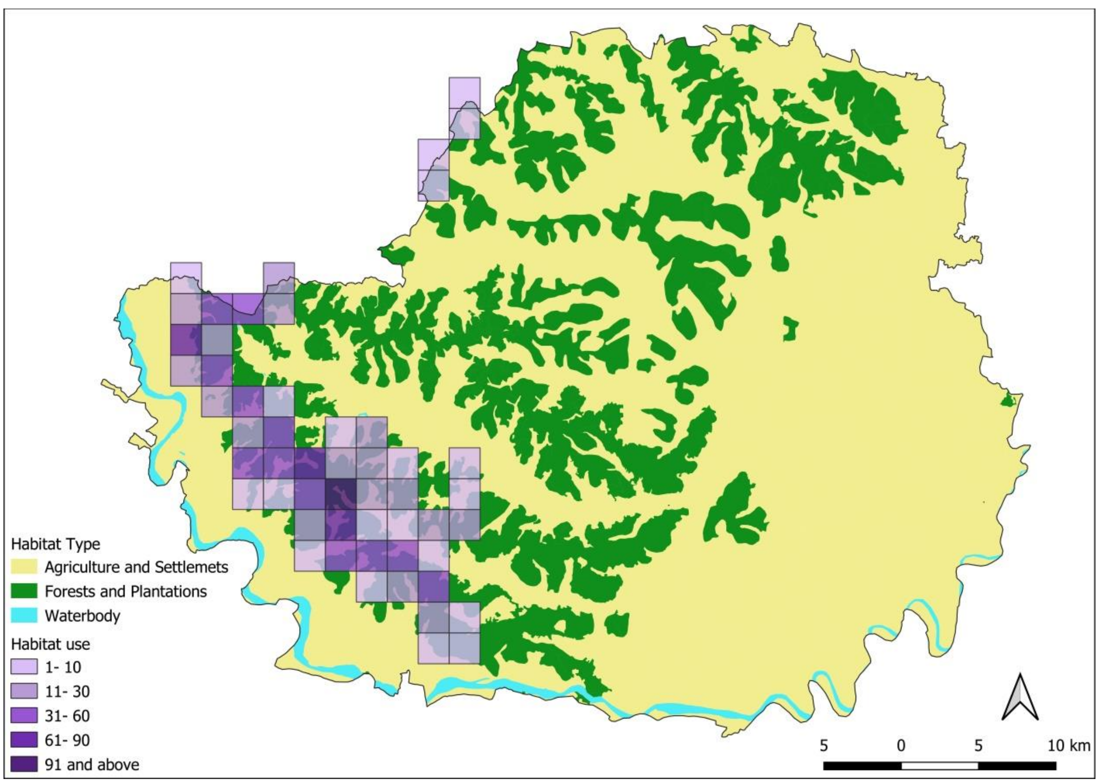

Figure 5.6 Intensity of habitat use by elephant herd-1 in Medinipur Forest Division

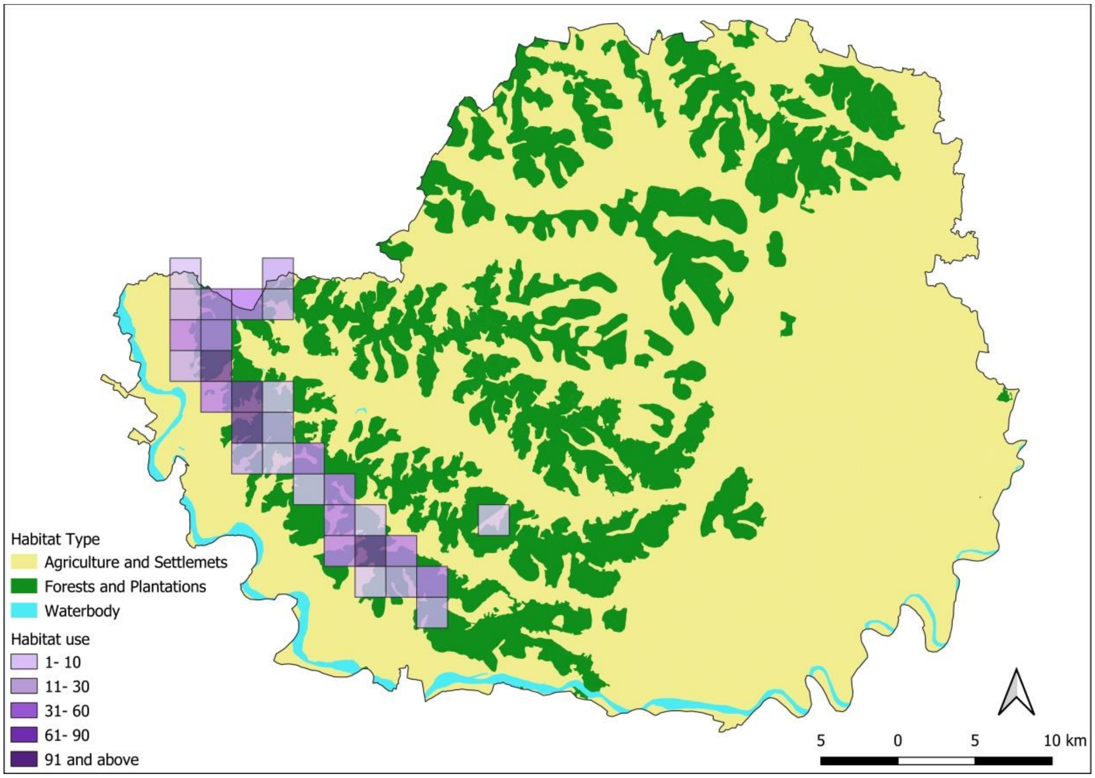

Figure 5.7 Intensity of habitat use by elephant herd-7 in Medinipur Forest Division

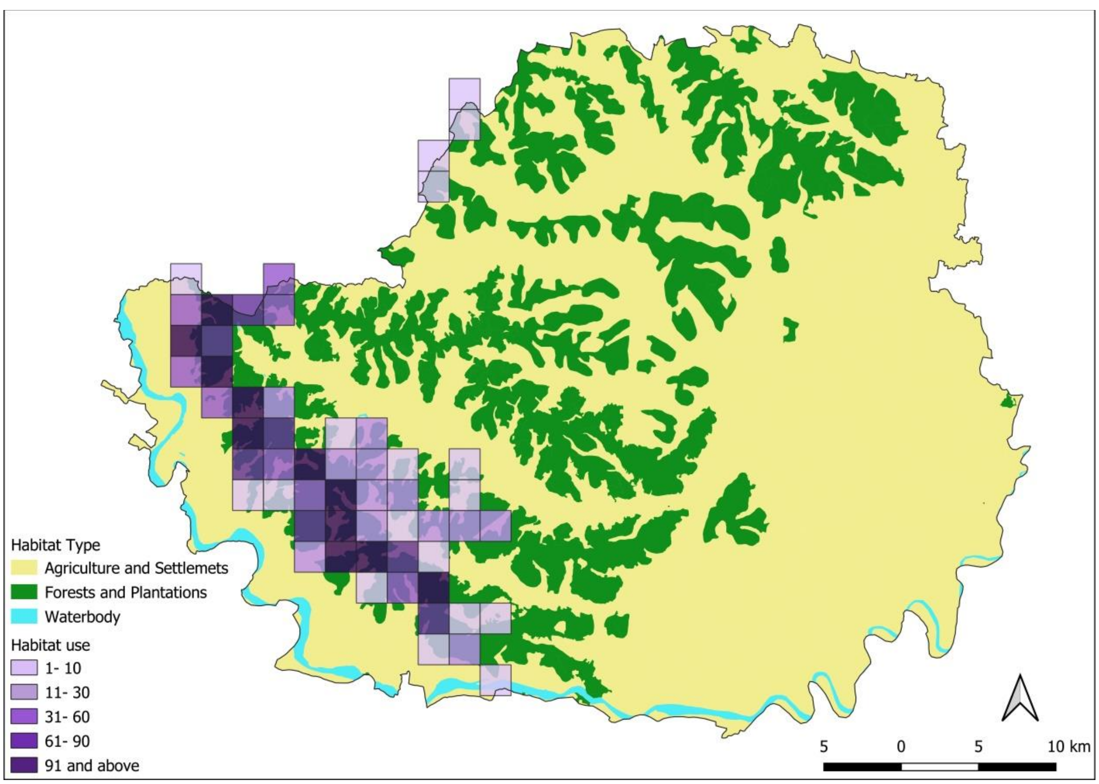

Figure 5.8 Intensity of habitat use by all the elephant herds in Medinipur Forest Division

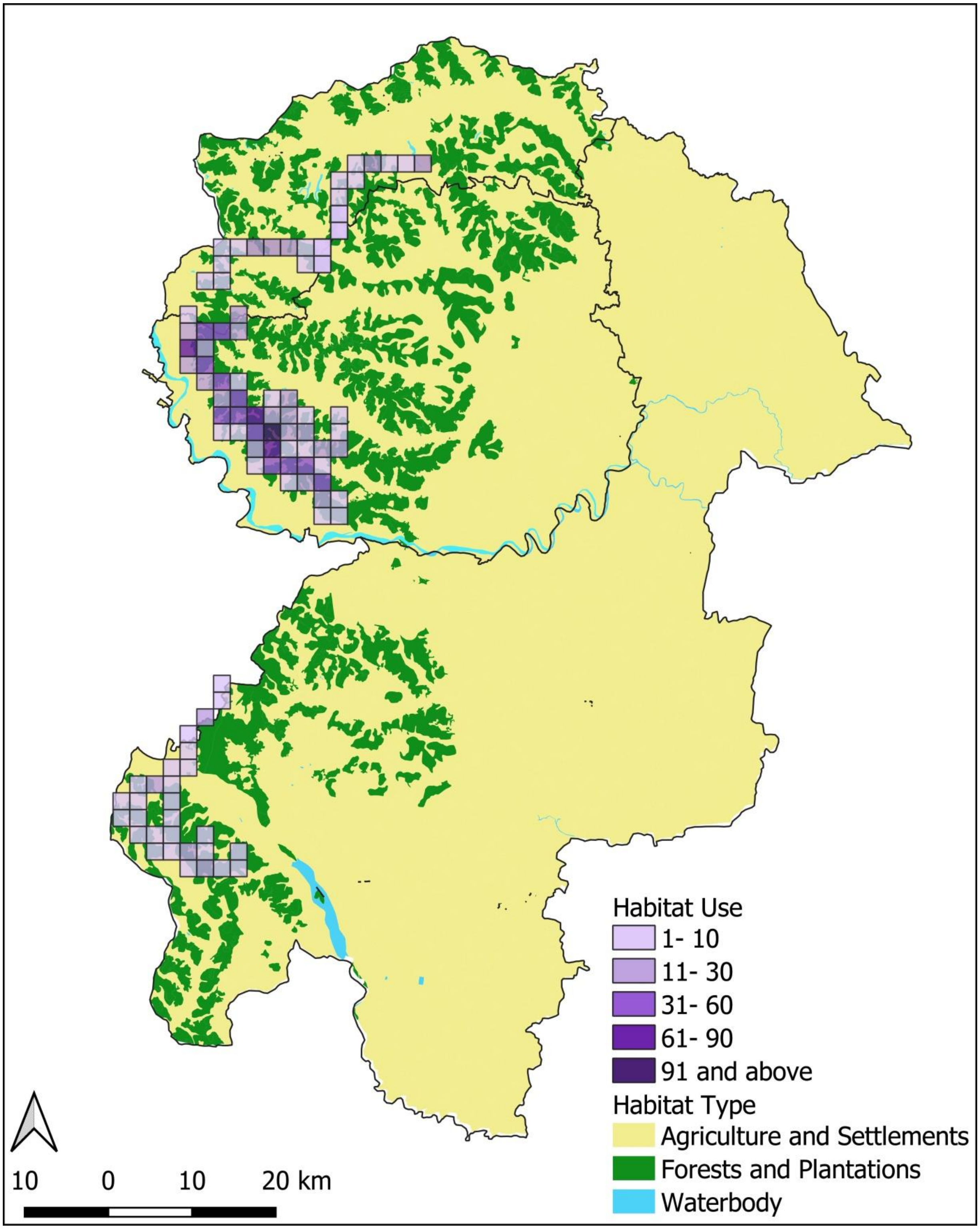

Figure 5.9 Intensity of habitat use by herd-1 in the three forest divisions of Kharagpur, Medinipur, and Rupnarayan

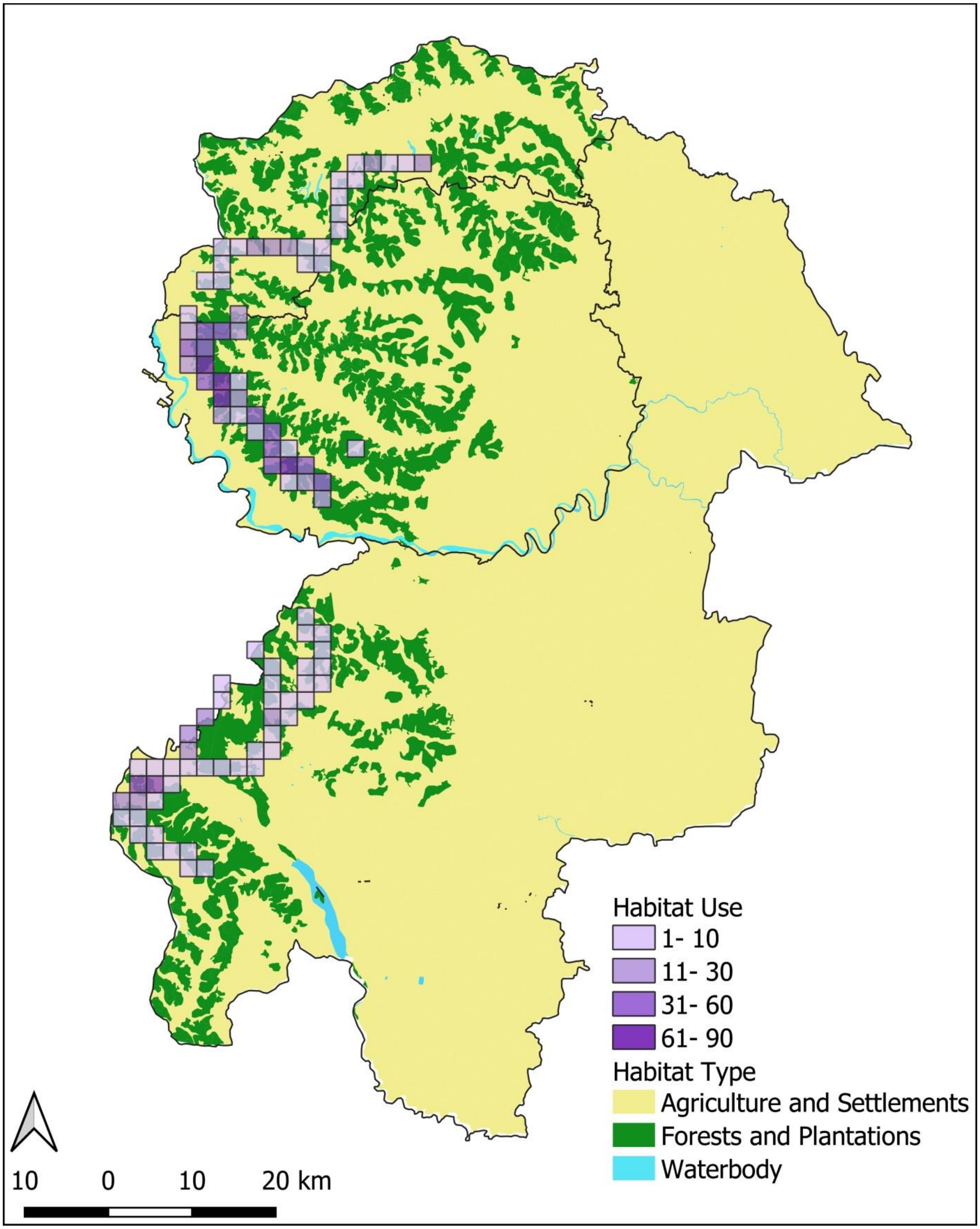

Figure 5.10 Intensity of habitat use by herd-7 in the three forest divisions of Kharagpur, Medinipur, and Rupnarayan

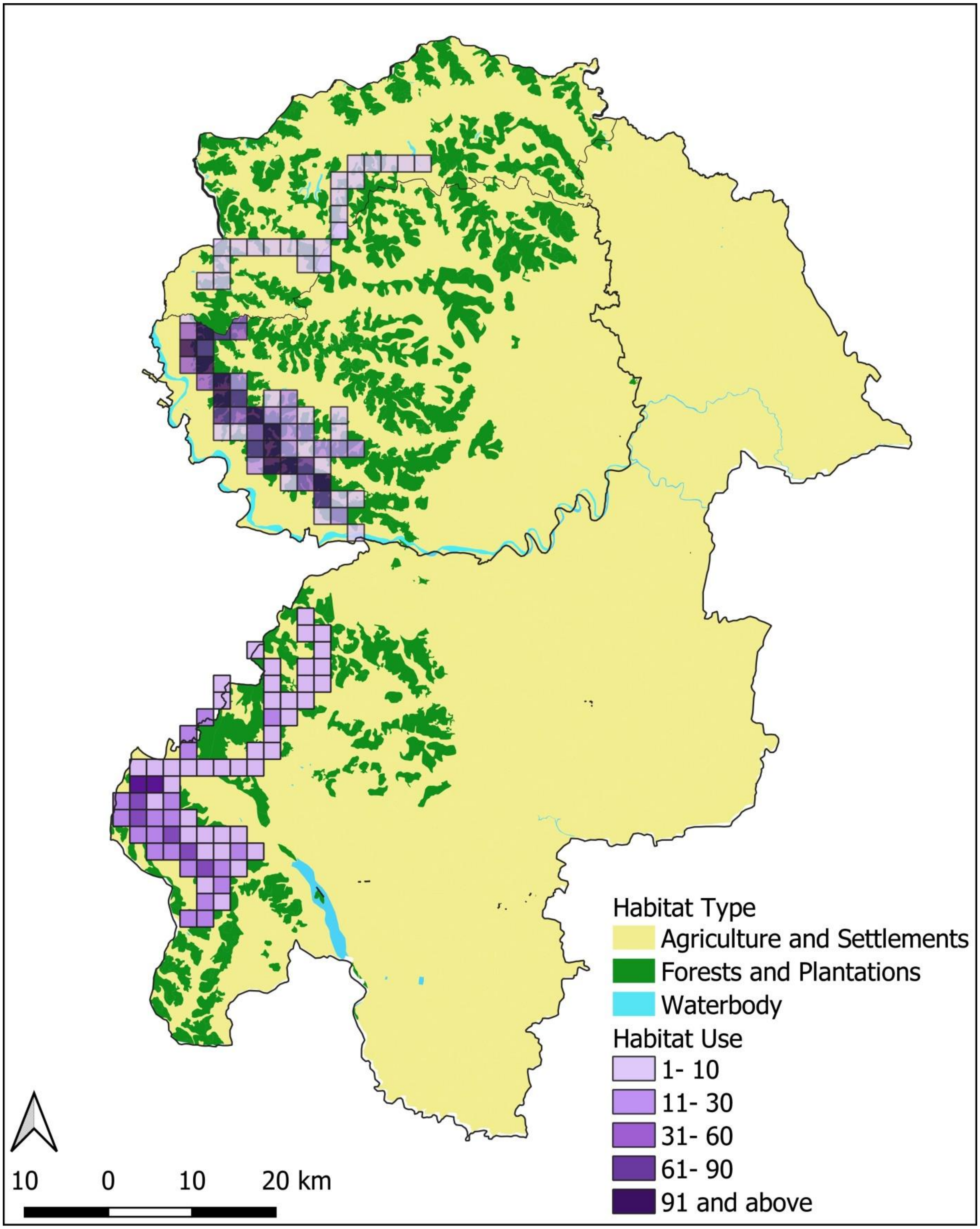

Figure 5.11 Intensity of habitat use by both the herds in the three forest divisions of Kharagpur, Medinipur, and Rupnarayan

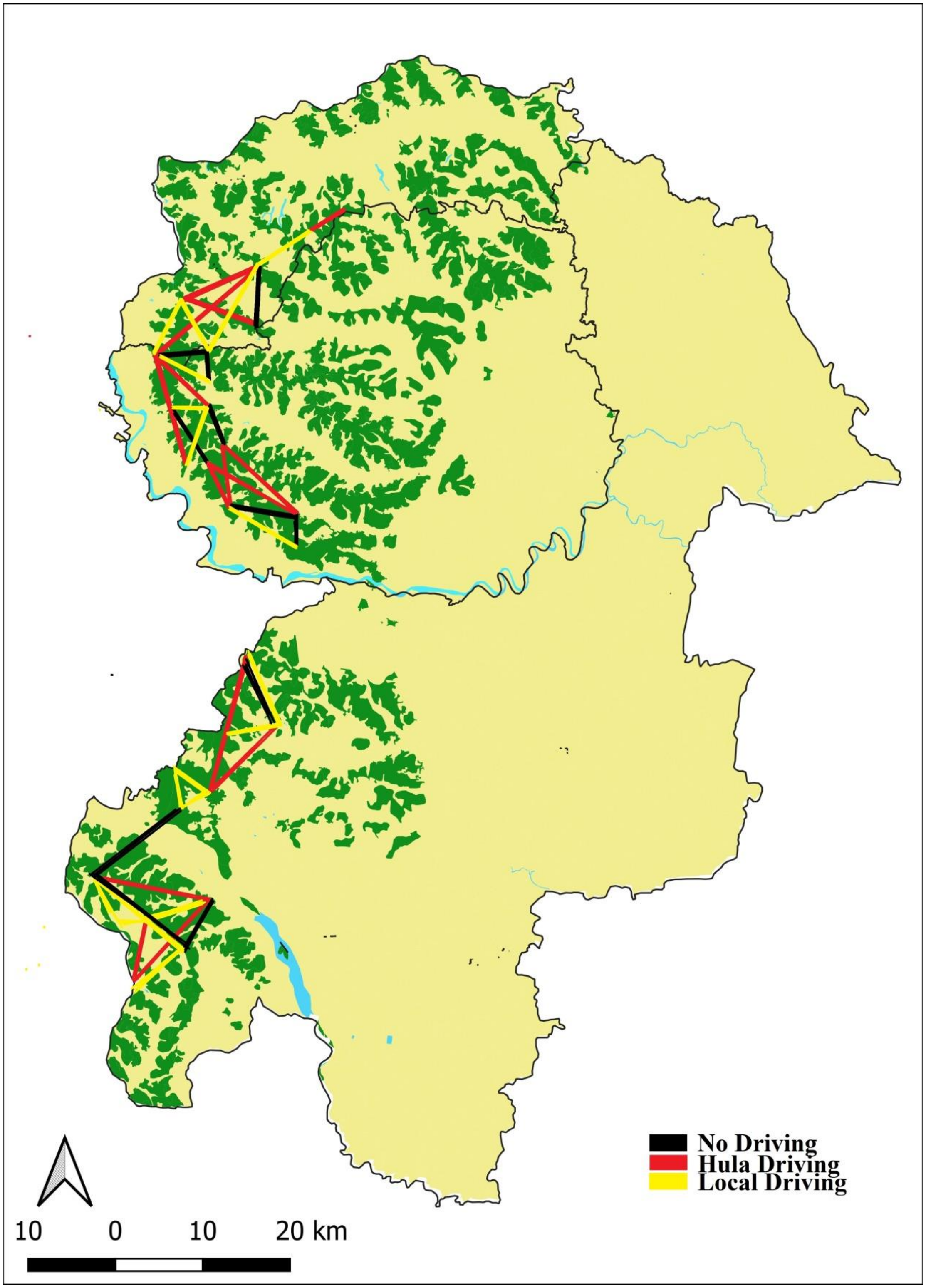

Figure 5.12 Movement patterns of focal elephant herds in Rupnarayan, Medinipur and Kharagpur Forest Divisions

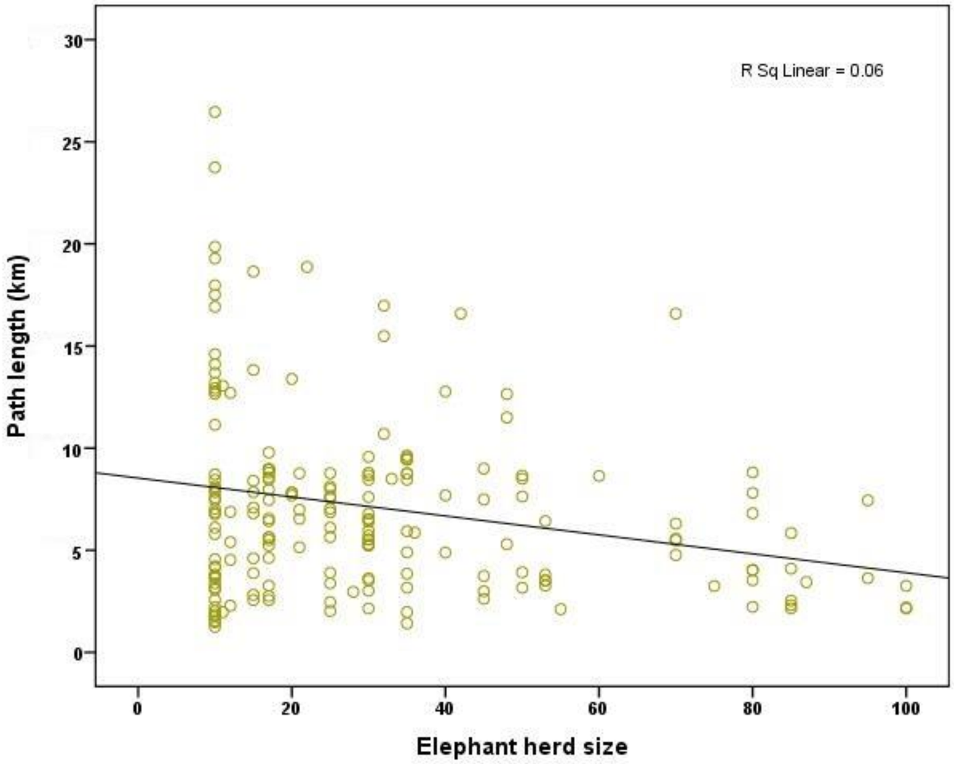

Figure 5.13 The relationship between elephant path length and their herd size

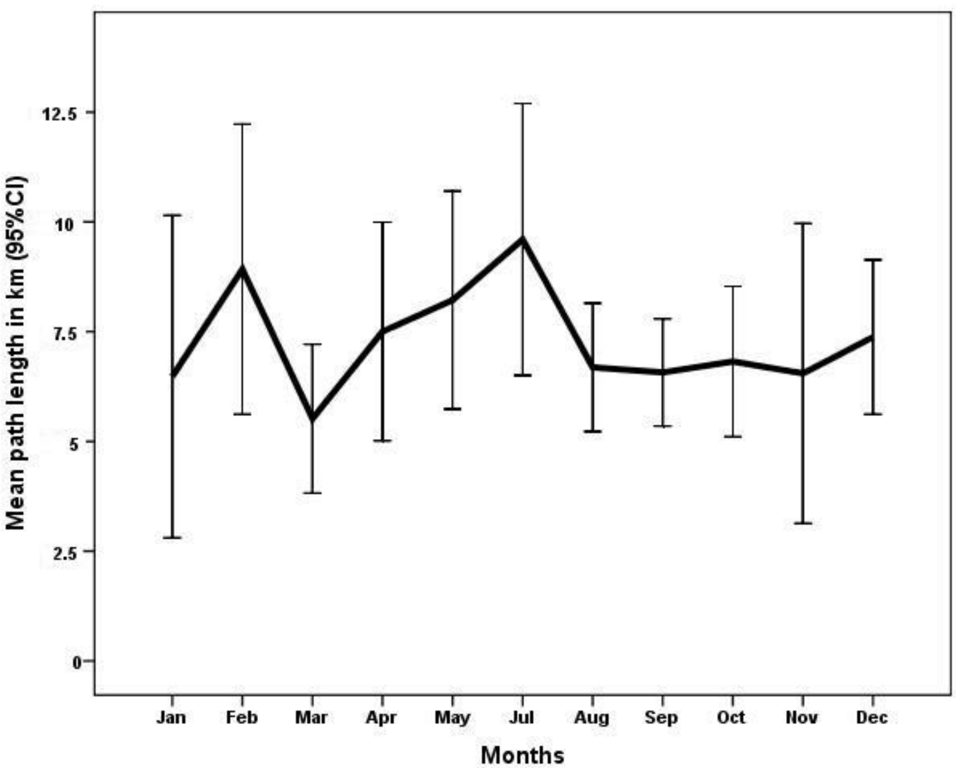

Figure 5.14 Mean path length of elephants in different months

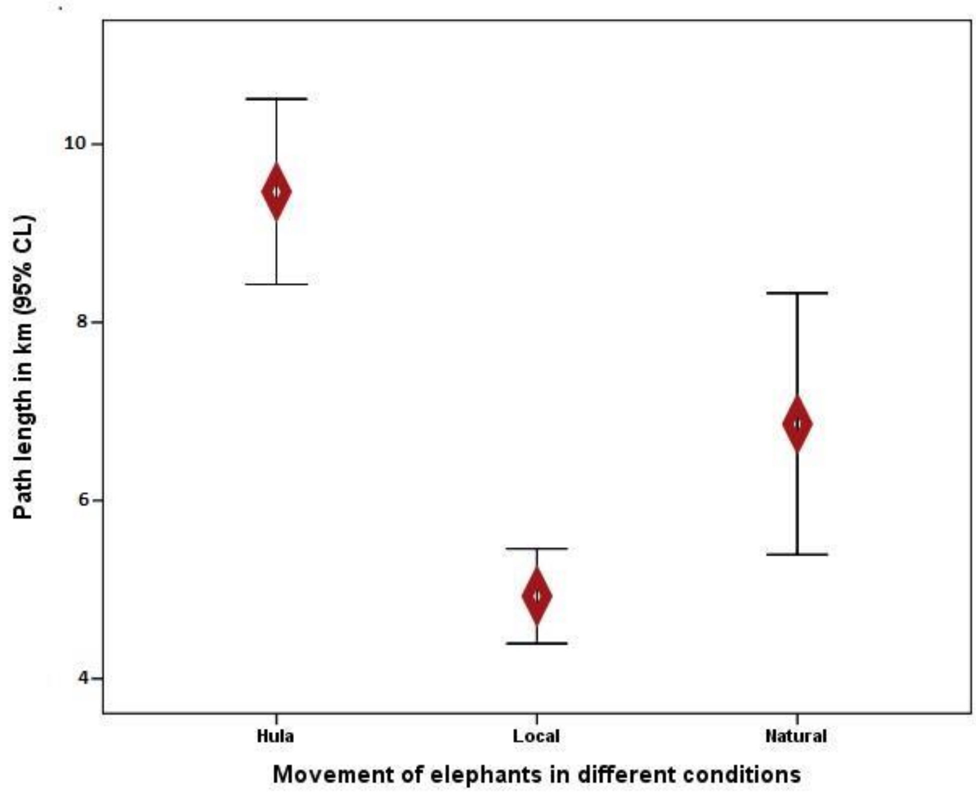

Figure 5.15 The path length of elephants in different conditions in South Bengal

5.4 Discussion

The study recorded 70 species belonging to 27 families dominated by the Fabaceae family. The stand density was 1716.38 individuals ha^{-1} and the mean basal area was 5.76 m^2 ha^{-1}. *S. robusta* dominates forests of South Bengal. Of the 13 wild plant species that elephants fed that were very low in the study site. *L. grandis* was most preferred (PI= 2.93) while the percent availability was only two. There was a presence of paddy all around the year while vegetables prevailed for about eight months in a year. Potato and sugarcane were present for nearly four months in a year. Crops make up to 45 % of their diet when in season and the rest is fulfilled by the forest produce. In total 92 grids were utilized by the elephants in Medinipur, 64 in Kharagpur and 22 in Rupnarayan Forest Divisions. Although the mean path length of elephants across the months was the same, the distance traveled due to *hula* driving was significantly more than the natural movement or when driven by the local people. The herd size of elephants was negatively related to the path length.

Mega herbivore like an elephant requires large quantity of food and water for their day-to-day activities (Owen-Smith, 1988). The number of species consumed by Asian elephants varied between different areas across the elephant ranges e.g., 132 species in the dry season in North Bengal (Das *et al*., 2022), 112 plant species in Hasanur of Tamil Nadu however, 85% of their diet consisted of only 25 species (Sukumar, 1990), 18 species of flowering plants in the Manas National Park in the dry season (Lahkar *et al*., 2007), 50 species in Rajaji National Park that includes 74% trees, 14% grass, 8% shrubs and 4% climbers (Joshi and Singh, 2008), 71 species including 56% tress in Central India (Mohapatra *et al*., 2013), 22 plant species in West Medinipur, Purulia and Bankura districts of West Bengal (Santra *et al.,* 2008), 106 species in the Shangyong National Natural Reserve in China (Chen *et al*., 2006), 57 species in Nepal (Koirala *et al*., 2016), and 26 species in Vietnam (Varma *et al*., 2008). Although, the diet is highly diverse across their range and reflects that there is high diversity and a huge difference in the nutrient content and the secondary compounds of the plants available in the landscape that they inhabit, the 13 wild species in the diet of elephants in South Bengal is too small. It is apparent that the diversity of the plant species is highly skewed and dominated by a single species *S. robusta*. Although, elephants nibble the *S. robusta* but it is not an important feeding tree for them. Thus, the proportion of crops consumed by elephants is indicative of their dependence on agricultural produce for their daily diet which constitutes ~45 %.

Crop raiding by elephants is affected by proximity crop field, density, seasonal availability of crops and the seasonal differences in nutrient concentration of wild and cultivated plants (Naughton- Treves, 1998; Sitati *et al*., 2005; Chiyo, 2000; Dudley *et al*., 1992; Nyhus *et al*., 2000; Sukumar, 1989a). Food crops are generally high in energy, easily digestible and low in secondary compounds (Rode *et al*., 2006) and may also provide secondary health benefits such as lower parasite loads (Finch, 2013) which make them attractive to the elephants (Jachmann, 1989; Omondi, 1995; Sukumar, 1989a). Conversely, forest food was found to be lower in protein and minerals than crops (Osborn, 1998; Sukumar, 1989a). Hence, the presence of large number of crop in diet of elephants could be attributed to supplementing deficient diets. Total area as well as seasonal availability do not seem to affect the frequency or the timing of the of elephant raids (Sukumar, 1990; Chiyo *et al*., 2005), indicating the total food availability alone is not the factor for their preference for specific crops.

The high preference for *A. marmelos* (PI=1.57), *S. cumini* (PI=1.56) and *T. elliptica* (3.13) during the pre-monsoon coincides with the fruiting season of these species which is similar to the observation made by Joshi and Singh (2008) where the preference for *A. marmelos*, *Zizyphus mauritiana*, *S. cumini* and *Ehretia laevis* increased during the fruiting season.

The elephants showed an inclination towards mixed forests and areas surrounding the agricultural land, which is consistent with other studies on elephants in Indonesia (Rood *et al*., 2010), India (Sukumar, 1989a; Desai and Baskaran, 1996; Areendran *et al*., 2011), Sri Lanka (Fernando *et al*., 2008) and China (Zhang *et al*., 2015). A large number of grids used by the elephants had both forests and agriculture fields or were associated with agriculture fields largely in marginal areas, similar to the reports from Nepal (Steinheim *et al*., 2005; Pradhan and Wegge, 2007), India (Sukumar, 1989a, 1990), and China (Zhang and Wang, 2003). Marginal areas are generally rich in elephant feed (Sukumar, 1989a, 1990; Zhang and Wang, 2003) and are close to the crop fields owing to their high nutritional values compared to other vegetation types (Anderson and Briske, 1995; Steinheim *et al*., 2005). Elephants retreat to forests for cover and/or shade when not feeding on grasses, and/or may travel through these areas while searching for food or for avoiding an encounter with humans while traveling. The sal forest provides low-quality food (Steinheim *et al.*, 2005) and elephants use sal vegetation considerably less compared to other vegetation types in India (Williams *et al*., 2008). However, the sal forest is the only forest in the entire landscape, and therefore the use of the available forest is inevitable for elephants there.

Due to a high degree of human-elephant conflict, the *hula* drive is often practiced in the landscape to avoid over-depredation of crops, thereby altering the natural movement pattern (direction and path length) of elephants. The local drives by the villagers are practiced to save their own land wherein the elephants are driven to short distances; thus, the mean path length was lesser than the *hula* drive. The mean path length in different months did not vary across the months because elephants almost have become residents and driving them have become a regular event in South Bengal. The incessant driving (both local and *hula*) of elephants leave only a small window for natural movement of elephants.

Mega herbivore like an elephant requires large quantity of food and water for their day-to-day activities (Owen-Smith, 1988). The elephants usually debark or uproot the entire trees while feeding or under stress (Höft and Höft, 1995). De-barking the trees or uprooting them terminates that particular tree and that leads to furthermore reduction in the already low number of fodder species in the forests. Hence, the absence of enough fodder in the forests compels the animals to raid nearby agricultural lands. That also makes the animal visit the croplands at regular intervals to feed. Such frequent raiding increases the interaction of the animal with humans and thereby increasing conflict. That means that it is very important to have an optimal amount of fodder in the forests to avoid human-animal interactions. Elephants often feed on fruiting trees inside the forest (Ngama *et al*., 2019) and create trails to them (Blake and Inkamba-Nkulu, 2004) and visit those areas regularly. Local farmers should be encouraged to avoid farming near such areas (Ngama *et al*., 2019) in order to avoid any interaction with elephants. Certain changes in the habitat of this region like a replacement of the species such as *S.robusta* and *Eucalyptus tereticornis* with fodder species such as *L. grandis, A. marmelos, M. longifolia, P. marsupium*, and *B. cochinchinensis* will help in enriching the forests in terms of food availability for the elephants. Presence of adequate palatable fodder in the forests might make the elephant spend longer time within the forests, and thus, they are likely to stay away from agricultural fields for a longer period, eventually reducing interactions and conflicts in the landscape.

6.1 Introduction

Loss of habitats and the ever increasing human population has escalated the conflict between human and wildlife to many folds (Hoare, 2000; Balmford and Whitten, 2003; Dublin and Hoare, 2004; Woodroffe *et al*., 2005). Globally, communities living around the periphery of wildlife areas are often more susceptible to conflict with wildlife (Karanth, 2005). These conflicts are likely to harm everyone involved, bringing in negative attitudes and a dwindling appreciation for wildlife that potentially affect conservation (De Boer and Baquete, 1998; Nyhus and Tilson, 2000). Conflict in the form of human deaths and injuries or in the form or economic losses due to crop depredation, house damages, loss of cattle due to predation and psychological stress are common very common across the world (Hoare, 1995; Naughton-Treves, 1998; Sukumar, 1990; Tchamba, 1996; Williams *et al*., 2001). Many wildlife species suffer from the human-wildlife conflict, especially the crop raiding mega herbivores. Elephants being one such mega herbivore are the center of the conflict issues (Sitati *et al.*, 2003). The biggest threat to the existence of elephants is the human-elephant conflict, particularly in the agricultural rural regions where human populations are expanding and encroaching on habitat used by elephants (Sitati *et al*., 2003). Alterations of the landscape by humans have impelled humans and elephants to live in closer proximity which leads to even more conflict issues (Shaffer *et al*., 2018). Habitat fragmentation further fuels this human-elephant conflict as the roads and the agricultural land surrounding the feeding grounds are often more susceptible to conflict (Fernando *et al*., 2005) and often lead to fatal results (Shaffer *et al*., 2018). The most common form of conflict comprises of elephants foraging in the agricultural fields to meet their dietary requirements (Sukumar, 1990; Williams *et al*., 2001; Sitati *et al*., 2003; Graham *et al*., 2010; Sitienei *et al*., 2014; Goswami *et al*., 2015; Liu *et al*., 2016). The elephant crop-raiding pattern has been documented in Asia and Africa (Sukumar, 1989a; Damiba and Ables, 1993; Hoare, 1995; Kiiru, 1995; O'Connell *et al*., 2000), and attempts have been made to estimate the costs of the crop damage (Bell and McShane-Caluzi, 1986; O'Connell *et al*., 2000). Crop raiding often peaks near harvest time threatening the survival of farming households due to high crop losses (Chen *et al*., 2006; Graham *et al.*, 2010; Webber *et al.*, 2011; Gubbi, 2012). As a result, elephants often stimulate fear and anger in rural communities (Sitati, 2003; Parker *et al*., 2007), often leading to retaliatory killings of elephants by these farmers (Parker *et al*., 2007).

Apart from crop raiding, human casualties and injuries are major conflict consequences faced by people across the world (Sukumar, 1990). India documented around 500 human deaths between 2010 and 2020 along with 150 elephant deaths due to conflict annually (Project Elephant Division, 2020). In Africa, Kenya reported deaths of around 200 people in human-elephant conflict between 2010 and 2017 (Mariki *et al*., 2015). Similar numbers are found in the entire range of Asian and African elephants (Saaban *et al*., 2011; Webber *et al*., 2011; Tchamba and Foguekem, 2012; Chen *et al*., 2013; Mariki *et al*., 2015; Sarker *et al*., 2015; Acharya *et al*., 2016; Pant *et al*., 2016). Although crop raiding and human and elephant casualties are often most commonly reported, hidden costs of conflict like the psychosocial well-being and disrupted social activities of people in the conflict prone areas remain unstated in any report (Jadhav and Barua, 2012; Barua *et al*., 2013). These emotional and unseen costs make it difficult for people to appreciate and tolerate elephants existing in their community. Human–elephant conflict thus challenges the support for elephant conservation and impend the future of elephant populations across their range.

India has the largest Asian elephant population (Daniel 1998), and hence it is apparent that humans and elephants compete for natural resources (Williams *et al*., 2001). However, the intensity of conflict might vary depending on the local habitat conditions (Shaffer *et al*., 2019). Asian elephants are found in four distinct geographical regions in India: (a) Shivalik Hills and Terai of Uttar Pradesh, (b) North Bengal to Manipur, (c) Bihar, Jharkhand, Odisha, and south-western part of West Bengal, and (d) Karnataka, Kerala and Tamil Nadu (Baskaran *et al*. 2011). In a country like India with a population of 1.4 billion people, where the elephant population is currently estimated to be 27,000 individuals (MoEFCC, 2019) and their range is expected to be involved in frequent conflict with humans. Meanwhile, habitat loss and fragmentation due to human encroachment, illegal felling, and land-use conversion over the last century have escalated human-elephant conflicts by forcing elephants to move out of the protected areas in search of food and space (Choudhury, 2004; Rangarajan *et al*., 2010; Gubbi *et al*., 2014; Guru and Das, 2021). Elephants became rare in large areas of South Bengal in the 18th century due to forest degradation and poor areal coverage of coppice sal forests (Palit, 1991; Malhotra, 1995;

Panda, 1996). The elephants have eventually expanded their distribution in South Bengal from the neighboring province of Jharkhand since 1950 (Shahi, 1980; Dey, 1991; Palit, 1991; Malhotra, 1995; Panda, 1996; Singh and Chowdhury, 1999). The high human density-agricultural landscape of South Bengal landscape with highly fragmented forests dominated by sal trees resulted in human-elephant conflict. The initial report of human-elephant conflict was reported in 1987 (Datye and Bhagwat, 1995). To manage and retain the elephants in such human-dominated agricultural landscape, a proper understanding of the pattern of human-elephant interactions and its consequences on humans and elephants is required for South Bengal.

6.2. Methods

I obtained information on human deaths and injuries (= attacks) by elephants for 2010 to 2018 from the records of the Forest Department of South Bengal. I recorded human deaths and injuries by elephants from September 2015 to March 2018. The data included the name of the victim, age-sex of the victim, date of the incident, and complete address of the victim. I also obtained all the records of elephant deaths and their details of the location, attributed the reason for the death, age and sex of the elephant from 2013 to 2018. I visited the victim's house or village and authenticated the incident from their families or local villagers. The families or victims of the injuries were interviewed about the background of the incident and the location of the attack by the elephants. I visited the location of human death, attack on humans by elephant and elephant deaths, and verified the details with the local people and the department personnel, and recorded the geo-coordinates. I compared the number of human deaths and injuries by elephants between the years using the Chi-square test of goodness of fit. I pooled the data on human deaths and injuries by elephants for each year as 'attacks' that were used for further analysis. I scored the number of attacks for each grid cell, pooled them into five classes (0, 1–5, 6–10, 11–15 and >16), and mapped them on the QGIS platform. I obtained the classified vegetation map of the South Bengal landscape from the Forest Department and extracted habitat variables including the area with forests, water body, barren land, settlements, and agriculture, and the Shannon index of them and the edge of the forest as habitat covariates.

I constructed 11 Generalised Linear Models (GLM) (Quasi Poisson distribution, link = log) to examine the effect of spatial variables on the intensity of elephant attacks in the South Bengal landscape. The number of elephant attacks in each grid cell was considered as the response variable, while six spatial variables, i.e., forest area, area of agriculture, area of the water body, area under settlements, barren area, Shannon index, and forest edge were used as explanatory variables. In addition to that, the model-averaged estimated probability of using a grid cell by the elephant (OC) was also considered as another explanatory variable. Over-dispersion for Poisson GLMs was checked using the "DHARMa" package (Hartig, 2018). All models showed evidence of over-dispersion. I, therefore, re-fitted my models as quasi-Poisson GLMs. All constructed models were ranked based on quasi-Akaike's Information Criterion (QAIC) value to select the most parsimonious model with the lowest QAIC and the highest model weight (Anderson, Burnham and White, 1998). The GLM model selection table was constructed with the R package "MuMIn" (Barton, 2020). The analysis was carried out in R statistical software RStudio ver. 1.1.383 (R Core Team, 2017). I summarised the elephant deaths, explaining the reasons behind the deaths in the period between 2013 and 2017.

I also assigned different time slots (taken on the 24-hour time scale) for human deaths and injuries and data was classified and pooled accordingly. I broadly pooled the details of circumstances of each attack under eight activities that include activities in the agriculture field, cattle herding, elephant driving, NTFP collection, open defecation, sleeping or activities around the house, traveling through forest road and through village road. The description and factors related to each activity are provided in Table 6.1. I calculated the percent of each activity of the victim during the elephant attack and mapped all the human deaths due to elephants. I also mapped all the human injuries, crop damage by elephants and elephant deaths on the map of forest divisions of South Bengal.

For crop depredation, data from August 2017 to December 2018 was collected from three divisions of Medinipur, Rupnarayan and Kharagpur. Whenever possible the elephants were observed from a distance while they were feeding and the next morning of their visit to any crop field, the same place was visited to collect data on depredation. I recorded the type of crop depredated and the approximate area of crop field damaged by elephants. The data were pooled according to seasons and the kind of crop depredated. The total loss incurred for each crop was calculated using the amount provided to the person claiming for the damage for crop depredation from the Forest Department.

Table 6.1 Description of the activities or circumstances of the victim during the accident considered to group them under broader categories of activity.

Broad activity of victim while the accident occurred	Description and factors considered
Activities in the agriculture field	Farming activity, field protection during day-night and resting in the field
Cattle herding	Herding the cattle for grazing to agriculture field or forest or wasteland
Elephant driving	Driving elephant is a common phenomenon in South Bengal. This may be a *hula* drive that is an organised drive involving many people, or local level drive.
NTFP collection	Collection of Sal leaves, firewood from forests
Open defecation	Defecating at village outskirts or out of the house
Sleeping or activities around the house	Household activities around the house and also people have a habit of sleeping outside near the house.
Traveling through the forest road	Due to lack of transportation, people had to walk or travel by cycle or motorbike to and from their village to a nearby town or market areas, they had to cross interspersed forest patches on the way. During such travels, if the incident happens at forest patches it is considered under this category
Traveling through the village road	Due to lack of transportation, people had to walk or travel by cycle or motorbike to travel to and from village to a nearby town or market areas, they had to cross interspersed forest patches on the way. During such travel, if the incident happens on village roads, it is considered under this category

6.3 Results

Human deaths and injuries due to elephants: A total of 640 elephant attacks on humans were recorded between 2010 and 2018 that includes 268 human kills (Fig 6.1) and 372 human injuries (Fig 6.2). The human deaths varied from 11 (in 2011) to 52 (in 2015) at an average of 30 deaths/ year, while the human injuries varied from 24 (in 2011) to 66 (in 2015 and 2016) at an average of 41 injuries/year (Fig. 6.3). The number of deaths ($\chi^2 = 51.953$, df = 8, $p < 0.000$), injuries ($\chi^2 = 49.649$, df = 8, $p < 0.000$) and total elephant attacks on humans ($\chi^2 = 92.011$, df = 8, $p < 0.000$) varied significantly between years. The elephant attacks on humans were recorded in 106 grid cells. Of those, 10 (9.4%) grid cells had more than 16 attacks on humans, 11 (10.37%) grid cells had 10 to 15 attacks, and 32 (30.18%) grid cells had 5 to 9 attacks (Fig. 6.4). The covariates in the most parsimonious models had probability of using a grid cell of elephants ($\beta = 2.72 \pm 0.37$ SE), forest area ($\beta = 0.01 \pm 0.004$ SE) and area with agriculture ($\beta = 0.005 \pm 0.004$ SE) as explanatory variables for elephant attacking humans (Table 6.2).

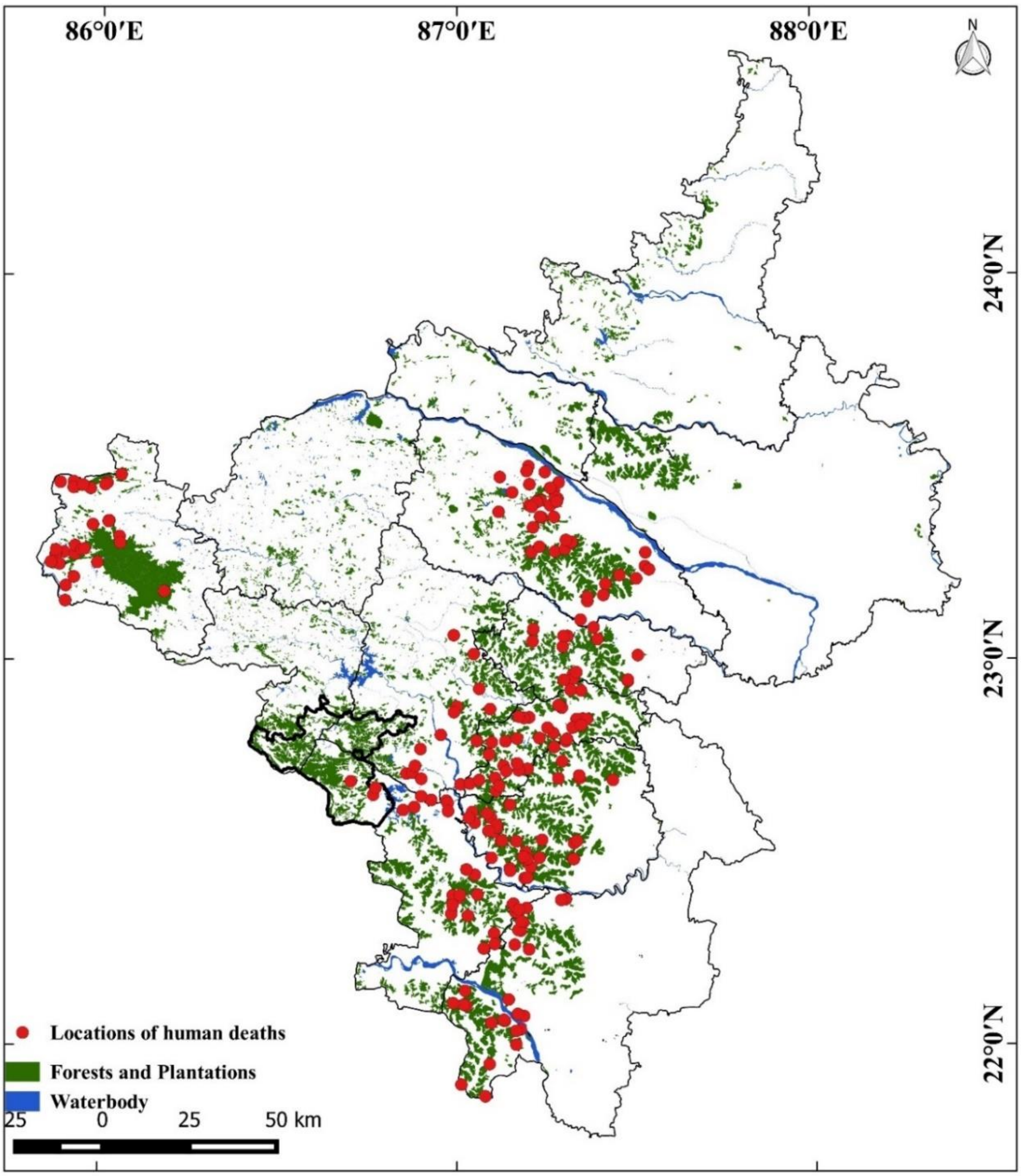

Figure 6.1 Locations of human death due to elephants in South Bengal from 2010 to 2018

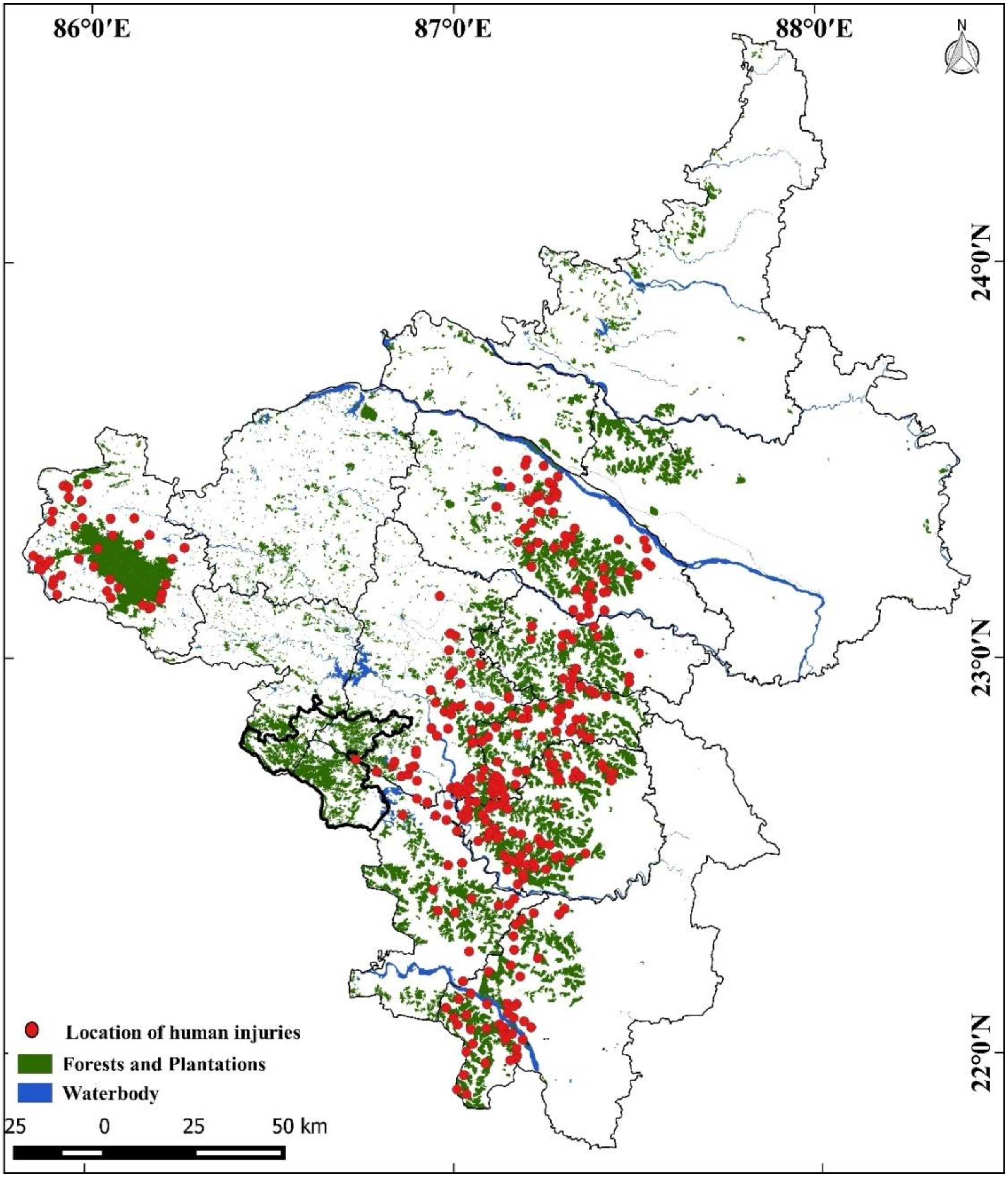

Figure 6.2 Location of human injuries due to elephants during 2010 - 2018 in South Bengal.

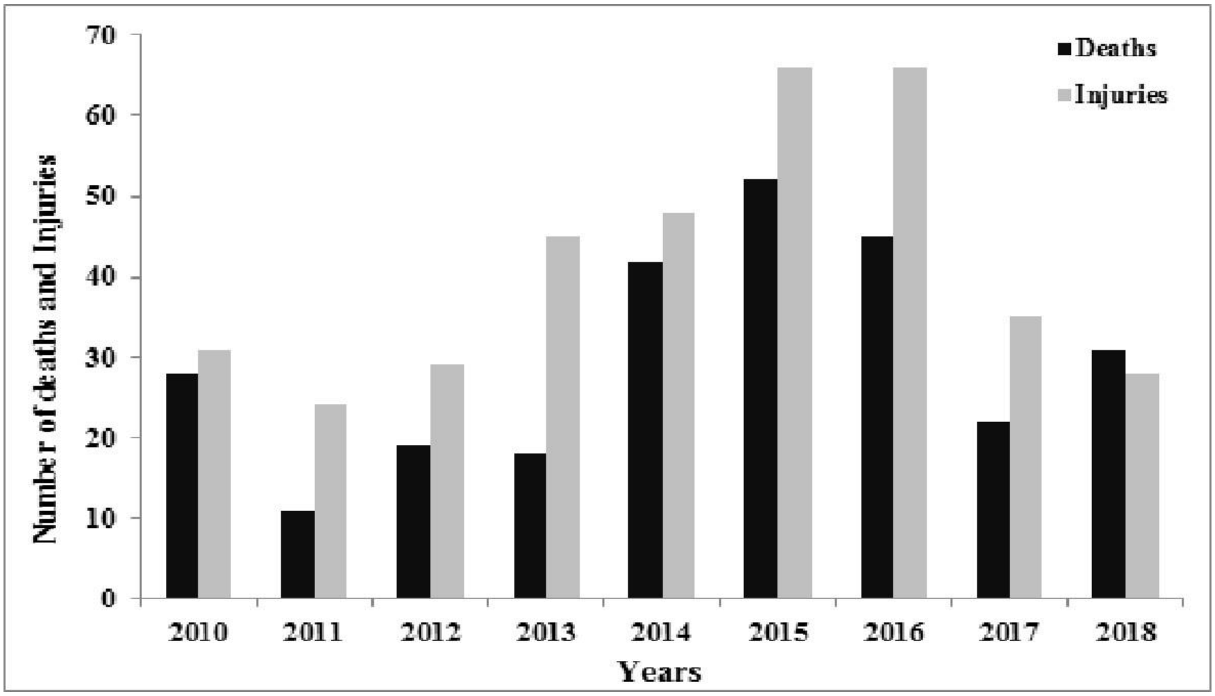

Figure 6.3 Year-wise human-elephant interactions (2010–2018) in South West Bengal

Table 6.2 Top models explaining the predictive variable for the elephant attack on humans in South Bengal

Model		***β* coefficient**	**($S\hat{E}$)**	**$QAIC_c$**	***P* value**
OC+FA+AG	Intercept	-1.498	0.365	552.05	0.000
	OC	2.72	0.37		0.000
	FA	0.01	0.004		0.000
	AG	0.005	0.004		0.256
OC+FA	Intercept	-1.251	0.278	552.61	0.000
	OC	2.581	0.342		0.000
	FA	0.014	0.003		0.000
AG+VA+FOREDG	Intercept	-0.137	0.204	554.45	0.000
	AG	-0.003	0.004		0.419
	VA	-0.137	0.040		0.000
	ED	0.000	0.000		0.000
OC+ FOREDG	Intercept	-0.687	0.240	574.64	0.000
	OC	1.622	0.714		0.023
	ED	0.000	0.000		0.185
OC	Intercept	-0.800	0.225	575.99	0.000
	OC	2.440	0.355		0.000
OC+AG	Intercept	-0.793	0.27	578.03	0.000
	OC	2.434	0.358		0.000

	AG	-0.000	0.004		0.963
FOREDG	Intercept	-0.329	0.166	582.22	0.000
	ED	0.000	0.000		0.000
AG+ FOREDG	Intercept	-0.322	0.214	584.25	0.000
	AG	0.000	0.004		0.959
	ED	0.000	0.000		0.000
FA	Intercept	0.081	0.157	658.38	0.007
	FA	0.009	0.003		0.005
AG	Intercept	0.509	0.140	665.73	0.052
	AG	-0.007	0.004		0.062
WA	Intercept	0.306	0.137	673.50	0.692
	WA	0.014	0.037		0.686

OC- Probability of using a grid cell by the elephants; FA- Forest area; AG- Agriculture area; VA- Village; WA- Water body; FOREDG- Forest edge density; QAICc, Quasi Akaike Information Criterion corrected for small-sample bias; *P*- Significance of each variable in the model

The number of human deaths highly varied between the years (Kruskal wallis $\chi^2 = 29.17$, df = 8 $p < 0.05$) (Fig. 6.5). Of the total human deaths, 214 (79.85%) were men and 54 (20.15%) women. The men deaths and women deaths vary significantly between the years (men: Kruskal wallis $\chi^2 = 23.93$, df = 8 $p < 0.05$; women: Kruskal wallis $\chi^2 = 5.40$, df = 8 $p = 0.71$, Fig. 6.6). Overall men ($23.78 \pm 11.51_{SD}$) and women ($6.50 \pm 3.21_{SD}$) deaths due to elephant significantly varied between years ($t = 4.094$, df = 15, $p < 0.001$, Fig. 6.6). The number of human deaths was more between January and June than in other months.

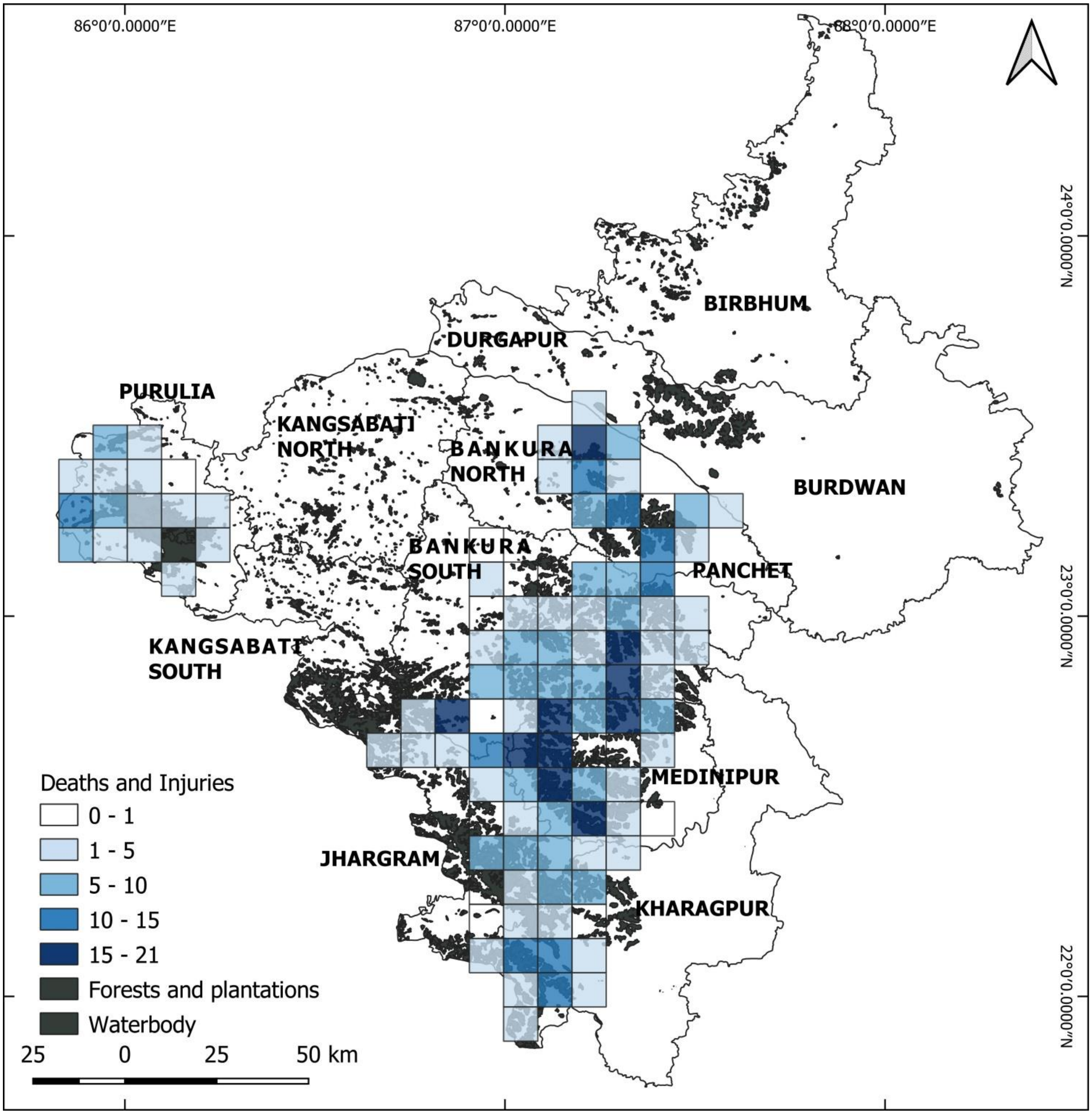

Figure 6.4 Grid cell wise occurrences of human-elephant interactions (human deaths and injuries, 2010–2018) in South West Bengal

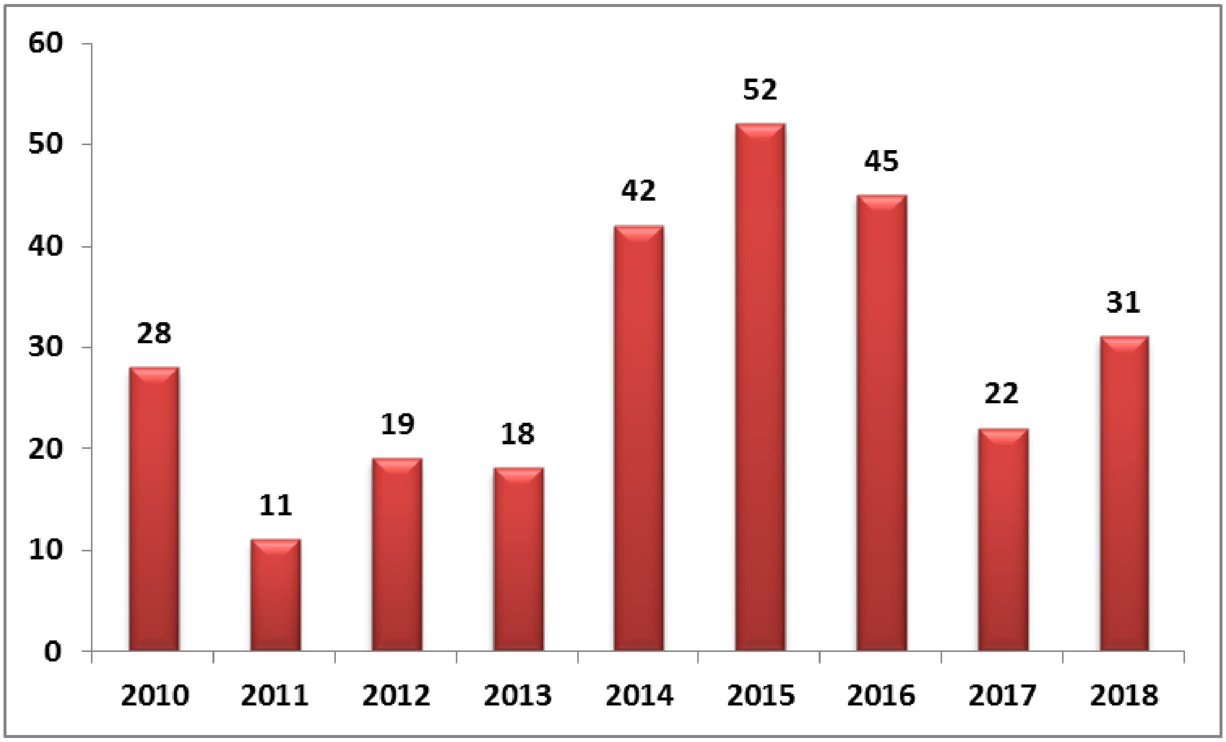

Figure 6.5 Numbers of human deaths due to elephants at South Bengal in different years

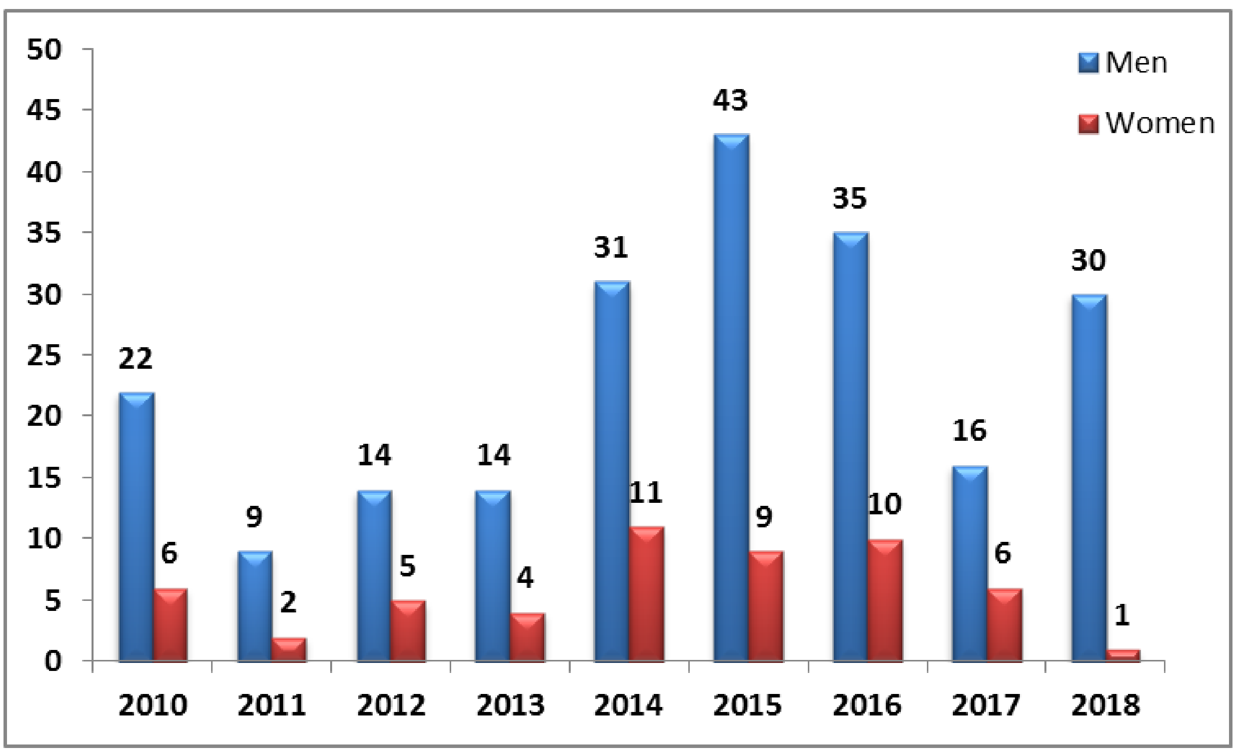

Figure 6.6 Number of men and women deaths due to elephants in different years at South Bengal (blue bar: men; red bar: women).

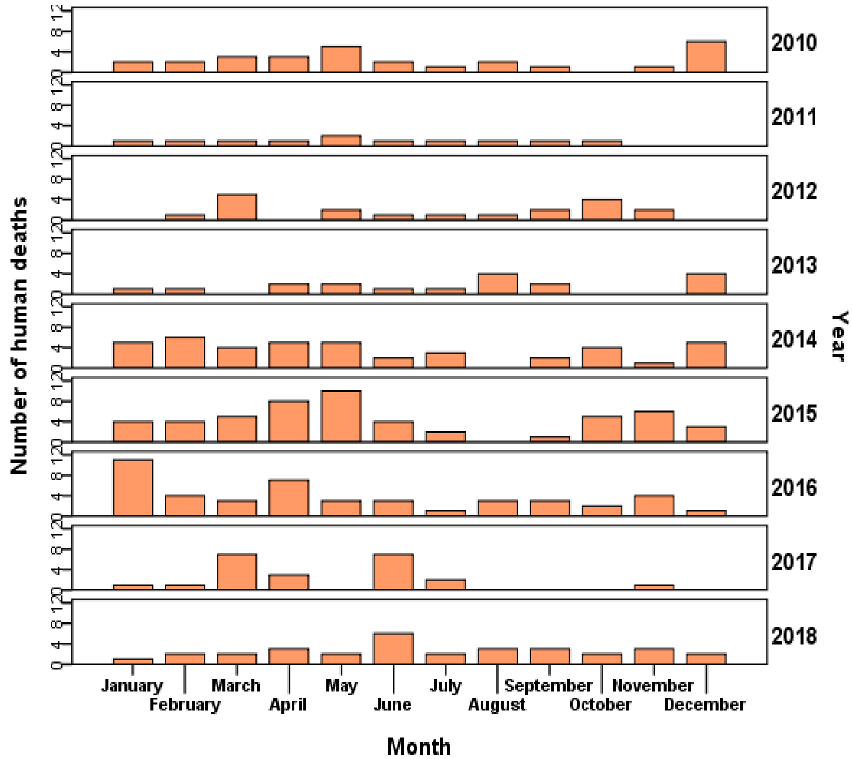

Figure 6.7 Number of human deaths due to elephants in different months of the years during 2010 - 2018.

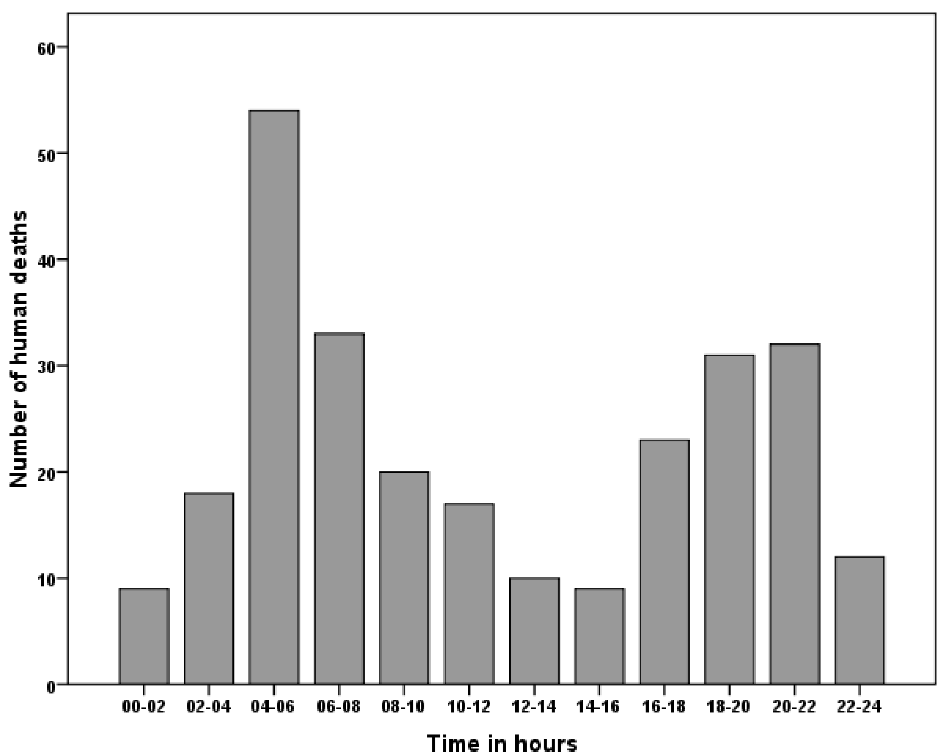

Figure 6.8 Human deaths due to elephants in different timings of the day (24-hour cycle) at South Bengal

Human deaths occurred all through the day of 24 hours; however, the highest deaths occurred between 0400 and 0600 hours (Fig. 6.8). Human deaths were more pronounced in two peaks i.e., between 0400 - 0800 hours and 1800 -2200 hours. The lowest human deaths were between 0000 – 0200 hours and 1200 – 1600 hours.

61.92 % of the human deaths due to elephants were in non-forest areas (Table 6.3). The locations of deaths were significantly ($\chi^2 = 13.594$, df = 1, $p < 0.001$) more in non-forest areas ($16.44 \pm 12.10_{SD}$) than in forest areas ($10.11 \pm 6.88_{SD}$). However, the proportions of human deaths between forests and no-forests highly varied between the forest divisions ($t = -2.733$, df = 7, $p < 0.05$). The victims were not aware of the presence of elephants (66.11% of human death cases) was highly significant against being unaware of the presence of elephants ($\chi^2 = 24.808$, df = 1, $p < 0.001$). But, the proportion of death while aware of unawareness highly varied between the forest divisions ($t = 3.043$, df = 7, $p < 0.05$).

Table 6.3 Human deaths (%) in the forest / non-forest area and aware/unaware of the presence of elephants in different forest divisions

Divisions	Location of human death		Awareness of the presence of elephants		Total
	Percent in Forest (N)	Percent in Non-Forest (N)	Percent-Yes (N)	Percent-No (N)	
Bankura North	33.33 (14)	66.67 (28)	54.76 (23)	45.24 (19)	42
Bankura South	35.29 (6)	64.71 (11)	29.41 (5)	70.59 (12)	17
Jhargram	36.36 (8)	63.64 (14)	27.27 (6)	72.73 (16)	22
Kharagpur	30.00 (9)	70.00 (21)	33.33 (10)	66.67 (20)	30
Medinipur	35.55 (16)	64.44 (29)	22.22 (10)	77.78 (35)	45
Panchet	50.00 (8)	50.00 (8)	31.25 (5)	68.75 (11)	16
Purulia	33.33 (10)	66.67 (20)	26.67 (8)	73.33 (22)	30
Rupnarayan	54.05 (20)	51.35 (19)	37.84 (14)	62.16 (23)	37
Total	38.08 (91)	61.92 (148)	33.89 (81)	66.11 (158)	239

Circumstances of human deaths due to elephants:

Of all the activities of the deceased due to elephants, the highest (17.91%) was when people had gone out for defecation. That was followed incidences when people were engaged in agricultural activities (15.67%) or when people had gone for collecting the NTFP (14.93%) or when the victims were sleeping or doing some household work around their houses (14.18%) or while traveling through forest patches on the road (21.64%, Fig. 6.9).

I developed a hotspot map using only the locations where people got killed while traveling to and from the village, when they had gone out for open defection, including all the death locations (Fig. 6.10). A few hotspots emerged out for each circumstance of deaths, even though circumstances of human deaths remain widespread. The two major hotspots due to open defection were in Rupnarayan and North Bankura. The identified hotspots for deaths while traveling to or from the village were in two locations in North Bankura, one in Rupnarayan, two in Medinipur, two in Kharagpur and one in Jhargram. All the hotspots of human deaths were certainly at the fringes of the forest or the patch having both forest and agriculture especially at Purulia, North Bankura, Rupnarayan, Medinipur, Jhargram and Kharagpur Forest Divisions. Of all the hotspots, the major ones were in Rupnarayan, Medinipur, North Bankura, and Kharagpur Forest Divisions.

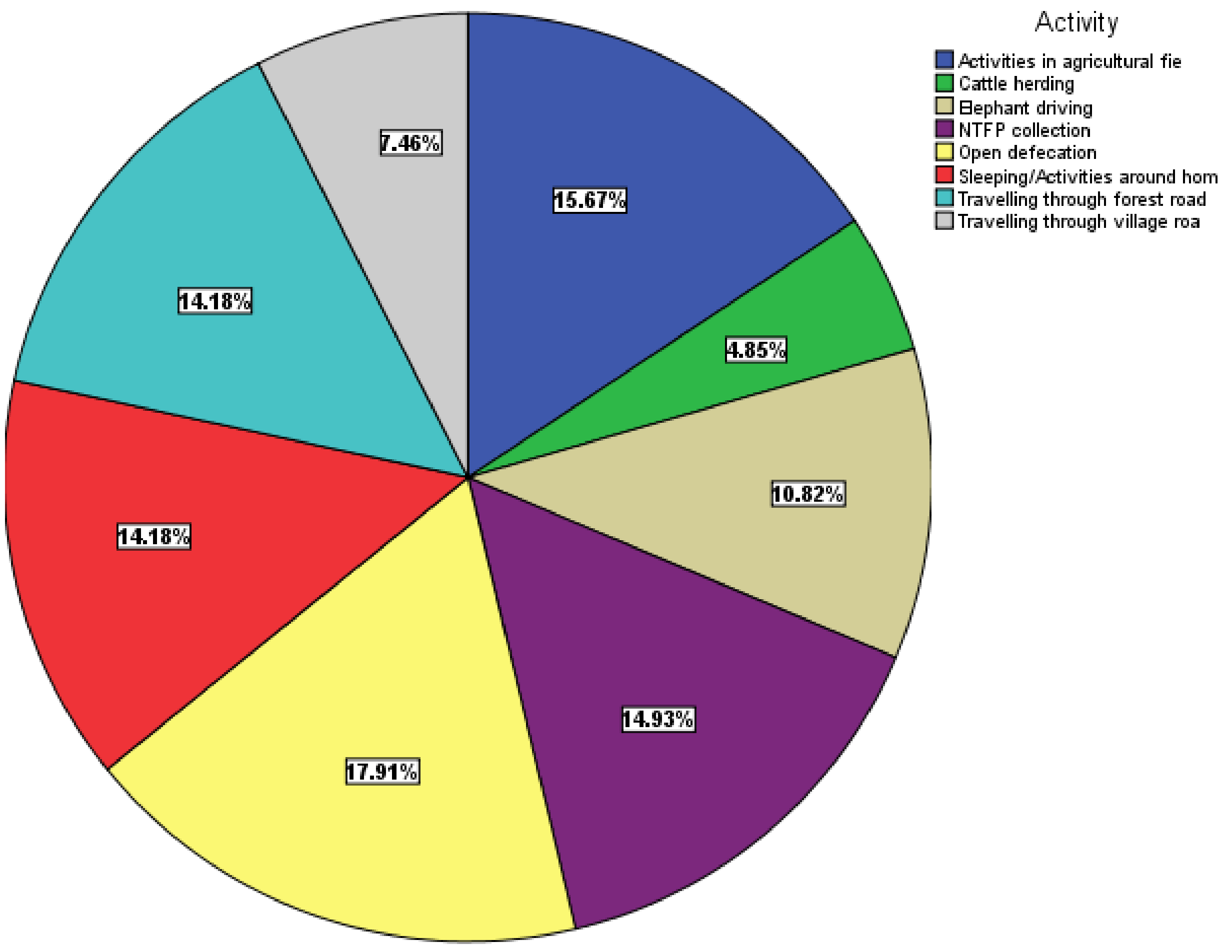

Figure 6.9 Activities the deceased were engaged while their death occurred due to elephants

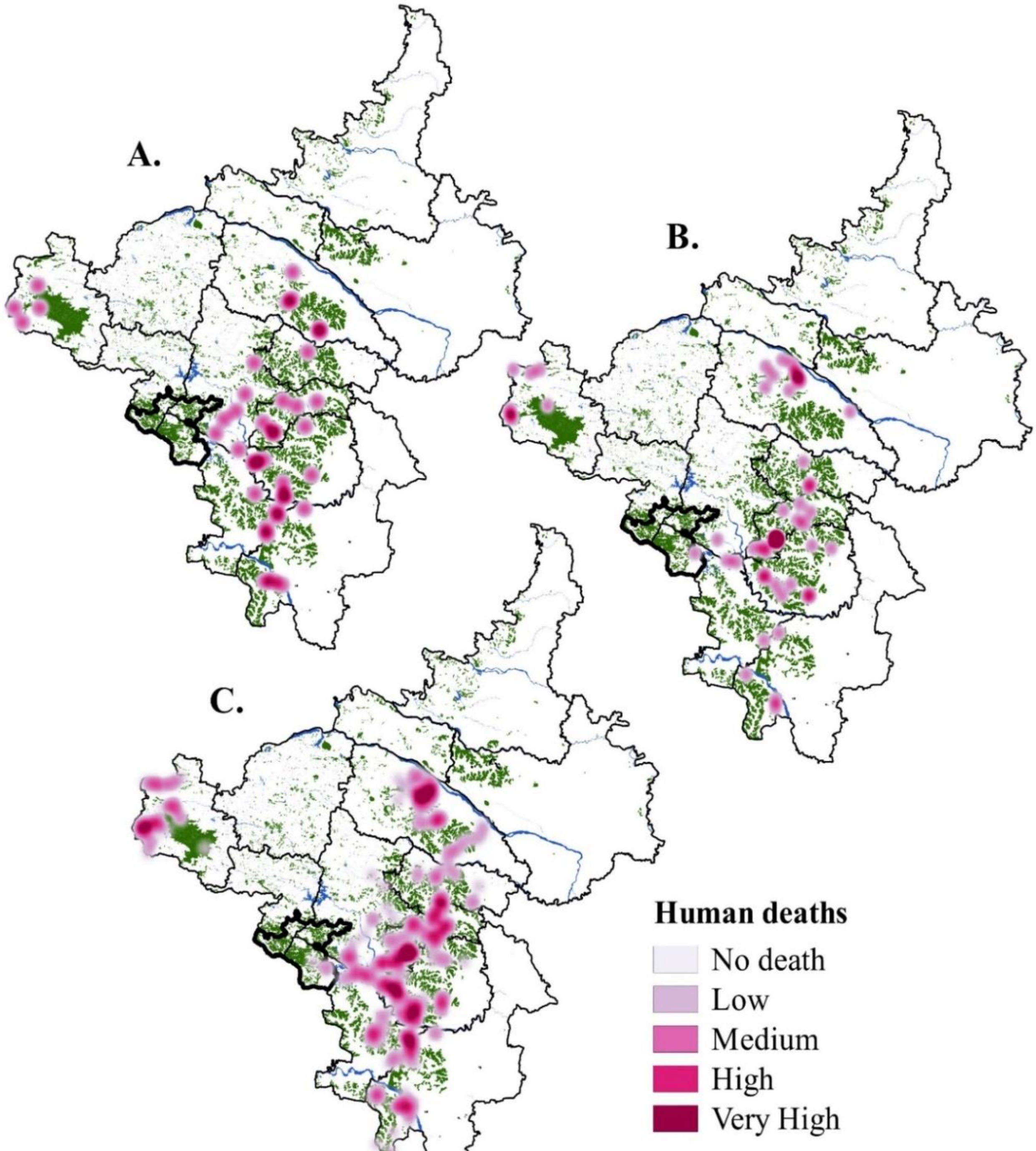

Figure 6.10 Hotspot analysis of human deaths due to elephants in South Bengal: A. While traveling to or from the village, B. while had gone out for open defecation, and C. Overall deaths.

The circumstances of human injuries due to elephant shows that 23.39% of incidence happened while people were traveling to and from the village, which is followed by during the NTFP collection (19.35%), activities in the agriculture field (13.44%) and open defecation (11.02%) (Fig. 6.11). Substantial injuries while watching the elephants, while people were sleeping in their homes or engaged in some household work around the home were also recorded.

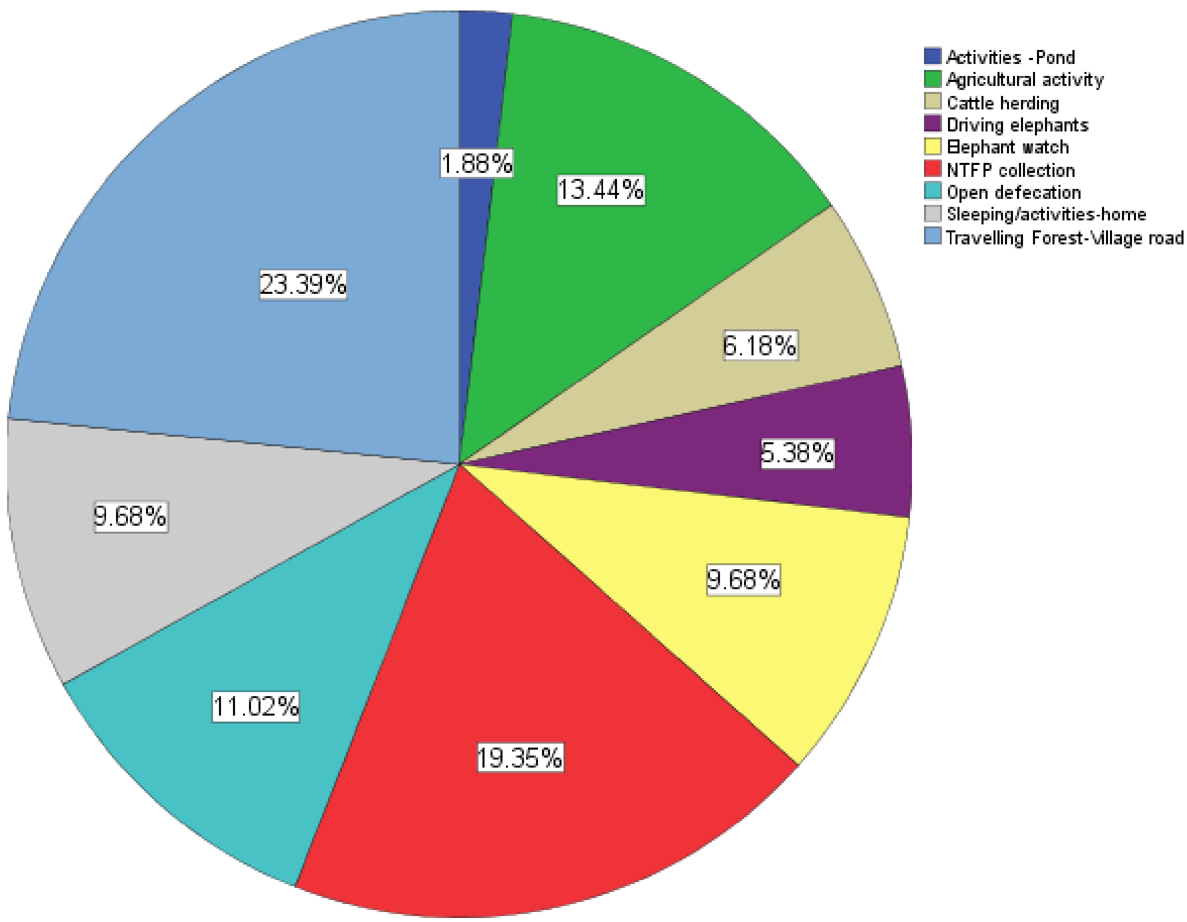

Figure 6.11 Circumstances when human injuries (in percent) occurred due to elephants in South Bengal.

Elephant deaths

Elephant deaths: A total of 23 elephant deaths were recorded between 2013 and 2018, of which 14 were males, eight were females, and one was a calf (Table 6.4). The highest elephant deaths were in January (N = 6), which was followed by April, August, and September (N = 3). The retaliatory killing was the major reason for elephant deaths (N = 10), which was followed by electrocution (N = 8), and train accidents (N = 3). The highest number of elephant deaths were reported from Bankura North (N = 13) wherein the retaliatory killing of elephants was eight. Panchet division had the highest number of elephant deaths due to train accidents (N = 2).

Table 6.4 Details of the elephant deaths that occurred in South Bengal

Year	Month	Range	Division	Reason of death	No. of elephants
2013	June	Beliatore	Bankura North	Electrocution	1ADM
	September	Garhbeta	Rupnarayan	Electrocution	1 ADF
	October	Manikpara	Jhargram	Train accident	1SADM
	December	Barjora	Bankura North	Electrocution	1 ADM
2014	April	Mejhi	Bankura North	Electrocution	1 ADF
	December	Bishnupur	Panchet	Train accident	1 ADM
2015	April	Barjora	Bankura North	Retaliatory killing	1 ADM
	September	Bankura north	Bankura North	Electrocution	1 ADM
	October	Sonamukhi	Bankura North	Electrocution	1 ADM
2016	January	Sonamukhi	Bankura North	Retaliatory killing	1 ADM
	January	Beliatore	Bankura North	Retaliatory killing	1 ADF
	February	Sonamukhi	Bankura North	Retaliatory killing	1 ADF
	January	Sonamukhi	Bankura North	Retaliatory killing	1 ADF
	January	Barjora	Bankura North	Retaliatory killing	1 ADM
	April	Bhadutala	Medinipur	Electrocution	1 ADM
	May	Sonamukhi	Bankura North	Retaliatory killing	1 ADM
	August	Bishnupur	Panchet	Train accident	1 ADF, 1 SADF 1 CF
	September	Bagmundi	Purulia	Electrocution	1 ADF
2017	January	Garhbeta	Rupnarayan	Retaliatory killing	1 ADM
	January	Bankura North	Bankura North	Retaliatory killing	1 ADM
	February	Beliatore	Bankura North	Retaliatory killing	1 ADM

ADM: Adult male; ADF: Adult female; SADM: Subadult male; SADF: Subadult female: CF: Calf

Crop depredation by elephants

During August 2017 - December 2018, in Medinipur, Rupnarayan and Kharagpur forest divisions with the total depredated area being 2370 hectares, a total of 683 crop depredation cases were reported (Table 6.5). A total loss of Rs. 355.50 lakhs was incurred by the forest department during this period. Paddy was the most depredated crop (n=394), 113 cases of Potato, 120 cases of vegetables and 56 cases of sugarcane. Paddy turned out to be the most depredated crop leading to a loss of Rs. 222.75 lakhs, followed by potato with a total loss of Rs. 43.50 lakhs.

Table 6.5 Seasonal crop depredation by elephants in Medinipur, Rupnarayan and Kharagpur Forest Divisions

Division	Crop	Season	Total no. of incidents	Area depredated (in ha)	Total loss (in Rs)
Medinipur	Paddy	Pre monsoon	50	180	2700000
		Monsoon	40	140	2100000
		Post monsoon	84	210	3150000
	Potato	Pre monsoon	0	0	0
		Monsoon	0	0	0
		Post monsoon	68	120	1800000
	Vegetables	Pre monsoon	30	110	1650000
		Monsoon	0	0	0
		Post monsoon	67	125	1875000
				Total	**1,21,75,000**
Rupnarayan	Paddy	Pre monsoon	42	140	2100000
		Monsoon	29	155	2325000
		Post monsoon	60	190	2850000
	Potato	Pre monsoon	0	0	0
		Monsoon	0	0	0
		Post monsoon	45	170	2550000
	Vegetables	Pre monsoon	0	0	0
		Monsoon	0	0	0
		Post monsoon	23	150	2250000
				Total	**1,20,75,000**
Kharagpur	Paddy	Pre monsoon	41	240	3600000
		Monsoon	10	50	750000
		Post monsoon	38	180	2700000
	Sugarcane	Pre monsoon	56	170	2550000
		Monsoon	0	0	0
		Post monsoon	0	0	0
				Total	**96,00,000**

6.4. Discussion

The human-elephant conflict has been persisting for centuries. However, the intensity of the conflict has been perceived to have increased in the recent past in the Indian Subcontinent (Olivier, 1978; Choudhury, 2004; Gubbi, 2012; Guru and Das, 2021). The loss of forest cover led to habitat fragments that forced the elephants to move out of the forests, either for foraging in agriculture fields or moving between the fragments (Sukumar, 1990; Zimmermann *et al*., 2009; Santiapillai *et al*., 2010; Wilson *et al*., 2015). The conflicts occurred largely outside the forests, especially along their movement paths (Choudhury, 2004; Nath *et al*., 2009; Das *et al*., 2012; Gubbi *et al*., 2014; Prakash *et al*., 2020). Asian elephant is a forest-edge species (Fernando, 2015). In south Bengal, the presence of elephants near the edge of forests and around agricultural land led to high conflict. Human-dominated landscapes are also prime habitat for Asian elephants in other countries in Asia where similar conflicts can be observed, such as high ecological overlap between elephants and people in Malaysia (de la Torre *et al*., 2021), and a higher number of elephant attacks on humans in Nepal in close proximity to the forest (Ram *et al*., 2021a). Elephants spend more time in closed canopy habitat during the day than at night, which is probably due to thermal regulation and the shade provided by the closed canopy during the day, but they come to the edge area more at night (Sitompul *et al*., 2013). Furthermore, continued habitat loss and fragmentation have most likely fragmented elephant populations over the last century (Ram *et al*., 2021b). Elephants move more in ranges with higher percentages of agricultural area (Chan *et al*., 2022). In south Bengal they spend more time near the edge of the forest because it is fragmented and less dense (close to human settlements). The proximity of elephants to human-dominated areas for their dietary requirements (Graham *et al*., 2010; Webber *et al*., 2011; Gubbi, 2012) has become a matter of concern from the management perspective too. According to my results, the conflict is influenced by the probability of using a grid cell by the elephants. Similarly, Goswami *et al*. (2015) reported the availability of crops is a major driver of elephant occupancy and crop depredation in the Garo Hills in Meghalaya. In South Bengal, more elephant attacks were at the periphery of the forests that can be attributed to the presence of elephants in the periphery for foraging from the agricultural land. The sal dominated forest with low availability of food resources (food species and their abundance) force the elephants to move out of the forest to feed on agriculture crops that make them to susceptible for conflict with humans. The *hula* drive increases the deprivation for a shorter period that can make the animals agitated and hungry, which in turn forces the elephants to be stubborn to driving them off, and their attempt to go for crop-raiding increases the chance of encountering the people leading to high human deaths and injuries. Thus, the high number of human deaths due to elephants was in non-forest areas than in the forest areas.

The number of elephant attacks on humans varied between the years and increased over the years, with a slight depression after 2016. This trend can be attributed to the continuous expansion of the elephant range. Therefore, the forest department adopted measures like erecting electric fences, digging trenches, and regular driving of elephants through *hula* parties (the practice of driving the elephants using a torch made of rugs and cloth which are put on fire using any flammable oil) to stop the movement of elephants on a daily basis (Chatterjee, 2016). Yet the intensity of human-elephant interactions persists as elephants have become residents of the agrarian landscape and continues feeding on agricultural crops, leading to conflict that sometimes results in human death and increasing retaliatory killing of elephants too. Elephant attacks on men were more frequent than on women and can be linked with the high movement of males as compared to females and their engrossment in chasing the elephants (Sarker *et al*., 2015; Ram *et al*., 2021a). A high number of human deaths in the months of January to June is due to the paddy harvesting season in this area. Paddy being one of the highly preferred food crops by elephant is regularly depredated upon which leads to increased interactions of humans with elephants ultimately leading to increased human deaths. Crop raiding by elephants has been documented to coincide with the harvesting seasons in Africa and Asia (Sitati *et al*., 2003; Chen *et al*., 2016; Naha *et al*., 2020). Peaks in the time of deaths between 0400 - 0800 hours and 1800 -2200 hours indicate the time of the day when the elephant activity is highest. Elephant activity is highest during early mornings and evening time when they spend most of their time feeding and are in contact with the human populations.

The retaliatory killing and electrocution of elephants is likely due to intolerance, which is a major concern in the entire elephant range (Sukumar, 1989b). Such negative steps by people may decrease the general support for any conservation initiatives (Guerbois *et al*., 2012; Kansky *et al*., 2016). The elephant deaths due to electrocution (N = 8) indicate the intentional use of high voltage transmission lines to tap electricity directly to the electric fences (Gubbi *et al*., 2014). Electrocution is widely known as an effective means to kill elephants and is a common practice reported in the entire elephant range in India (Sukumar, 1989b; Gubbi, 2009). People take retaliatory steps against elephants also due to psychosocial impacts due to loss of their crops, kin's or properties, that too if they are uncompensated for the loss (Ogra, 2008; Barua *et al*., 2013).

The human-animal conflict is a global issue that can have multiple dimensions, this scenario being one of them. Considering the highly dynamic situation of the human-elephant conflict in this region, regular monitoring of the populations would help in a better understanding of the scenario and its management. A large-scale awareness program to the farmers and local people in the high conflict areas and immediate attention by the forest department on conflict issues only help to win the confidence of people towards the initiatives by the forest department and about the elephant. Native food tree species of elephants can be propagated in the degraded forest areas especially where elephants spend most of their time. That might help in reducing the crop feeding by elephants, and to retain them in the forest.

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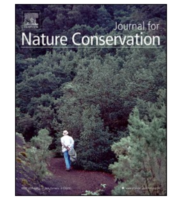

Anthropogenic driven range expansion of Asian elephant *Elephas maximus* in an agricultural landscape and its consequences in South West Bengal, India

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A R T I C L E I N F O

Keywords:
Elephas maximus
Geographic range
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Human-elephant interactions, people perception

A B S T R A C T

Alterations of the geographical ranges of animals have become a reason for interactions with humans, leading to various consequences. We describe the pattern of range expansion of Asian elephants (*Elephas maximus*) and implications for human-elephant interactions in the agricultural landscape of South West Bengal, India. We enquired about past and current sightings of Asian elephants from local people to gather information on range expansion from the 1950 s to 2018. We also collected the records of human deaths and injuries by elephants from 2010 to 2018 from the records of the Forest Department. We employed an occupancy framework to understand the probability of the occurrence of elephants in the landscape from 2010 to 2018. The range of elephants in the landscape increased from ~ 1200 km^2 in the 1950–60 s to ~ 13200 km^2 by 2010–18. The calculated probability of use of grid cells was 36 % and the forest edge had a high influence on the space usage by the elephants. Elephants occurred in an average of 26 grid cells per month, and the number of grid cells with elephants did not differ between the months. A total of 640 attacks on humans occurred, which significantly varied between the years. The probability of elephant occurrence in a grid cell was the major determinant factor for the elephant attacks on humans. Although people respect elephants, there is a sense of intolerance towards them if they enter the crop fields, owing to the small land holdings and the incapacity to endure the monetary losses of the farmers.

1. Introduction

The changes in the geographic range of species are a natural phenomenon; however, most of these changes during the last century have been caused by human actions (Ripple et al., 2014). Understanding the underlying causes of such changes is crucial for the management of species and the maintenance of biodiversity (Lalibetre & Ripple, 2004). The changes in the range also depend on the habits or adaptations to the habitat conditions of a species. For example, flying animals (e.g., *Pteropus poliocephalus*: Williams et al., 2006) over terrestrial animals (e.g., *Sciurus niger*: Geluso, 2004), habitat generalists (e.g., *Didelphis virginiana*: Beatty, Beasley & Rhodes, 2014) over habitat specialists (e.g., *Enhydra lutris*: Lubina & Levin, 1988), non-fossorial species (e.g., *Cervus elaphus*: Szemethy et al., 2003) over fossorial species (e.g., *Hystrix cristata*: Mori et al., 2018) successfully expanded their ranges to diverse habitat. Apart from their habits, many environmental and anthropogenic factors can impact the shift in the range (Wang et al., 2021). Some of the major anthropogenic factors include the hunting of animals, habitat conversion or encroachment (Laurance et al., 2014), and various developmental activities.

Anthropogenic factors frequently cause shrinkage in the range of a species particularly in large-bodied animals e.g., 24 species of the 43 species evaluated had lost their geographic range, however, 17 of them showed expansion of their range while three species remained unchanged in their range, further the species showed range expansion was relatively smaller body size in North America (Lalibetre & Ripple, 2004). Similarly, Benedict et al. (2000) pointed to the range expansion of many small mammals, while the species that required large tracts of habitat showed a decrease in their range in Nebraska.

Despite various challenges, large carnivores have managed to survive in human-modified landscapes with a strong potential for human-wildlife conflict and have naturally expanded their geographic range

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Rapid communication

Mayurjharna Elephant Reserve is just a gateway for elephants: Changes in the range use pattern by Asian elephants over seven decades

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Abstract. Persistent use of the Mayurjharna forest by elephants led to its declaration as "Mayurjharna Elephant Reserve (ER)" in 2002; however, the usage changed over time. We describe the elephant movement pattern and the quality forage availability in the Mayurjharna ER. We collected past and current sightings of elephants from people and records of the Forest Department and constructed the range used from 1950 to 2018. Initially, the range of elephants in the reserve was ~80 km^2 in 1950–1959 that increased to ~572 km^2 by 1990–1999 but later decreased to ~152 km^2 in 2010–2018. The high human settlements, alteration, and overexploitation of the forest might lead the elephants to the rich agricultural lands outside the reserve, making the reserve just a gateway for elephants to move to other parts of the South Bengal landscape.

Key words: *Elephas maximus*, Elephant Reserve, range use change, West Bengal.

Animal movement is the soul of many important ecological processes and is considered crucial for an enhanced understanding of population dynamics and animal behavior (Horne et al. 2007). Studying animal movement patterns allows ecologists to determine the distribution of species both in space and time especially migrating wildlife populations and the factors that influence their movements in different environments (Pinaud 2008). Wide-ranging species of mammals frequently foray into new areas, an activity more common in the mosaic landscape comprising natural and human-modified land uses. These mosaic landscapes are often human-dominated owing to the increasing human density, which turns the forest areas into cultivable land or settlements. Though elephants get preferable feed by venturing into these areas, the movement often leads to high conflicts in these human-dominated landscapes. The elephant, a keystone species (Kurt 1974), is of high conflict in India and thus becomes an important species from a management point of view.

In India, Asian elephants are found in four distinct geographical regions: the northwestern population is found in the Shivalik Hills and Terai of Uttar Pradesh, the north-eastern population is distributed from North Bengal to Manipur, the central Indian population inhabits the states of Bihar, Jharkhand, and Orissa and the south-western part of West Bengal, and the south Indian population is distributed in the states of Karnataka, Kerala, and Tamil Nadu (Baskaran et al. 2011). The estimated elephant population in India is ~27 000 individuals, including 3000 individuals of the central Indian population (Project Elephant Division-MoEFCC 2017). The central Indian population is diffused in a mosaic of natural forest (often degraded or fragmented), village forest, as well as cultivated land, and highly fragmented (Baskaran et al. 2011). On the other hand, the human population has increased in the past few decades with a large tract of forests converted into agricultural lands and human settlements (Dutta et al. 2017). Large-scale mining for minerals has become the single most serious threat to the conservation of elephants in northern Orissa and southern Jharkhand (Baskaran et al. 2011), which frequently drives elephants out of these forests. Sand mining for minerals in the Singhbhum district adjoining Dalma Wildlife Sanctuary (WLS) of Jharkhand in the 1950s disturbed the forests (Singh and Chowdhury 1999) and eventually drove the elephants

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The Expansion of Range of Elephants in South West Bengal

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Abstract

Range expansion in animals is influenced by natural, human-induced factors, and the distribution of food resources and water availability. Asian elephants in South West Bengal are the recent intruders from the Dalma Wildlife Sanctuary in the adjoining state of Jharkhand. The study was focused on understanding the changes in the elephant's range and its effects on the human population. Entire South Bengal landscape was gridded with 10 X 10 km (100 km^2) and for each grid five people were interviewed between January 2018 and February 2019 for the elephant presence for the last six decades (i.e., 1950 to 2018). Based on responses, confirmed geo-coordinates of elephant detections were recorded and overlaid on the grids. The elephants were confined to Purulia Forest Division (near Ajodhya Hill) during 1950-60s and only a few elephants used to enter South Bengal through Mayurjharna Elephant Reserve via Kankrajhore and used around 1200 km^2 area. Gradually, the use of landscape increased with each decade throughout the landscape with use of about 18500 km^2 by 2000-10, however, the elephant range has shrunk to 13200 km^2 during 2010-18. This movement form Dalma WS started due to mining impactsin the area, and the vast agricultural plains of South Bengal lured the elephants. Over the years, usage of the same foraging grounds, absence of continuous forest patches, and the presence of agricultural land on peripheries of the forest fragments have led to the depredation of agricultural land which, in turn, has given rise to human-elephant conflict in the landscape.

legum... This magnificent bustard affects bare, open semi-desert plains and sparse grass-covered country inters...sed with low scrub and bushes or with cultivation. In current scenario, It is facing existential crisis due to high r...uction population number and high mortality. This situation arised from habitat destruction. Habitat destru...n is backed by various developmental project (Wind energy, electricity transmission etc.), irregular and inconsis...ce agricultural activities irrational use of pesticides, hunting etc. Govt of India is implementing a conserva... project. Govt of Rajasthan declared it as state animal. Recently Supreme Court of India has given a verdict to underground deployment of power transmission. Conservation of bustard is requirement to save grassland ecosystem. It is also representing a balanced ecosystem.

KEYWORDS: Godavan, Semi-desert plains, Verdict, Grassland ecosystem.

NSAB-OP-39

AVIFAUNAL DIVERSITY OF AJMER AND NEED FOR THEIR CONSERVATION

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ABSTRACT:

The avifaunal diversity of Ajmer was studied during 2015-2016. Ajmer is located centrally in Rajasthan. Rajasthan is the western state of India. Total 25 species of birds belonging to orders Apodiformes, Bucerotiformes, Passeriformes, Columbiformes, Psittaciformes Piciformes, Coraciiformes, Cuculiformes, Galliformes, Stringiformes were observed. The highest number is from Passeriformes (*Passer domesticus, Acridotheres tristis, Acridotheres ginginianus, Sturnia pagodarum, Gracupica contra, Pycnotus cafer, Sexicoloides intermedius, Corvus splendens, Urocissa erythroryncha, Orthotomus sutorius, Dicrurus macrocercus* etc.), and the lowest number Psittaciformes (*Psittacula krameri*). Bee-eater or *Merops ornatus* belongs to Coraciiformes, *Centropus sinensis* belongs to Cuculiformes. *Dinopium benghalensis* belongs to Piciformes. Birds of more than 10 orders were observed. Least number were observed from order Bucerotiformes. Need for conservation of these birds were also discussed in the present paper.

KEYWORDS: Avifaunal diversity, Ajmer, Orders.

NSAB-OP-40

DYNAMICS OF HUMAN- ELEPHANT CONFLICT IN SOUTH WEST BENGAL

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ABSTRACT:

There are several factors which are responsible for causing human-elephant conflict. In India, elephant ranges are now beginning to have greater human density, which lead to greater pressure on elephant landscapes. The existing data on human-elephant conflicts (human deaths, injuries, crop damage and elephant deaths) in entire South Bengal