ECOLOGY AND RANGING BEHAVIOUR OF ELEPHANTS, *Elephas maximus*, AND ITS IMPLICATIONS FOR MANAGING HUMAN–ELEPHANT CONFLICT IN CHHATTISGARH, INDIA

A Thesis

Submitted by

N. LAKSHMINARAYANAN

For the award of the Degree of

DOCTOR OF PHILOSOPHY

IN

WILDLIFE SCIENCE

Under the guidance of

DR. BIVASH PANDAV

भारतीय वन्यजीव संस्थान

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DECLARATION

I hereby declare that the work conducted under the thesis titled "**Ecology and Ranging Behaviour of Elephants, *Elephas maximus*, and its implications for managing human–elephant conflict in Chhattisgarh, India**" is a record of orginal and independent research work done by me and subsequently submitted for the award of the degree of **Doctor of Philosophy in Wildlife Science to Saurashtra University, Rajkot, Gujarat**. This research work has been carried out under the guidance and supervision of **Dr. Bivash Pandav,** Scientist F, Wildlife Institute of India. The work has not formed the basis for the award of any other degree, diploma or any other qualification. I also declare that the thesis embodies my own work, analysis, observation, understanding and the particulars given in it are true to the best of my knowledge.

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CERTIFICATE

This is to certify that the thesis by Mr. N. Lakshminarayanan, titled "**Ecology and Ranging Behaviour of Elephants, *Elephas maximus*, and its implications for managing human–elephant conflict in Chhattisgarh, India**" is an original work and independent research work submitted to the Saurashtra University, Rajkot (Gujarat), for the award of the degree of **Doctor of Philosophy in Wildlife Science**

Mr. Lakshminarayanan (Registration number: 19206 date 06-02-2019) has put more than six semesters of research work embodied in this thesis under my guidance and supervision. The work presented in this thesis has not been submitted to any other University or Institute for the award for any degree, diploma or distinction.

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

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CERTIFICATE OF PLAGIARISM CHECK

It is certified that the Ph.D. thesis titled "**Ecology and Ranging Behaviour of Elephants, *Elephas maximus*, and its Implications for Managing Human–Elephant Conflict in Chhattisgarh, India**" submitted by **Mr. N. Lakshminarayanan** has been reviewed by us for plagiarism check as per UGC (Promotion of Academic Integrity and Prevention of Plagiarism for Higher Educational Institutions) Regulations. The following inferences are drawn from this check:

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EXECUTIVE SUMMARY

In the East-central region of India that supports the smallest regional elephant (*Elephas maximus*) population, the elephant ranges have expanded in northern Chhattisgarh (erstwhile eastern Madhya Pradesh) since late 1980s. Chhattisgarh was carved out of Madhya Pradesh during the year 2000, and thence, the State has been witnessing elephant range expansion and concomitant population growth resulting in acute human–elephant conflict. Over 60 human lives are lost every year due to human–elephant conflict, and the trend is only increasing. Chhattisgarh scenario represents challenges facing management of elephant populations undergoing environmental dispersals that typically result from saturated habitat conditions in the elephant home ranges. In response to the prevailing conflict situation, the study aimed to understand facets of elephant ecology and aspects of human–elephant conflict to generate management perspectives.

Historic information available as fragments in literature indicates that elephant distribution in the whole of East-central region was marked by both range expansions and local extinctions during the last one century. In particular, the contemporary phenomenon of elephant range redistribution in the East-central region peaked after 1980s, and coincides with large-scale human-induced disturbances to the formerly intact elephant habitats in the region. There were also pull factors like creation of pseudo-habitats (providing only cover for elephants) through forestry operations that possibly attracted elephants to human–dominated areas perpetuating human-elephant conflict.

In Chhattisgarh, the elephant distribution during the period 2012 to 2017 was reported from 16 Forest Divisions and four Protected Areas in the north and north-central regions of the state. The elephant population, as enumerated by Chhattisgarh Forest Department during 2021, ranged from 250 to 300. Besides being a relatively small population, elephants in Chhattisgarh occur scattered over large areas in small groups facing a perpetual risk of getting isolated by linear infrastructure and other associated developmental activities.

The estimated average home range (95% minimum convex polygon) of elephants in Chhattisgarh was 2571.4 km^2 (± 2300.2 km^2). The 95% kernel density home ranges of elephants were much lower averaging 517.5 km^2 (± 235.3 km^2). The elephant home ranges were not wholly well defined, and marked by inter-annual shifts caused by exploratory behaviour. The elephant home ranges were relatively large. The dry season home ranges were significantly lower than monsoon and winter ranges. Monthly variations in home ranges were significant, and best explained by idiosyncrasies of individual elephants. Among the forest types of open, moderately dense and very dense forests classified by Forest Survey of India based on crown densities, elephants selected open forests that were predominantly juxtaposed human–use areas. Although the crown density was low, the patches of open forests support dense strands of Sal (*Shorea robusta*) coppice with rank undergrowth offering adequate cover for elephants. Elephant habitat selection of these open forest patches appears to be influenced by potential foraging opportunities in human–use areas, and further facilitated by low inter-patch distance.

Crop losses caused by elephants were acute and widespread in Chhattisgarh. To draw an analogy, Karnataka's *ex gratia* payment towards crop losses by elephants during the period 2015-2020 was comparable with Chhattisgarh, although the former's elephant population is 93% more than the latter. The landscape-level assessment covering the whole of northern Chhattisgarh, and fine-scale assessment covering select areas in Surguja circle identified correlates of crop losses at both spatial scales. Elephant-related human deaths were widespread in the state. However, nearly 70% of incidences occurred in areas of high intensity of habitat-use by elephants. The human fatalities due to elephants were both temporally and spatially auto-correlated. An assessment of livelihood aspects of local communities in select conflict hotspots identified household-level activities that predispose frequent human–elephant interactions. Timely compensation of elephant-related losses elicited favourable attitudes in local communities towards conservation.

In a nutshell, "Chhattisgarh elephant problem" is typified by distribution of only a few hundred elephants over a very large mosaic landscape characterized by high interspersion of forests and human–use areas of agricultural fields and rural settlements. The challenges facing management of human-elephant conflict in

Chhattisgarh were further compounded by undefined elephant home ranges caused by exploratory behaviour of elephants, resulting in spread of human–elephant conflict. The conflict-related losses were increasing for both elephants and people with potentially negative longterm consequences for elephant conservation. While local conflict mitigation options to address the proximate causes of human–elephant conflict were manifold, and includes judicious land-use planning and identification of elephant conservation zones, Chhattisgarh human–elephant conflict situation is a wake-up call to devise and zealously implement landscape-level policies intended to stem habitat threats in the remnant, intact elephant ranges in the whole of East-central region with an overarching aim of minimizing environmental dispersals of elephants.

The TE herd in one of the water holes in Surajpur district of Surguja

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List of publications

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LIST OF ABBREVIATIONS

Symbol	Abbreviation
a.s.l	Average sea level
AIC	Akaike information criterion
BCS	Body condition Scores
CGFD	Chhattisgarh forest Department
CI	Confidence interval
FSI	Forest survey of India
GDP	Gross domestic product
GPS	Geographic positioning system
ha	Hectares
HEC	Human elephant conflict
IFD	Ideal free distribution
IUCN	International union conservation nature
KDE	Kernel density estimates
km	Kilometre
km^2	Square kilometres
LULC	Land use land cover
m	Meters
MCP	Minimum convex polygon
mm	Millimetres
MoEF&CC	Ministry of Environment, Forests and Climate Change
MSI	Mean shape index
MVT	Marginal value theorem
n	Sample size
N	Number of animals
NP	National Park
NTFP	Non-timber forest produce
PE	Project Elephant Division
R^2	Coefficient of determination
SD	Standard deviation
SE	Standard error
TWH	Trivers-Willard hypothesis
UD	Utilization distribution
WLS	Wildlife Sanctuary

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CHAPTER-1

GENERAL INTRODUCTION

Large mammalian herbivores that include many species of wild cattle, rhinoceros, and elephants have resource requirements that are similar to those needed by human settlements — i.e., flat terrain, proximity to water sources, and productive tropical climate. This similarity in resource requirements often results in competition between humans and large herbivores (Gordon, 2009). The biological theory of competitive exclusion suggests that complete competitors may outcompete each other (Hardin, 1960). The observed contemporary range contraction of many species of large herbivores in the world (Ripple et al., 2015) lends support to this theory. The rate of loss of species richness and abundance of large herbivores had increased manifold when compared to background rates in the face of human expansion (Ripple et al., 2016a, 2016b). Sustained conservation efforts would be required to maintain the remnant populations of endangered large herbivores.

Paradoxically, some of the endangered large herbivores like the Asian elephants (*Elephas maximus*) can pose a threat to lives and livelihoods of local communities presenting a unique challenge for management, which must reconcile conservation priorities of elephants while safeguarding human livelihoods at the same time (Desai and Riddle, 2015; Natarajan et al., 2021; Rangarajan et al., 2010; Sukumar, 2003).

Historically, elephants ranged widely in Asia, stretching from the river basins of Tigris–Euphrates in the west, to Yangtze–Kiang River basin in the east encompassing most of the present-day Asian countries (Shoshani and Tassy, 1996; Sukumar, 2003). In a way, historic Asian elephant distribution in the continent mirrored the present day African elephant distribution in terms of both the extent and population sizes (Sukumar and Santiapillai, 1996). However, Asian elephant ranges suffered massive range contraction and corresponding population declines. Concurrent population guesstimates of Asian elephants is about 40,000, which are distributed in 13 range countries (Rangarajan et al., 2010; Sukumar, 2006). As summarized by Blakes & Hedges (2002), the population estimates emanating from range countries outside of India and Sri Lanka, particularly from the southeast region were mere educated suppositions. Among the myriad causes of elephant range contraction, loss of habitats due to agricultural expansion and human settlements were overriding (Elvin, 2008; Leimgruber et al., 2003).

Among the Asian elephant range countries, India harbors more than 60% of the extant wild elephant populations. This is in spite of being a highly populous country with over 1.3 billion people and having a rapidly growing economy with targeted GDP rates of about 9% per annum. In India, both the elephant ranges and their populations have remained reasonably intact during the last few centuries in comparison to most other range countries. The country has some of the strongest legislations to protect elephant populations and their habitats. Elephants are placed in Schedule-I of the Wildlife (Protection) Act, 1972 that accords highest possible legal protection to the species (Bist, 2006). Besides this, elephants have cultural and religious significance in India and were declared as the national heritage animal during the year 2010. Therefore, it is apparent that long-term conservation of Asian elephants rests on how pragmatically India manages the remnant elephant populations and habitats (Rangarajan et al., 2010).

India has four major regional elephant populations occurring in the North-west, North-east, East-central and in the South. The North-west population occurs in the Himalayan foothills encompassing the Shivalik hills in the Terai Arc Landscape, primarily in the state of Uttarakhand comprising of around 2000 elephants (Project Elephant Division, 2020; Natarajan et al., 2021). The North-east population occurs in the northeastern states of Assam, Arunachal Pradesh, Meghalaya, Manipur, Nagaland, Mizoram, Tripura and north West Bengal with an estimated population of about 6000 elephants (Project Elephant Division, 2020). The South Indian elephant population is the largest in the world with over 15,000 elephants occurring primarily in the three southern states of Tamil Nadu, Karnataka and Kerala spread out in the Western Ghats and Eastern Ghats mountain ranges (Rangarajan et al., 2010). The East-central elephant population of about 3000 elephants occurs in the states of Odisha, Jharkhand, Chhattisgarh, South West Bengal, and lately, in Madhya Pradesh. The combined distributional range of elephants in India is about 1,60,000 km^2, which is about just 4% of India's land mass.

Elephants are habitat generalists and their distributional range in India encompasses a variety of habitats ranging from semi-arid scrub to dense tropical evergreen forests (Natarajan et al., 2016; Sukumar, 2003). Elephant home ranges recorded in Asia varies from 50 to 3000 km^2 (Desai, 1991; Desai and Baskaran, 1996; Fernando et al., 2008; Joshua and Johnsingh, 1993; Sukumar, 2003, 1985; Tiwari, 2002; Williams et al., 2008). Within set elephant home ranges, there could be profound seasonal variations in the intensity of habitat use (Natarajan et al., 2016; Sukumar, 2003, 1989). The Protected Areas set aside for wildlife in India, including those for the elephants were often demarcated not based on distribution of wildlife, but based on lesser possibility of using those areas for other land-use forms. Therefore, elephant occurrence in India is not restricted to Protected Areas, but also includes multiple-use forest areas outside of the protected area network. Less than

25% of the distributional range of elephants in India falls within the Protected Area network. There are well-connected, large tracts of forests constituting elephant habitats outside of Protected Area network. Thus, the elephant habitats outside of Protected Area network should not be wrongly interpreted as elephants occurring in non-forests. The combination of Protected Areas and other forests including the semi-natural habitats (eg. Forest plantations) forms the 'elephant habitat', which constitutes more than 80 to 85% of elephants' distributional range in India (Project Elephant, 2017). Elephants also occur in 'human–dominated areas' characterized by high interspersion of forests and agriculture, with the fraction of latter being predominant (Kumar and Raghunathan, 2014). The human–elephant conflict occurs both in the interface areas of elephant habitats (usually along the perimeter), and in the human–dominated areas (Balasubramaniam et al., 1995; Desai and Riddle, 2015; Gubbi, 2012; Sukumar, 2003).

Human–elephant conflict is one of the most intensively researched topics in applied conservation. Yet, there remain many gaps in our understanding, which precludes developing appropriate conflict mitigation approaches that are required to identify site-specific strategies. While there could be myriad drivers rooted in elephant ecology; human demography, resource-dependence and livelihoods, cultural belief systems, and landscape characteristics that explain human–elephant conflict, threats to elephant habitat is commonly identified as one of the first main triggers for conflicts (Balasubramaniam et al., 1995; Goswami et al., 2015; Sukumar, 2003). In India, all the four regional populations face varied levels of human–elephant conflict. More than 5,00,000 marginal families in India reportedly suffer due to human–elephant conflict (Rangarajan et al., 2010). Further to this, over 500 human lives are lost annually in addition to leaving a huge number of unreported human injuries.

From the perspective of elephant conservation, more than 200 elephants are lost directly due to human–elephant conflict with long-term demographic and behavioural ramifications (Rangarajan et al., 2010).

Efforts to address human–elephant conflict can broadly be classified into short- and long-term. The former is aimed at addressing the proximate causes (or the symptoms) of conflict; the latter is aimed at addressing ultimate causes (Sukumar, 2003). One of the ultimate causes of HEC is recognized as threats to elephant habitat owing to direct competition between humans and elephants over shared space. Elephant conservation primarily entails protection and judicious management of the habitat (80% of the distributional range) along with proactive conflict management and compatible land-use policies in the human–dominated areas (20% of the distributional range). Unlike many south Asian countries where forest loss occurs at alarming rates, gross loss of forest cover in India is comparatively less. However, the forest loss in India has been more insidious, resulting from fragmentation, perforation, and degradation (Puyravaud et al., 2019). In the recent years, infrastructure development in the form of major roads, railway, power transmission lines, irrigation canals and mineral mines, and associated development had emerged as one of the major forms of habitat loss for elephant habitats in India (Nayak et al., 2020; WII, 2016). Some of the sustained pressures on elephant habitats result in serious degradation reducing their inherent capacity to support elephant populations (Datye and Bhgawat, 1995; Singh and Chowdhury, 1999). When habitat conditions saturate, elephants may start expanding their home ranges or altogether shift them, resulting in environmental dispersals. In either case, such shifts in home ranges could result in major human–elephant conflicts as the 'fundamental niche' available for elephant colonization in India is limited in all the four elephant bearing regions.

Among the four regional elephant populations, the per-capita human–elephant conflict proportional to its elephant population is highest in the East-central region (Bist, 2006; Rangarajan et al., 2010). The East-central region harbors less than one-tenth of the elephant population in the country, but loses over 200 human lives, accounting for more than 40% of all elephant-related human fatalities reported in India. The main challenge facing elephant conflict management in the East-central region originates from large-scale immigration of elephants into areas that did not have elephants for many decades (Singh et al., 2002). There could be multiple underlying reasons for such large-scale elephant immigrations caused by dispersals from original home ranges. However, available evidences indicate that chronic threats to former in-tact habitats like that of Singhbhum in Jharkhand and many others in Odisha from mineral mining could be one the many major reasons that triggered environmental dispersal of elephants in the East-central region (Singh et al., 2002; Singh and Chowdhury, 1999; Sukumar et al., 2018). As a consequence of these dispersals, human–elephant conflict has surfaced newly in numerous areas throughout East-central region.

The state of Chhattisgarh, which was carved out from Madhya Pradesh during the year 2000 has been witnessing increasing levels of human–elephant conflict since the year 2000 when elephants from neighbouring states of Odisha and Jharkhand started re-colonizing historic ranges from where they retreated at the dawn of the 19th century. During the last two decades (2000 – 2020) the distributional range of elephants as well as the population size increased with further immigration of elephants from Jharkhand and Odisha, which have direct forest connectivity with Chhattisgarh. The range expansion in Chhattisgarh had resulted in spread of human–elephant conflict, which had emerged as a major social, economic and political challenge in the adivasi-dominated State. Due to absence of elephants for many decades, the Chhattisgarh Forest Department is neither equipped nor adequately trained to address human–elephant conflict. Further to this, the baseline scientific information required to reliably assess the situation and plan for appropriate conflict mitigation approaches was also not available. The scantily available information was sketchy and fragmented as most of them were collected during rapid surveys (Singh, 2002) and remote-sensing based assessments (Areendran et al., 2011) that do not adequately capture the finer field details indispensible for management. This was the background in which Chhattisgarh Forest Department invited Wildlife Institute of India to initiate a long-term ecological study during the year 2017 (2017–2021). My thesis was carried out as part of this study.

This thesis examines elephant ecology using tenets of wildlife sciences besides focusing on human dimensions of human–elephant interactions in the mosaic landscape of northern Chhattisgarh. The Wildlife Institute of India's project and constituent thesis that I present are first of the intensive field assessment of human–elephant interactions in northern Chhattisgarh after elephants expanded their range in the state during the year 2000. The study broadly falls in the sphere of applied ecology relevant to conservation biology and wildlife management. Owing to paucity of even basic information required for management of elephants in Chhattisgarh, the thesis focused on generating information on elephant ecology and aspects of human–elephant conflict immediately relevant for management instead of examining human–elephant conflict from theoretical underpinnings.

The main objectives of the thesis and the organization of the technical chapters are described below:

1. Historic overview of elephants in Chhattisgarh

2. An overview of distribution and basic elephant demography
3. Home range, movement and dispersal patterns of elephants
4. Patch use and habitat selection by elephants
5. Patterns and determinants of cropland–elephant conflict in Chhattisgarh
6. Spatial occurrence and patterns of human fatalities due to elephants
7. Household perceptions of risk towards elephants and attitude towards conservation of local communities in Surguja

1.1 Organization of the thesis

The overall organization of the thesis is as follows:

Chapter-1 introduces the general ecology, behaviour, and habitat requirements of elephants. Besides this, the chapter elucidates historic and contemporary elephant distribution in Asia and India with reference to country's regional populations. The chapter also provides details on aspects of human–elephant conflict and its broad drivers. The chapter sets the context and background for initiating the long-term study on elephant ecology in Chhattisgarh.

Chapter-2 introduces the study area covering aspects of biogeography, biophysical attributes including the hydrology, soil characteristics, vegetation types and demographic aspects of major local communities that live in the landscape.

Chapter-3 provides a historic overview of elephant occurrence in Chhattisgarh through the ages as condensed together from fragments of available information. The chapter describes historic distribution of elephants in Central Indian landscape and putative reasons for their retreat. Further, the influence of various government policies that inflenced elephant occurrence and retreat was discussed as well.

Chapter-4 provides an overview of elephant demography in northern Chhattisgarh. In this chapter, the concurrent elephant distribution in Chhattisgarh along with population size, and other population parameters estimated from both primary data and secondary information (forest department sources) was presented.

Chapter-5 provides insights on elephant home ranges and how they compare with other regions. The home ranges estimated from six GPS satellite collared elephants were presented. Additionally, patterns of habitat-use by elephants estimated using high-resolution land-use and land-cover information have been provided as well. Attempts were also made to describe fine-scale movement and consequences of such movements for management. In addition to collared elephants, home ranges were also estimated for some of the individually recognized elephants that were closely monitored in Surguja. Additionally, events of elephant dispersal recorded during the study were elaborated.

Chapter-6 provides details on habitat selection by elephants across different seasons. In this chapter, the third order habitat selection elucidated by Johnson (1980) involving assessment of within home range habitat-use was carried out using telemetry data obtained from satellite collared elephants. Further to this, sesonal habitat selection across different habitats was evaluated.

Chapter-7 provides details on patterns of crop losses by elephants in Chhattisgarh at two different spatial scales. At the landscape scale, the variations in the intensity of crop losses across most of the elephants' distributional range in northern Chhattisgarh were assessed. At finer spatial scales, crop losses by elephants were quantified and the influence of covariates on spatial patterns of crop losses by elephants were evaluated.

Chapter-8 provides details on the complex conservation issue of elephant-caused human fatalities in Chhattisgarh. It attempted to identify associations between spatial distribution of such fatalities and potential environmental covariates. Further, the circumstances surrounding human fatality incidences were described.

Chapter-9 describes the local communities' farm and off-farm practices that potentially increase the likelihood of encounters with elephants. The chapter also quantified the local villagers' attitudes towards elephant conservation and factors influencing such attitudes.

Chapter-10 In this chapter, general inferences based on the results of the study emanating from various chapters have been condensed and appropriate management recommendations to possibly manage human–elephant conflict in Chhattisgarh were discussed.

All the technical chapters mentioned above contain separate introductory sections, relevant methodology followed by results and discussions, as appropriate. As most of the chapters were individually prepared as separate manuscripts, the writing style of the chapters may follow different journal formats and therefore, the language and overall formatting could vary between chapters. I followed the citation style of the journal "Biological Conservation" throughout the manuscript.

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CHAPTER-2

STUDY AREA

2.1 Location

The study was conducted in the north and north-central Chhattisgarh covering the districts of Raigarh, Korba, Jashpur, Balrampur, Koriya, Surajpur and Surguja administered under nine forest divisions in two forest circles of Surguja and Bilaspur (Fig-1.1). The focus of intensive study was Surajpur, Balrampur and Surguja Forest Divisions while the Forest Divisions in Bilaspur forest circle acted as a peripheral study area. Forest cover with seasonal and sporadic elephant occupancy in north and north-central Chhattisgarh was around 17,500 km^2.

Plate-2.1: Panorama of Guru Ghasidas National Park in the Central Highlands

The forest cover is patchy, and interspersed with agricultural and human settlements. The landscape is part of Indian Peninsula comprising of rugged hills, flat hilltops and forested plains collectively known as the "Central Highlands" (Forsyth, 1920; Rodgers and Panwar, 1988). There are many eco-climatic sub-regions within the

Central Highlands in which my study area mostly fell under the Satpura–Maikal–Maikal extension sub-region and southern extension of the Chota-Nagpur plateau. Over 50% of the north and north-central Chhattisgarh is forested. The altitude in the study area ranges from 400 to 1100 m a.s.l. Characteristic of the region is the flat hilltops locally known as "pats" (Mani, 1974).

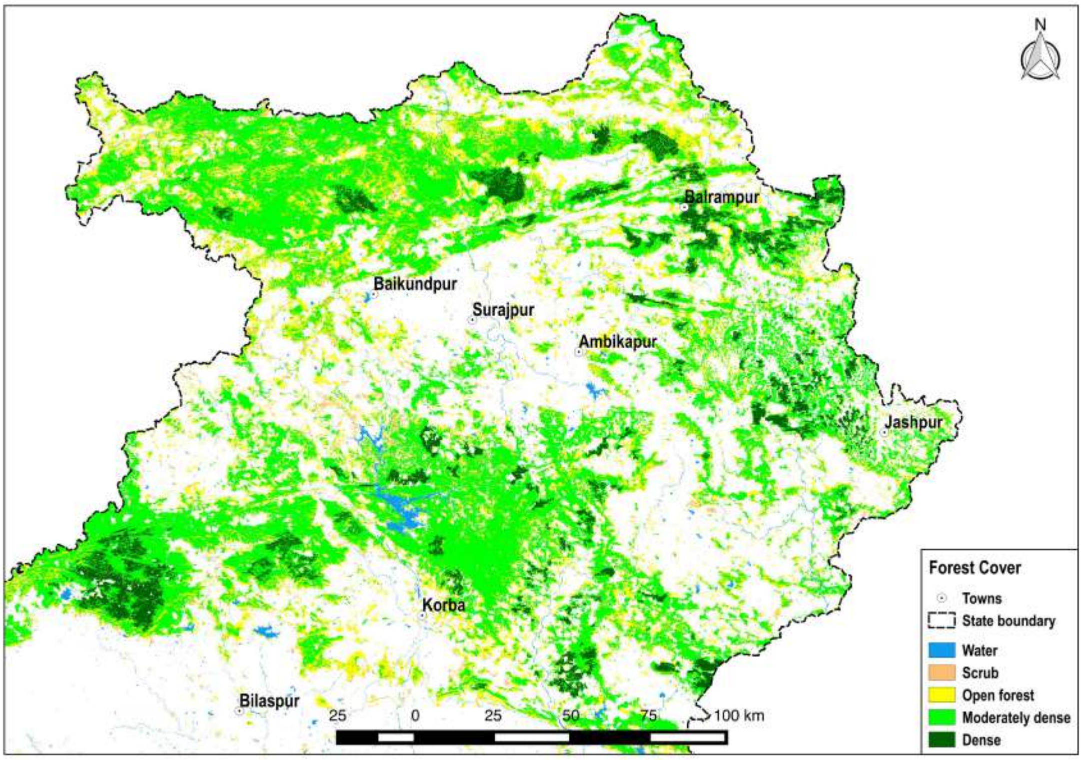

Fig-2.1: Forest cover map of northern Chhattisgarh. Prepared based on Forest Survey of India (FSI), 2019

2.2 Geology and soils

The geology of the northern Chhattisgarh is primarily Archean, and comprises of elements of middle Gondwana (Champion and Seth, 1968; Mani, 1974). The foundational rocks in northern Chhattisgarh is prominently of Gondwana, which Champion & Seth, 1968 defined as freshwater sediments of plant fossils with coal deposits that are over 100 to 200 million years old. In the north-central Chhattisgarh (Bilaspur area), the foundational rocks are even older – that of Pre-Cambrian with ancient crystalline rocks that are over 500 million years old (Champion and Seth, 1968). The dominant soil type is the 'red and yellow' from the main Gondwana rock system, covering over 60 to 65% of northern and central zones of the state. The red soil is typically coarse, relatively poor in organic matter and nutrients, but rich in ferric concentrations. The red soil tends to favors moist and dry deciduous forests dominated by Sal (*Shorea robusta*) (Champion and Seth, 1968). The red-yellow soils, alluvial soils occur along the riverine tracts, and laterite soil exists in the hilltops. Further to this, the red and yellow soil favors paddy cultivation (*Oryza sativa*).

Plate-2.2: A rivulet in the catchment area of River Rihand near Matringa in Surguja

2.3 Climate and rainfall

The climate in northern Chhattisgarh is sub-tropical with three well-defined seasons namely dry (March to June), monsoon (July to September) and winter (October to February). The annual temperatures range from 1º C (minimum) to 45º C (maximum). Southwest monsoon accounts for more than 90% of the region's annual rainfall. The average annual rainfall is around 1200 to 1600 mm, which is usually spread-out for well over 100 days.

2.4 Hydrology

The study area is the watershed for two major river systems namely the Sone (part of Gangetic river system) and the Mahanadi. River Sone originates in the Maikal ranges near Amarkantak at 1000-m altitude overlooking the Chhattisgarh plains (including the Achanakmar Tiger Reserve in Mungeli District) towards the east. The origin of River Sone is less than a kilometer away from the source of another major peninsular Indian River, the Narmada that flows in the westward direction to meet the Arabian Sea. River Sone generally flows in the northward direction emptying into River Ganga near Patna in Bihar. Some of the major tributaries of River Sone that originate from elephant-range areas in Surguja include Mahaan, Rihand, and Kanhar. The second major river catchment in north and north-central India is that of River Mahanadi. Its upper course is in the Damtari district of south Chhattisgarh. However, tributaries originating from elephant range areas of northern Chhattisgarh feed the middle course of the river. The major tributaries include Hasdeo, Maand, and Ib that have their major catchments in both Surguja and Bilaspur circles (Fig-1.2). In addition to these rivers, there are many other relatively smaller rivers – many of them perennial with at least trickle of flow even during peak dry months eventually feeding into Sone, Mahanadi or their major tributaries. Most of the rivers in northern Chhattisgarh are shallow, unbraided and not navigable. In addition to river systems, there are numerous ponds and lakes in the villages, which are extensively used by villagers for irrigation, water-requirements of livestock and other domestic purposes. These ponds are usually created by impounding seasonal streams flowing from forest patches. Due to their multipurpose utility, villagers maintain the village ponds well. Elephants occurring in human-use areas also occasionally use these village ponds.

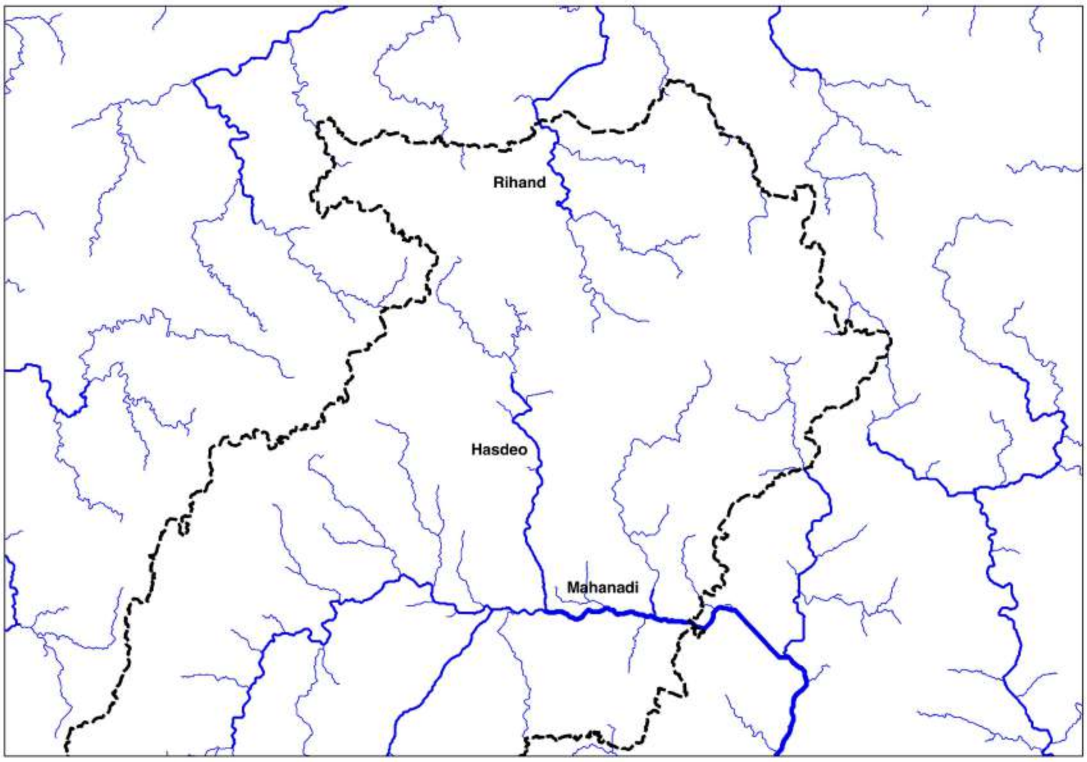

Fig-2.2: Drainage map of northern Chhattisgarh

2.5 Forest types

The forests in Chhattisgarh can be classified in to two broad types namely tropical moist deciduous (in the relatively rainier tracts) and tropical dry deciduous. These have been further divided into 12 Forest types (FSI, 2019). The forest types and corresponding floristics as described by Champion and Seth (1968) is reproduced below[1] (Fig-1.3).

[1] **The floristics is reproduced as such from Champion & Seth (1968). However, I made minor modifications in the list, as appropriate based on my direct field observations.**

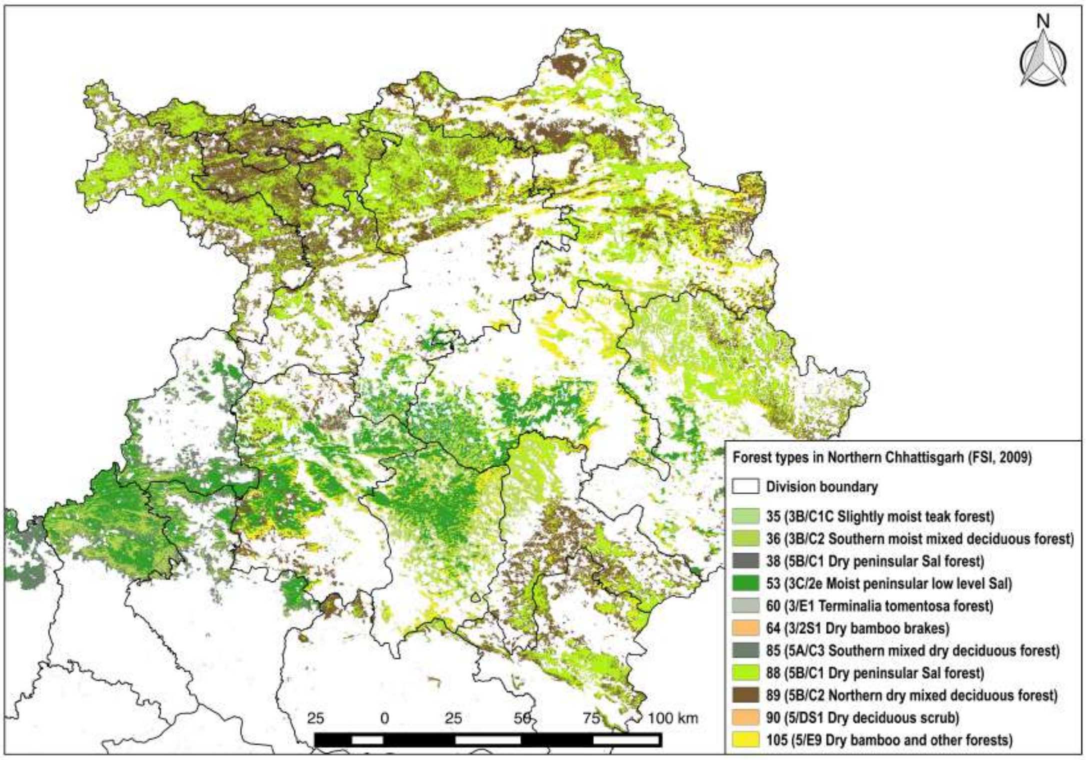

Fig-2.3: Forest types in northern Chhattisgarh. Classified based on Champion and Seth, 1968

2.5.1 Moist Peninsular Low-Level Sal Forest [3C/2E (II)]

I & II: *Shorea robusta, Terminalia tomentosa, Anogeissus latifolia, Syzygium cumini, Bauhinia spp., Pterocarpus marsupium, Madhuca latifolia, Largerstroemia parviflora, Phyllanthus emblica, Bridelia retusa, Terminalia chebula, Diospyros tomentosa, Buchanania lanzan, Casearia graveolens, Wendlandia exserta, Zyzyphus zyloprus, Butea monosperma, Randia spp,* and *Aegle marmelos*. In the IIIrd storey, there is *Phoenix spp*, *Grewia hirsuta, Helicteres isora, Desmodium pulchellum*, and *Woodfordia floribunda*. Grasses have become rare other than in the protected areas. In the protected areas, the grass species include *Themada spp, Imperata cylindrical, and Heteropogon contortus*. The climbers include *Bauhinia vahlii* and *Smilax macrophylla*. Bamboo (*Dendrocalamus strictus)* has become rare outside of protected areas.

2.5.2 Dry Peninsular Sal Forest [5B/C1c]

The floristics include *Shorea robusta, Terminalia tomentosa, Pterocarpus marsupium, Anogeissus latifolia, Boswellia serrata, Buchanania lanzan, Diospyros melanoxylon, Terminalia chebula, Phyllanthus emblica, Bauhinia spp, Cleistanthus collinus,* and *Bridelia retusa* in the first and second storeys. In the third storey, plants include *Woodfordia fruticosa*, *Indogofera spp, Ixora arborea*, and *Pheonix acaulis*. Grasses include *Themeda spp*, and *Cynadon dactylon*[2]. Climbers of Bauhinia vahlii and Smilax spp are fairly common in areas with minimal human disturbance.

2.5.3 Northern Dry Mixed Deciduous Forests [5B/C2]

Floristics includes *Terminalia tomentosa, Anogeissus latifolia, Diospyros melanoxylon, Buchanania lanzan, Terminalia chebula, Cleistanthus collinus, Madhuca latifolia, Boswellia serrata,* and *Largerstroemia parviflora* in the top storey. The II and IIIrd storey includes *Phyllanthus emblica, Zizyphus xylopyrus, Phoenix acaulis* and *Woodfordia fruticosa*.

2.5.4 Sal-coppice dominated forests

In addition to aforementioned natural forests, there are numerous forest patches that have been extensively modified by people through biomass extraction, livestock grazing and recurrent forest fires. These forest patches were dominated by dense strands of young Sal (*Shorea robusta*) coppices.

[2] **Grass cover has become sparse in northern Chhattisgarh other than in Protected Areas**

Plate-2.3: Moist deciduous forest in Semarsot Wildlife Sanctuary, Balrampur District

Plate-2.4: Dry deciduous forest (during peak dry season) in Tamor Pingla Wildlife Sanctuary, Surajpur District

Plate-2.5: River Piyari (tributary of Rihand) in Guru Ghasidas National Park, Koriya District

Plate-2.6: Densely forested Mainpat slopes in Surguja district. Chain of hills in Surguja reach upto 1000m. The hilltops are usually flat and known as "pats" locally.

2.6 Mammalian fauna

North and north-central Chhattisgarh harbours most of the peninsular Indian mammals, albeit in very low densities. In addition to elephants, the large mammals that occur in the study area include the leopard (*Panthera pardus*), Indian wolf (*Canis lupus*), golden jackal (*Canis aureus*), wild dog (*Cuon alpinus*), sloth bear (*Melursus ursinus*), striped hyena (*Hyaena hyaena*), gaur (*Bos gaurus*), sambar (*Rusa unicolor*), chital (*Axis axis*), barking deer (*Muntiacus muntjac*), four-horned antelope (*Tetracerus quadricornis*) and wild pig (*Sus scrofa*). During the course of fieldwork, I have seen all these animals except that of wild dogs. Tigers (*Panthera tigris*) sporadically occur in the two protected areas of Guru Ghasidas National Park and Tamor Pingla Wildlife Sanctuary and rarely from other areas as well. In addition to large mammals, many species of lesser mammals like small Indian civet (*Viverricula indica*), Asian palm civet (*Paradoxurus hermaphrodites*), jungle cat (*Felis chaus*), rusty spotted cat (*Prionailurus rubiginosus*), oriental honey badger (*Mellivora capensis*), smooth-coated otter (*Lutrogale perspicillata*), black-naped hare (*Lepus nigricollis*), Indian crested porcupine (*Hystrix indica*) and giant squirrel (*Ratufa indica*) occur in northern Chhattisgarh. Although occurrence of Chinkara or the Indian gazelle (*Gazella bennettii*) and leopard cat (*Prionailurus bengalensis*) was reported in Surguja, I did not come across any evidence during the period of my study. The list of mammals also includes many species of the orders Rodentia and Chirpotera that I did not list down.

2.7 Local communities

In Surguja and Surajpur districts, the population density is 150 persons per km^2 with a sex ratio of 978 females per 1000 males (https://censusindia.gov.in/2011census/dchb/2202_PART_B_DCHB_SURGUJA.pdf. The scheduled tribes constitute 55% of the total population (https://censusindia.gov.in/2011census/dchb/2202_PART_B_DCHB_SURGUJA.pdf. The main tribes include Kunwar, Baiga, Gond, Agaria, Binjwar, Manjwar, Rajwar, Teli, Nai, Panika, Dand-Korwa, Pando, Kudako, Pahari Korwa, Oraon, and others (Areendran et al, 2011 & Present Study). Literacy rates in the district are around 60% (Directorate of Census Operations, 2011). Tribal and forest dependent communities in northern Chhattisgarh collect a variety of non-timber forest products including timber, food plants, fodder, medicinal plants, honey, and others. The human population density on an average is 150 persons per km^2. Paddy (*Oryza sativa*) is widely cultivated (<70% of all the cereals cultivated in northern Chhattisgarh) during monsoon while sugarcane (*Saccharum officinarum*) is cultivated in the relatively well-irrigated tracts. There are many local varieties of paddy that are relished for their aroma including the famous varieties of *Jeera phool* and *Vishnubhog*. In addition to paddy, wheat (*Triticum aestivum*) and local varieties of maize, millets, pulses, and vegetables are widely cultivated.

Plate-2.7: A village near Bagicha in Jashpur district during monsoon with paddy in vegetative stage. The forests and human-use areas are interspersed in Chhattisgarh

Plate-2.8: Villagers in northern Chhattisgarh are predominantly forest dependent tribal communities

2.8 Forest Administration

The districts with elephant occupancy in northern Chhattisgarh are managed under two forest circles namely Surguja and Bilaspur. Although elephants do occur outside of these two circles too, our study was carried out only in the two aforementioned forest circles. Divisions with frequent elephant occurrence in Surguja forest circle included Surguja, Surajpur, Balrampur, Jashpur and occasionally Koriya. In Bilaspur forest circle the divisions with regular elephant occupancy included Raigarh, Dharamjaigarh, Korba and Katghora. The legal classification of forests in Chhattisgarh include (i) Reserved Forests (RF), (ii) Protected Forests (PF) and (iii) Orange areas (OA) besides protected areas (PA). There are four PAs within elephants' range in northern Chhattisgarh that include Guru Ghasidas NP in Koriya district, Tamor Pingla Wildlife Sanctuary in Surajpur distict, Semarsot Wildlife Sanctuary in Balrampur district and Badalkhol Wildlife Sanctuary in the Jashpur

Forest Division. There is one notified elephant reserve namely the Tamor Pingla – Badhalkhol Elephant Reserve in Surguja and another, Lemru Elephant Reserve is in the process of getting notified in the Korba district of Chhattisgarh.

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CHAPTER-3

HISTORIC OVERVIEW OF ELEPHANTS DISTRIBUTION

3.1 Introduction

Understanding the past and present distribution of endangered species can provide insights on the vulnerability of the species to contemporary threats that cause extinctions (Karanth et al., 2010). Although there could be myriad drivers of species extinctions, the process involves decline in both abundance and distributional range (Pillay et al., 2011). Two complementary paradigms namely "small population paradigm" and "declining population paradigm" explain species extinctions (Channell and Lomolino, 2000). Small population paradigm describes vulnerability of small populations to Allee effects[3]; demographic and environmental stochasticities, and inbreeding depression (Fryxell et al., 2014; Lande, 1993; Lande Russell, 1988; Sutherland, 1998). The declining population paradigm describes threats like harvest (or removal) and habitat loss that further increase the vulnerability of small populations to extinction (Channell and Lomolino, 2000). The effects of small populations are particularly acute for large vertebrates.

Among the large vertebrate, elephants (*Elephas maximus*) have relatively slow life history traits like late sexual maturation, single offspring in the litter, longer inter-calf interval, and high natal mortality that render them particularly vulnerable to demographic stochasticities, whereby the persistence of populations would be determined by chance rather than being deterministic (Leimgruber et al., 2008; Sukumar, 2003). Since the effect of demographic stochasticities are pronounced in small populations, monitoring small and insular elephant populations would be crucial

[3] **Per-captia reduction in reproductive fitness with decrease number of individuals in the population**

for devising long-term conservation plans, especially in the fragmented landscapes. In fragmented landscapes, elephant distribution and population dynamics generally follow the theory of meta-population, which comprises of spatially separated populations with interactions mediated by dispersals (Nordén et al., 2020). While meta-population theory can provide contemporary insights on how elephants fare in the landscape, gleaning historic information on elephant occurrence can be helpful in generating long-term perspectives on elephant conservation.

Across Asia, elephant ranges have shrunk with corresponding decline in populations (Leimgruber et al., 2003; Sukumar, 2003). Such declines were drastic in countries like China, where retreat of elephants was attributed to expansion and intensification of Chinese settlements to a large extent (Elvin, 2008). Overall, the retreat of elephants in Asia lends support to biological theory of competitive exclusion (Hardin, 1960), which suggests that organisms with overlapping niches cannot coexist resulting in one species supplanting the competing species from the ecosystem. In India, which holds the largest Asian elephant population in the world, elephants' distributional range constitutes less than 4% of the country's land area indicating competitive exclusion from most of the country (Rangarajan et al., 2010). According to Trautmann (2015), the range contraction of elephants in India was comparatively gradual, but accelerated after 1800s.

There are four major extant elephant populations in India and all of them occur as meta-populations (Rangarajan et al., 2010). Among these, the East-central regional population occurring in the states of Odisha, Chhattisgarh, Jharkhand, and South West Bengal had been witnessing major redistribution of elephants characterized by local extinctions and dispersals resulting in range expansions.

Among the elephant range states in the East-central region, range expansion of elephants into Chhattisgarh was fairly recent (< 30 years). After elephants expanded their range in Chhattisgarh; the State has emerged as one of the conflict hotspots in the country with disproportionately high number of elephant-related human fatalities. To provide long-term perspectives of elephant conservation in Chhattisgarh, it would be relevant to understand historic distribution of elephants. Nonetheless, collating reliable information to interlace a plausible account of pulses in historic elephant distribution, along with the putative factors that led to their disappearance during the 20th century and the concurrent range expansion presents a challenge owing to paucity of information.

Here I collate pieces of information available as fragments to draw a perspective on elephant distribution in Chhattisgarh in particular and the East-central region in general.

3.2 Methods

I relied on published information accessed through Internet search engines using relevant key words. Further, using ad libitum observations, informal interviews and discussions with local Forest Department staff (both serving and retired personnel) as well as local naturalists, I collated information on elephant occurrence in northern Chhattisgarh.

3.3 Observations and discussion

3.3.1 Retreat and redistribution of elephants in East-central region

During the last 70 – 80 years, the distributional range of elephants in the East-central region had changed considerably, as could be inferred from the existing literature.

Shahi, (1977) mentioned about elephant herds suddenly appearing in the Palamau (presently Palamau tiger reserve of Jharkhand) of the then unified Bihar. (Sankhala, 1977) speculated that elephants of Palamau were from captive stock left maintained by Maharaja of Surguja (the princely state of Surguja district borders Palamau), which became feral and later naturalized. This theory of Palamau elephants being released by Surguja king was mostly unlikely as mounting evidence shows that Central Highlands remained a stronghold for wild elephants till early 1800s. For example, Mughul emperor Akbar hunted wild elephants during 1564, which involved capture of a large herd of elephants in the present-day Narwar district of Madhya Pradesh, which is closer to Gwalior district ("The Imperial Gazetteer of India," 1908). This example indicates the plausible two-fold pressure on elephant populations stemming from captures and climate change as the habitat then would have been different from that of contemporaneous semi-arid conditions in Narwar and Gwalior districts.

Using the atlas of the Mughal empire (drawn by renowned historian Irfan Habib), Trautmann (2015) opines that elephants were widely distributed throughout Central India during the period 1600–1700 when the forests were contiguous. (Trautmann, 2015) further mentioned of numerous locations in Central India with reports of wild elephants during the Mughal era. It is noteworthy that the Mughal army had over 2000 captive elephants during the year 1739 (Nossov and Nossov, 2012). Incidentally, the entire East-central India presently has about 2000 – 3000 wild elephants (Project Elephant, MoEF&CC, 2017). Arthasastra, an ancient Indian text, reportedly mentions that the "best quality" (the quality here refers to war suitability of the elephants) elephants had come from the central and East-central regions of India (Trautmann, 2015). This hints that the elephants in central India were under intensive pressure of capture during the last 500 years.

Presently, although elephants occur only in a small fraction of their historic range; concurrent folklore, mythology and symbolism of ethnic tribal groups is replete with elephant-lore hinting long-term association between elephants and people in the region. In Odisha, a temple pillar at Bhuvaneshwar depicts capturing of wild elephants in central Indian forests (Van der Geer, 2008). The forests around Bhuvaneshwar still harbor wild elephants.

Although historic wild elephant occurrence in Central India is well documented, the process of the decline and total disappearance of elephants from many areas remain vague. The major retreat of elephants in Central India had probably occurred during the last two hundred years (after 1800s) (Trautmann, 2015). This period was witnessed overwhelming expansion cum growth of human populations and associated development that resulted in loss and isolation of forests. The Imperial Gazetter of 1908 suggested that the Sighbhum forests (present day Jharkhand) were rapidly felled causing elephants scatter and become exceedingly rare. The "Forest Resources of Raigarh District (in the present day Chhattisgarh)" published by the Forest Survey of India mentions that elephants were common in Raipur and Jashpur districts of Chhattisgarh till 1900s (FSI, 1989) and subsequently started disappearing with rise in human populations.

The extent of changes in elephant distribution in the East-central region is unparalleled in comparison to other regional elephant populations. During the last 50 years in particular, the elephant population in East-central India had experienced considerable redistribution in range areas. British naturalist and forest service officer from Orissa, (Mooney, 1928) mentioned that elephants in Orissa were confined to north of River Mahanadi during 1930s and that they seldom occurred in districts south of the river. However, in the present, elephants occur in many districts of Odisha located in the southern bank of River Mahanadi and even extended their range into northern Andhra Pradesh in the districts of Srikakulam and Vizianagaram having recently moved in from Rayagada Forest Division in south Odisha (Sukumar et al., 2018).

Similar to Odisha, elephants reportedly occurred only in the two districts of South Bihar (presently Jharkhand) namely Singhbhum, Palamau and Dalbhum till 1980s (Shahi, 1977). However, in the present, elephants occur in 29 out of 34 forest divisions in Jharkhand (Project Elephant Division, 2020). In Jharkhand, the Singhbhum region remained an elephant stronghold till 1980s (Shahi, 1977). Here large-scale felling of natural forests by Forest Corporation of India with an aim to expand teak forests and expansion of large-scale mineral mines along with tribal agitation saw major disturbance to forests in Singhbhum during 1980s (Datye and Bhgawat, 1995; Singh and Chowdhury, 1999). During the same period, major movement of elephants into Keonjar district (in Odisha) and districts in south West Bengal was recorded (Datye and Bhgawat, 1995). Incidentally, while natural forests were felled in Jharkhand during 1980s, southern West Bengal created forest plantations of Sal (*Shorea robusta*) through afforestation programs under the Joint Forest Management (JFM). This probably had resulted in attracting elephant herds into West Bengal from the neighboring Jharkhand.

3.3.2 Contemporary elephant immigration in Chhattisgarh

Wild elephants occurred in the northern and north-central districts of the present day Chhattisgarh (Bilaspur, Surguja, Surajpur, Koriya, Korba, Raigarh, Balrampur and Surajpur) until 1920s (Burton, 1951; Dunbar Brander, 1982; Forsyth, 1920; Sagreiya, 1969; "The Imperial Gazetteer of India," 1908). During the period between 1930 and

1988, there were no authentic records of elephant occurrence in eastern MP/Chhattisgarh suggesting local extinction of elephants during this period. There could have been sporadic incidences of elephant dispersals that probably went unnoticed. The Government of Madhya Pradesh had also kept a policy of keeping elephants off the state (Dr. R.K. Singh, retired Principal Chief Conservator of Forests, Govt. of Chhattisgarh, personal communication). As per official records, elephants started extending their range from Jharkhand (then south Bihar) and Odisha during late 1980s. During 1988, a group of 18 elephants immigrated into Surguja, northern Chhattisgarh resulting in acute human–elephant conflict prompting the then Madhya Pradesh government initiate elephant captures. With technical assistance from Karnataka Forest Department involving deputation of trained veterinary unit, *kumki* elephants, skilled mahouts and trackers, the elephants were captured and held in captivity.

After a brief hiatus, elephant immigration into Surguja commenced again from the year 2000 onwards. The elephants entered Surguja from both Odisha and Jharkhand during the year 2000 (during the months of September and October). During 2000, the tribal dominated states of eastern Madhya Pradesh were consolidated and notified as a new state of Chhattisgarh on 1st November 2000. Unlike Madhya Pradesh, Chhattisgarh followed a policy of accommodating elephants migrating into the state. During 2001, 24 elephants were reported from Surguja. Elephant numbers and concomitant distributional area gradually increased during the next two decades.

The cause of elephant exodus from Chhattisgarh is difficult to conjecture. Possibly, habitat degradation, conflict with local people, and poor demographic viability as characterized in small populations caused local extinction of elephants during 1900s. It is also plausible that intermittent elephant captures added to the existing threats in driving the small population of elephants to extinction. The concurrent immigration of elephants in Chhattisgarh and lately into eastern Madhya Pradesh could have been triggered by both push and pull factors. The push factors identified by previous studies in the East-central region include habitat degradation due to mining and associated development particularly in the Singhbhum region (Datye and Bhgawat, 1995; Singh et al., 2002; Singh and Chowdhury, 1999). Elephant habitats in Odisha too suffered from mining and associated threats.

3.4 Summary

Distributional ranges of large vertebrates like elephants that evolved high mobility are seldom static as they respond to periodic changes in resource availability and threats to survival. For elephants, from conservation and conflict mitigation standpoints, monitoring fluctuations in elephant distribution is critical. More than any other regional population, the East-central regional elephant population has been witnessing both local extinctions and range expansions. Thus, landscape-level processes that influence elephant demography and corresponding changes in distribution are critically important to monitor in the East-central region. Simple population metrics like occupancy at the beat-level would be essential to assess periodically. This exercise needs be done throughout East-central region synchronously using simple interview surveys with forest department staff so that presence-absence of elephants at the beat-level can be reliably estimated. Change in occupancy would be a more sensitive metric in the East-central region than aspiring for estimating elephant abundances. Change in occupancy can be correlated with variables like habitat loss, and human disturbance etc.

Furthermore, the elephant ranges in Chhattisgarh are just a part of the larger elephant range in the east-central region. Thus, in light of recent range expansion of elephants in Chhattisgarh and other parts of the East-central region, multi-pronged landscape-level assessment of habitat threats and elephant demography can provide insights on causes of changes in elephant occupancy.

In addition to environmental variables, elephant distribution in a landscape can be profoundly influenced by the political economy and concurrent policy decisions by different stakeholders as elucidated in the review. For example, the forestry policy of South Bihar (currently Jharkhand) aimed at replacing teak (*Tectona grandis*) at the expense of natural forests of Singhbhum, and opening up of mineral mines caused habitat degradation and resultant elephant displacement (Singh and Chowdhury, 1999). On the other hand, the forestry policy of West Bengal aimed at increasing agro-forests of Sal (*Shorea robusta*) in the relatively open landscapes of Southern West Bengal resulted in creating "pseudo-habitats" for elephants. I refer to such habitats as pseudo-habitats as they are small and isolated, but provide cover without fodder for elephants. These patches can act as daytime refuge habitats for elephants and perpetuate human–elephant conflict in the surrounding human use areas that will be extremely difficult to manage. Furthermore, political decisions can have profound on elephant occurrence in the landscape. While Madhya Pradesh government maintained a status quo of having no elephants, upon inception, the new state of Chhattisgarh allowed elephant colonization, thereby becoming a full-fledged elephant ranging state.

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CHAPTER-4

AN OVERVIEW OF DISTRIBUTION AND ELEPHANT DEMOGRAPHY

4.1 Introduction

Elephants being k-selected species are long-lived, with life-history traits such as late sexual and delayed social maturation, and slow rate of reproduction (Arivazhagan, 2005; Moss, 2012). Therefore, assessing their demographic parameters reliably would require longitudinal studies spanning many years and involve following cohorts of individually recognized elephants (Moss, 2012; De Silva et al., 2013; Wittemyer et al., 2013). In addition to individual-based monitoring, in Africa, baseline estimates of demographic variables were estimated from samples of elephants culled for management (Laws et al., 1975). Vital demographic variables needed to gauge elephant populations are sex ratio, age structure, birth and death rates. Although number in the population (or size) is an important metric that determines viability of animal populations (Williams et al., 2002), knowledge about population vital rates like fecundity, mortality, and dispersal would be crucial to forecast the future trajectories of elephant populations (Leimgruber et al., 2008).

From conservation standpoint, for relatively small elephant populations, assessing demographic parameters is often a precursor for evaluating viability, in light of population ecology theory that suggests higher probability of local extinction for populations that are small and insolated (Hanski, 2013). Further, from the perspective of managing human–elephant conflict, knowing the trajectory of the population would be central to devising long-term conflict resolution strategies.

Chhattisgarh is one of the five states in the East Central India region, which has elephants. The district gazetteers make it evident that wild elephants occurred in present-day districts of Surguja (Verma, 1989), Raigarh (Guru, 1976), and Bilaspur (Nelson 1910) till early nineteen hundred. The district gazetteer of Surguja mentioned that during 1909, elephants in the district were becoming scarce possibly owing to *Khedda* (=organized capture operation involving driving of elephant herds into stockades) operations (Verma, 1989). Subsequently, elephants became locally extinct in Surguja and other northeastern districts of the then undivided Madhya Pradesh. Contemporary elephant re-colonization in Chhattisgarh has been a relatively recent phenomenon, resulting from range expansion of elephants from the neighboring states of Odisha and Jharkhand during the last two decades. Sustained stress on intact elephant habitats and elephants in both Jharkhand and Odisha owing to mineral mining and associated developments is often said as the major reason for large-scale elephant immigration into areas adjacent to Jharkhand and Odisha (Singh et al., 2002). The elephant distribution as well as ranging continues to be dynamic in Chhattisgarh with profound implications for managing human–elephant conflict in the state (Pandav et al., 2019). While assessing elephant demography is a challenge in itself, doing so in areas where elephants have relatively large and fluid home ranges is even more challenging. Yet, considering the importance of understanding elephant demography, we attempt to provide baseline data on population trends and demographic vital rates using both secondary data obtained from Chhattisgarh forest department and field observations predominantly from Surguja forest circle. In addition to demographic parameters, elephant body condition scores, which can be indicative of nutritional status, have been estimated for animals observed during the study (Pokharel et al., 2021). As demographic parameters estimated were from population sampled opportunistically, computationally intensive population modelling approaches for making predictions on population vital rates with statistical credence were not used. Rather, this study attempts to provide baseline estimates of basic population parameters for future comparisons given that our study is the first systematic assessment of elephant ecology and human–elephant conflict in the state.

4.2 Materials and methods

4.2.1 Study area

Our study was carried out in northern Chhattisgarh covering the districts of Raigarh, Korba, Jashpur, Balrampur, Koriya, Surajpur and Surguja administered under ten forest divisions namely Surguja, Surajpur, Balrampur, Jashpur, Manendragarh, Koriya, Katghora, Korba, Raigarh and Dharamjaigarh in two forest circles of Surguja and Bilaspur. Within this landscape, there are four protected areas namely Guru Ghasidas National Park (1411 km^2), Tamor Pingla (543 km^2), Semarsot (430 km^2) and Badhalkol wildlife sanctuaries (104 km^2). More than 50% of the landscape in northern Chhattisgarh is forested (FSI, 2019). The landscape in northern Chhattisgarh is part of the Central Highlands in the Indian Peninsula comprising of rugged hills, flat hilltops and forested plains (Rodgers and Panwar, 1988) with altitude ranging from 400–1200 mm and annual rainfall ranging from 800 – 1600 mm received during the July to September. The forests are predominantly of Sal (*Shorea robusta*) - dominated moist and dry deciduous formations (Champion and Seth 1968). The landscape is predominantly rural with a population density of 150 persons per km^2 (Directorate of Census Operations, 2011). Over 55% of the local populace is forest-dependent tribal communities, comprising of Kunwar, Baiga, Gond, Pando, Kudako, Pahari Korwa, Oraon, and others (Areendran et al., 2011).

4.2.2 Secondary data

The Chhattisgarh Forest Department estimated elephant population during the year 2017 following a block-count method prescribed by the Project Elephant, MoEF&CC, Government of India. Block-count method is a total count approach prone to statistical problems of imperfect detection and spatial sampling. Therefore, the population trends presented are indicative especially in light of the fact that there is significant immigration and emigration of elephants from the neighboring states. Nevertheless, wide discrepancies may not exist as Chhattisgarh Forest Department has a statewide daily monitoring system, wherein range-level elephant distribution along with rough estimates of elephant numbers were collated and centrally pooled by the office of Director, Elephant Reserve, Surguja and transmitted to divisional forest department heads electronically. In any case, because elephants occur in clusters and range over a large area in Chhattisgarh covering many forest divisions conventional population estimation approaches like distance-sampling, which is based on robust sampling theory (Jathanna et al., 2015) may not be appropriate in the state.

4.2.3 Field surveys

Field surveys to assess elephant demographic parameters were carried out during the period July 2017 to January 2020. The surveys involved opportunistically following and registering elephants with photos and videos recorded in the field. Systematic sampling approach was not followed to register elephants for demographic classification and rather, that objective was to provide crude estimates that can be useful for making future comparisons. Although direct elephant sightings were numerous, only on 158 occasions we could reliably record, photograph and video-record elephants during day-light conditions, which were eventually used for estimating demographic parameters.

4.2.4 Age classification

The elephants were classified into five age categories that included calf (< 2 years), juveniles (2 – 5 years), sub-adult-1 (5 – 10 years), sub-adult-2 (10 – 15 years), and adults (>15 years). Age-classification of elephants was done based on (i) Ear characteristics recorded: Assessment of lateral folds along with the degree of folds indicates relative ages. With age the pinnae get, thicker, develop depigmentation and get ragged along the margin.

(ii) Temporal depression: A qualitative assessment of temporal gland depression was carried out, as with age, the temporal depression (the concaveness) gets pronounced in elephants.

(iii) Relative heights and body length: A qualitative assessment of relative shoulder heights and body lengths were recorded as elephants grow almost throughout their life. While shoulder heights stop, the body lengths continue to increase and serve as a good indicator of relative ages.

(iv) For tuskers, tusk characteristics like thickness, appearance and length were recorded as they can indicate age-class of bulls.

(v) For adult cow elephants, extent of sagging of mammae was noted. Additionally, for bulls and cows, buccal cavity depression (brought about by molar progression), forehead hump (above the nasal cavity), development of head domes, relative skull size etc. was qualitatively recorded to classify the elephants into different age classes.

Plate-4.1: Age classification of elephants using a picture obtained from Surajpur Forest Division

4.2.5 Individual identification of elephants

Identification of individual elephants was carried out using a combination of variety of body characteristics such as shape and size of tusks, ear pinnae and others. This technique has been used in both Africa and Asia for many decades (Douglas-Hamilton and Douglas-Hamilton, 1978; Moss, 2001; Vidya et al., 2014). The following body characteristics were used for individual identification:

i. Ear characteristics: Nicks, holes, notches, cuts and serrations in the ear margin that elephants develop with age along with ear folds (ranging from no folds to rolling folds) were noted. Further, the variations in the size, level of depigmentation (that usually increases with age), and shape of the lobe (lower part of the ear) were recorded.

ii. Tusk and tush characteristics: Tusks are modified upper incisors that grow almost throughout an elephant's lifespan. The characteristics related to tusks recorded include intact tusks, broken tusks, and single-tusked along with a written description. In addition to the above, the tusk arrangement, thickness, length and angle with respect to the ground (during stable head position) were recorded. The tusk characteristics were recorded for both the left and the right tusk individually. Tuskless bulls were recorded as *makhnas*.

iii. Tail characteristics: Variation in tail length, presence of prominent kinks (abrupt twists in the caudal bone), and patterns of tail brush (tassels in the tail) were recorded.

iv. Prominent wounds and other body features like warts, scar tissues, deformities and other injuries were also recorded.

4.2.6 Assessment of body-condition scores (BCS)

While palpation techniques are readily available for assessing body condition of captive and immobilized elephants, for free-ranging elephants only visual-based assessments can be done. The downside of using visual-based assessment is the wide margin of possible errors in assigning scores. Therefore, the methods need to be simple to follow in the field. We followed Fernando et al., (2009), which was based on relative scoring of the body characters. The scoring ranged from 1 (poor) to 9 (healthy condition). We assigned BCS to individual elephants using photos and videos.

4.2.7 Data analysis

The age-structure, group size and sex ratios reported in the study were presented either in proportions or in relative percentages. Wherever appropriate, descriptive statistics were used to present the data. For comparing variations in the group size across seasons, and body condition scores between bulls and cows belonging different age groups and across seasons, we used the non-parametric Kruskal-Wallis analysis of variance (Sokal and Rohlf, 2012).

4.3. Results

4.3.1 Distribution and population size

As part of the synchronized elephant census of the year 2017, Chhattisgarh Forest Department enumerated 247 elephants, which were distributed in seven forest divisions (Surajpur, Surguja, Jashpur, Dharamjaigarh, Korba, Raigarh and Mahasamund) and two protected areas (Tamor Pingla WLS and Guru Ghasidas National Park). Based on the daily elephant monitoring effort of Chhattisgarh Forest Department, we noted that the elephant numbers had ranged from 240 to 280 during period 2017–2020. The reported elephant occurrence across forest divisions in Chhattisgarh during the period 2012 to 2017 is provided in Table-4.1.

Table-4.1: Reported elephant occurrence in northern Chhattisgarh during the period 2012 to 2017

S.No	Forest Division	Remarks
	Raipur circle	
1	Mahasamund	Regular. Elephants occur almost throughout the year
2	Balado Bazar	Elephants occur sporadically
3	Dhamtari	Range expansion during 2020. Elephants occur sporadically.
4	Ghariyaband	Range expansion during 2020. Elephants occur sporadically.
5	Raipur	Elephant movement into Naya Raipur was observed since the year 2018. Movement is sporadic
	Bilaspur circle	
6	Korba	Regular. Elephants occur almost throughout the year
7	Raigarh	Regular. Elephants occur almost throughout the year
8	Dharamjaigarh	Regular. Elephants occur almost throughout the year
9	Katghora	Movement was sporadic till 2018. But has become regular since then.
	Surguja circle	
10	Surguja	Regular. Elephants occur almost throughout the year
11	Surajpur	Regular. Elephants occur almost throughout the year
12	Balrampur	Regular. Elephants occur almost throughout the year
13	Jashpur	Regular. Elephants occur almost throughout the year
14	Koriya	Sporadic occurrence for a few days in a year
15	Manendragarh	Sporadic occurrence for a few days in a year

S.No	Forest Division	Remarks
	Raipur circle	
16	Tamor Pinlga WS	Regular. Elephants occur almost throughout the year
17	GuruGhasidas NP	Regular. Elephants occur almost throughout the year
18	Badalkhol WS	Regular. Elephants occur almost throughout the year
19	Semarsot WS	Sporadic occurrence for a few days in a year

$ NP = National Park, # WS = Wildlife Sanctuary

4.3.2 Population trends

As per the existing records, range expansion of elephants possibly from the neighboring states of Odisha and Jharkhand into northern Chhattisgarh began from 1988 onwards. During 1988, 18 elephants were reported from then undivided Surguja district of eastern Madhya Pradesh (presently in Chhattisgarh). Following intensive human–elephant conflict, all these elephants were captured and held in captivity. As a sequel, from the year 2000 onwards, elephants dispersed into Chhattisgarh, where their ranges expanded with concomitant increase in population (Table-4.2).

Table-4.2: Elephant population trend collated from Chhattisgarh Forest Department for the period from 1988 to 2021. The 1988 data was recorded by Madhya Pradesh Forest Department

S.No	Year	Elephant population	Rate of change (times)
1	1988	18	NA
2	2001	24	+ 1.3
3	2005	123	+ 5.1
4	2007	122	- 1.0
5	2015	247	+ 2.02
6	2017	247	No change
7	2021 (as on September 2021)	279	+ 1.12

4.3.3 Group size dynamics

We used 156 direct elephant sightings to assess group size dynamics. Among the direct sightings, 33% (n = 52) were solitary males, 56.4% (n = 88) were groups (herds), and 10% (n = 16) were all-male groups. Of the 52 solitary male sightings, 48 sightings pertain to 3 collared bulls that were regularly tracked. The frequency distribution of group size of female groups in the study area is provided in Fig-4.1. The mean group size of female groups observed in northern Chhattisgarh across all the seasons was 10.9 (± 6.9, median = 9, range = 2 – 41). Seasonal variations observed in the group-size of the female groups have been provided in Table-4.3. Inter-seasonal variations in female group sizes were not significant (Kruskal-Wallis $\chi^2 = 27.8$, df = 24, $P = 0.26$). However, there were significant monthly variations in the group sizes (Fig-4.2).

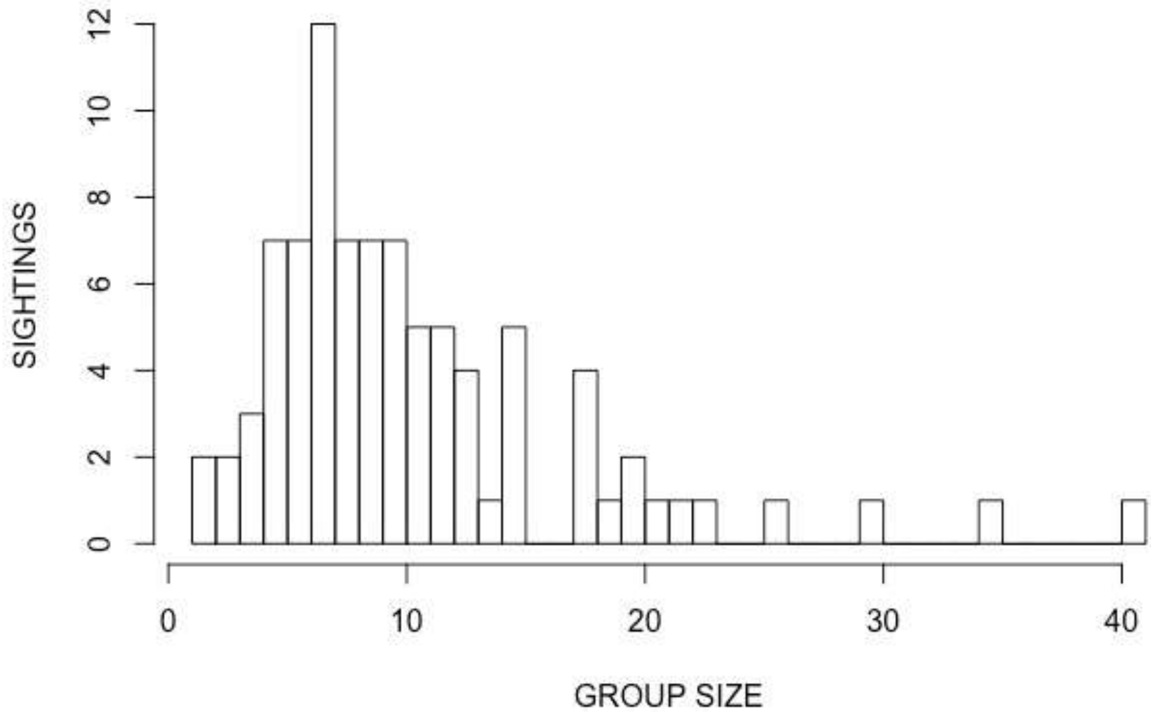

Fig-4.1: Frequency distribution of group size of female elephant groups recorded in northern Chhattisgarh (n = 88). The data has been pooled for three-year period 2017 - 2020

Table-4.3: Seasonal variations in the elephant group-size

Season	Group size
Dry season	μ : 10.4, (σ: ± 6.1), Median: 9, Range: 3 – 30
Monsoon	μ : 8.1, (σ: ± 8.6), Median: 5, Range: 3 – 35
Winter	μ : 12.1, (σ: ± 6.8), Median: 10.5, Range: 2 – 41

In the all-male groups, the mean group size observed was 2.6 (± 0.7). The maximum number of bulls seen in the all-male groups was 4. The number of sightings of all-male groups was few to make season-wise comparisons.

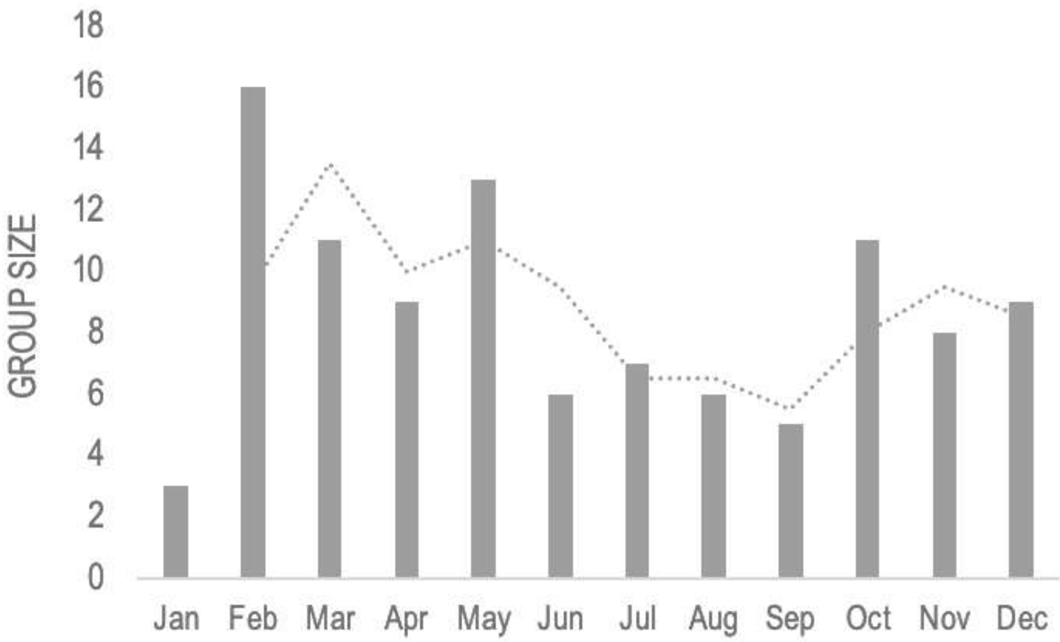

Fig-4.2: Frequency distribution of monthly group size of female herds. The data has been pooled for three years from 2017 to 2020

4.3.4. Age-structure and sex ratio

In northern Chhattisgarh, a total of 34 adult cow elephants were individually identified based on morphological features (Natarajan *et al.* 2019). In addition to these individually recognized adult cows, 13 different female elephants were observed, but not individually identified. Adding the identified females and unidentified individuals, we estimated a minimum number of 47 adult females in northern Chhattisgarh.

Furthermore, during the intensive study period (2017–2020), 11 bulls were recorded. The number of bulls reported here is best considered minimal number as there were reports of other bulls in the area, which could not be located. Of the 11 adult bulls observed, 5 were followed with GPS collars. Two of the 11 adult bulls were *makhnas*. The sex ratio of elephants across different age-classes as estimated in northern Chhattisgarh is provided in Table-4.4.

Table-4.4: Ratio of male to female elephants across different age classes recorded in northern Chhattisgarh during the period 2017 - 2020

S.No	Parameter	Estimates	Remarks
1	Ratio of adult bull: adult cow	1: 4.5	Estimation largely based on identified bull and cow elephants, and a small fraction of unidentified elephants
2	Ratio of sub-adult bull: sub-adult cow	1: 0.6	Estimation based on the elephants age-classified in the field and from the photo/video repository
3	Ratio of juvenile male: juvenile female	1: 1.8	- do -
4	Ratio of adult *makhna* to tusker	1: 4.5	Estimation based on the repository of identified bull elephants

The age-structure of the female herds expressed as proportion of individuals classified across different age groups is presented in Fig-4.3.

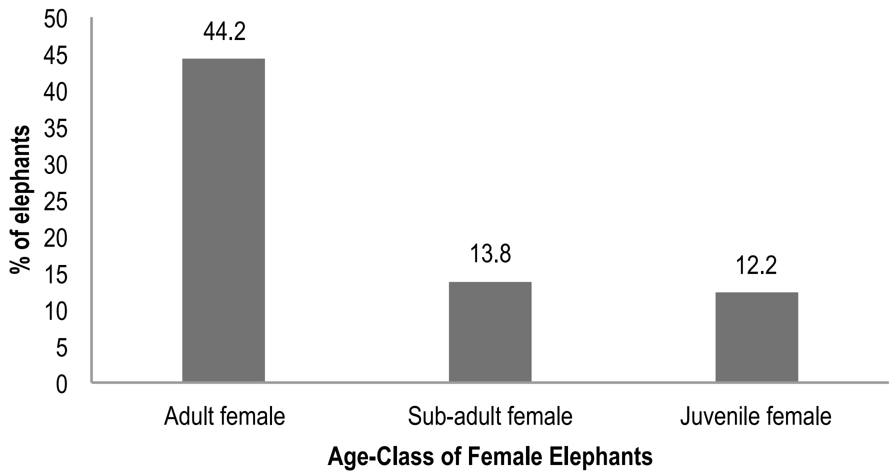

Fig-4.3: Age-structure of female elephants classified based on photographic methods in northern Chhattisgarh. The identified individuals were not removed from the analysis

4.3.5 Birth rate

The ratio of number offspring produced per adult female in the population can be used to calculate reproductive rates, particularly when reliable observations are made over time (Williams et al., 2002). The ratio method has been widely been used for assessing fertility and birth-rate of elephants and other large herbivores (Sukumar 1985; Tiwari 2002; Bonenfant et al., 2005). In this study, all the 47 adult females (>15 years of age) were considered as putative mothers. Further to this, a total of 14 calves (< 2 years) were recorded. Thus, the mother to calf ratio was estimated at 3.35:1. Using this ratio, the fertility rate of 0.29 births per adult cow elephant was estimated. Based on the observed female to calf ratio, mean inter-calf interval of 3.4 years was estimated.

4.3.6 Body condition scores

In the adult segment of the population, the recorded BCS of bulls [μ = 8.08 (σ = ± 0.7)] were significantly higher than the females [μ = 7.8(σ = ±0.9)] (Kruskal-Wallis χ^2 = 18.7, df = 3, P = 0.0003). However, across all age groups, the BCS did not appear different between males and females (Fig-4.4). Further to this, we observed no significant seasonal variations in the BCS for both males and females (Fig-4.4).

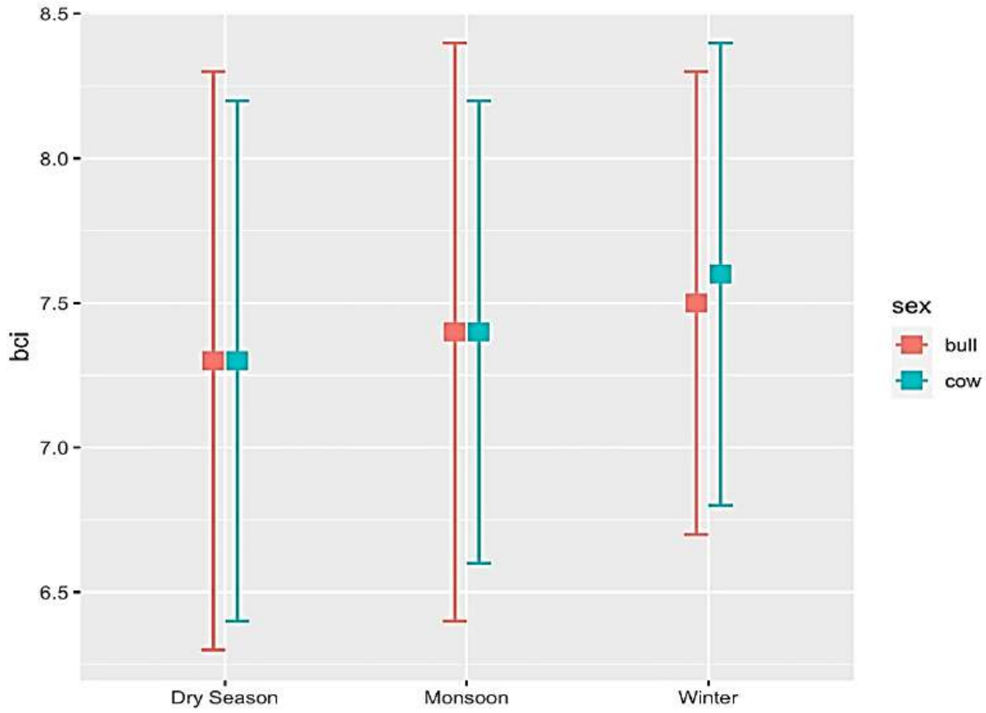

Fig-4.4: Seasonal comparison of body condition scores between cow (n=536) and bull (n=351)

4.4 Discussion

4.4.1 Population trends

During the 20-year period from 2001 to 2021, the elephant population in Chhattisgarh largely by immigration has increased from 24 elephants in 2001 to over 270 elephants in 2021 translating into 12.3% increase per annum. However, the indicated rate was estimated based on broad comparison made using population estimates of two discrete years of 2001 and 2021, and therefore, may not reflect the actual annual increase. Further to this, the observed growth in elephant population needs cautious interpretation in light of: (i) for a relatively small population, even a marginal increase can inflate growth rates (ii) the elephant population in Chhattisgarh is not isolated, but connected with populations in Odisha and Jharkhand with significant immigration and emigration. Based on the population trend collated from CGFD, the observed increase in elephant population in Chhattisgarh was likely due to immigration of elephants to a large extent and *in-situ* births as well.

4.4.2 Group size dynamics

In natural habitats with minimal human influence, elephant group-size dynamics would be primarily determined by their underlying social organization and resource availability (Moss, 2012). During resource limiting seasons, elephants may form smaller groups to avoid conspecific competition. On the contrary, when primary productivity is high, they may form large groups of genetically related individuals to maximize social interactions. Migratory elephants (long-distance movement of elephants) and elephants that disperse out of natal areas due to saturated habitat conditions too may form large groups (even of un-related individuals) (Daniel et al., 2008). Such large groups could be temporary in nature. In northern Chhattisgarh, seasonal variations in elephant group sizes were not significant. However, monthly variations were significant indicating high variability, probably owing to high frequency of fission and fusion of groups. The average group size recorded in the study is comparable to the group size of Asian elephants reported from different landscapes (Sukumar, 1985; Tiwari, 2002; De Silva et al., 2013).

4.4.3 Age structure and sex ratio

The estimated adult sex ratio of 1:4.6 in the study area is comparable with the sex ratio of 1:5.1 estimated by Sukumar (1985) in the Biligiri Rangan hills, Southern India and this landscape was vulnerable to poaching of tuskers. Williams (2005) reported a sex ratio of 1:1.87 in Rajaji National Park, Uttarakhand where then poaching was not reported indicating higher proportion of males in the population. In Chandaka wildlife sanctuary of Odisha, which occurs in the East Central landscape and thus, ecologically similar to Chhattisgarh, Tiwari (2002) reported a sex ratio of 1:2.1. Tiwari (2002) urged caution that since the elephant population size in Chandaka was small (< 60), the remnant bulls in the population were important regardless of the adult sex ratios. As elephants are polygynous, minimal skew in the sex ration for large populations may not as such affect population growth rates, which are determined by fertility rate of females (Sukumar, 1991). In northern Chhattisgarh, the male segment of the elephant population is represented in all age-classes (juveniles, sub-adults, and adults), and the adult sex ratios do not appear skewed. However, as the population size is relatively small, even loss of a few adult bulls could potentially affect population viability. In the sub-adult segment of the population (5 – 15 years of age), proportion of males was higher than females. Williams (2005) too reported a relatively higher number of sub-adult males in Rajaji National Park, Uttarakhand. In sexually dimorphic polygynous animals, Trivers & Willard hypothesis (TWH) predicts that there will be more males in populations where resource conditions are optimal (Trivers and Willard, 1973; Clutton-Brock and Iason, 1986; Sheldon and West 2004; Krüger et al., 2005). However, for Chhattisgarh, in the absence of information on sub-adult survival, it would be difficult to confirm if the observed sex ratio in the sub-adult segment confirms to the predictions of TWH regardless of optimal nutritional status of elephants that indicate higher resource availability for elephants in the landscape. Furthermore, it is plausible that some of the sub-adult males observed with female herds may be a result of 'loose associations' of individuals that are in the dispersal phase.

In the juvenile segment (2 – 5 years of age), the females were numerically higher than males. Arivazhagan (2005) observed a similar pattern in the Nilgiris, southern India. In general, juvenile elephants are difficult to sex-classify, and there is a possibility of misclassification. Therefore, the inherent difference between males and females in the juvenile segment could have resulted from a sampling artifact.

The adult females constituted over 44% of the female segment of the population, which corroborates with the age-structure estimates obtained from other elephant landscapes (Sukumar, 1985; Tiwari, 2002; Arivazhagan, 2005; De Silva et al., 2013). For example, age-structure of female herds in the BR Hills and Sathyamangalam (Karnataka & Tamil Nadu), Chandaka WS (Odisha), Mudumalai (Tamil Nadu), Nagarahole (Karnataka) and Uda Walave (Sri Lanka) indicated that adult females constituted 40 – 45% of the whole female segment of the population. Our estimates from northern Chhattisgarh (44.2%) fell within this range.

4.4.4 Birth rate and inter-calf interval

The inter-calf interval reported in the study is lower than the estimates reported from other elephant landscapes (Table-4.5). This requires a cautious interpretation as well. Although ratio method is widely used, it is prone to errors and thus, less reliable than the estimates obtained from monitoring individually identified animals (Bonenfant et al., 2005) highlighting the need to have longitudinal demographic assessment for at-risk elephant populations. Further to this, using long-term demographic dataset of elephants form Amboseli, Moss (2001) snap-short ratio assessments may only reflect short-term pulses in the population growth that can mislead interpretation.

Table-4.5: Comparison of elephant inter-calf interval across different elephant landscapes

S.No	Inter-calf interval	Landscape	Reference
1	4.8	Biligiri Rangan Hills, South India	Sukumar (1985)
2	4.5	Rajaji National Park, Uttarakhand	Williams (2005)
3	4.7 – 4.9	Chandaka Wildlife Sanctuary, Odisha	Tiwari (2002)
4	5.1	Nagarahole National Park, Karnataka	Arivazhagan (2005)
5	5.3	Mudumalai Wildlife Sanctuary, Karnataka	Arivazhagan (2005)
6	6.9	Periyar Wildlife Sanctuary, Kerala	Arivazhagan (2005)
7	4.5	Amboseli National Park, Kenya (African elephant, *Loxodonta africana*)	Moss (2001)
8	3.4	Northern Chhattisgarh	Present study

4.4.5. Body condition scores

As Asian elephants occur in seasonal environments with pronounced fluxes in resource availability, their body condition scores are expected to exhibit significant seasonal differences (Pokharel et al., 2017). However, in Chhattisgarh, the seasonal differences in the body condition scores were not significant for both males and females. This was likely a result of elephants (both bulls and female herds) foraging intensively on cultivated crops. Crop foraging by elephants is widespread in Chhattisgarh. Crop losses are significantly high for paddy (*Oryza sativa*) followed by wheat (*Triticum aestivum*) and local varieties of pulses, maize, vegetables, and sugarcane (*Saccharum officinarum*) in relatively well-irrigated tracts. Conversely, the quality of fragmented forest patches used by elephants is poor, as plant biomass in such patches is dominated by Sal (*Shorea robusta*) coppice and associated species with negligible grass cover. Many of these forest patches are regularly burnt to collect *mahua* flowers (*Madhuca latifolia*) used for distilling local brew.

The average body condition scores of elephants recorded in Chhattisgarh were higher in comparison to elephants that predominantly occur within protected areas as observed in Rajaji National Park in Uttarakhand and Bandipur National Park in Karnataka (L. Natarajan, Wildlife Institute of India, *personal observation*). While crop foraging may result in higher body condition scores in elephants, the downside of long-term demographic impacts of crop foraging by elephants is poorly understood. For example, crop foraging can result in conflict-induced elephant injuries and mortalities. Injuries can affect the health condition of an animal (Goswami *et al.* 2014). Further, there is considerable potential for crop foraging elephants to get exposed to agricultural pesticides and other intoxicants that are being increasingly used in India. The effect of such exposure on elephant survival and other aspects of fitness is a research question that begs urgent investigation.

4.5 Conclusion

As the data used was collected opportunistically that did not follow sampling theory, it was not amenable for modelling required vital rates like intrinsic growth rate (*r*) (or the rate of population change), and for performing population viability analysis. Further, we did not present mortality data, as the information available was sketchy. Nevertheless, during the period during 2009 to 2019, 34 elephant deaths were reported due to conflict-related reasons (Project Elephant, Government of India, unpublished data). Additionally, episodes of local outbreaks of infectious diseases like Elephant Endotheliotropic Herpesvirus (EEHV) and Hemorrhagic Septicemia (HS) resulting in mass deaths were reported from both Chhattisgarh and neighboring Odisha during 2019 - 2021. Thus, including age-specific mortality data would be crucial in understanding the elephant population trajectory in Chhattisgarh. For vertebrates, Reed et al., (2003) suggested that population comprising of a few thousand individuals would be crucial for long-term persistence of populations. For Asian elephants, many populations may not meet this criterion. As a worst-case scenario, Sukumar (1995) suggested that 100 – 200 elephants could be a minimum viable population. Although the population size of elephants in Chhattisgarh is above this prescription, elephant groups are spatially scattered occurring in numerous discrete forest patches. Accelerated habitat fragmentation can potentially result in isolation of spatially scattered elephant groups rendering them vulnerable to extinction. Therefore, advancing landscape-level policies with functional corridors aimed at maintaining elephant meta-populations in relatively large forested habitats both in Chhattisgarh and in the entire East Central region would be paramount.

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CHAPTER-5

HOME RANGE, MOVEMENT AND DISPERSAL PATTERNS OF ELEPHANTS

5.1 Introduction

In wildlife–habitat assessments, evaluation of animal "home ranges" is important, as animals tend to use sites repeatedly over time (Powell, 2000). Thus, based on repeated use of areas, it is possible to objectively delineate geographic space of animals in the landscape (Nielsen et al., 2008). Although an understanding of animal home ranges is crucial for both management and conservation, the definition of home range remains equivocal. Burt (1943) defined animal home range as an area traversed by individual or group of animals during activities associated with feeding, resting, reproduction, and shelter (cited by Powell, 2000). This definition is widely used in literature with suitable modifications and extensions, as appropriate. Regardless of the strict definition, home ranges can be summarized as geographic space within which animals use different habitats as facilitated by their ability to move (Ranc et al., 2020). Thus, assessment of animal home ranges along with corresponding movement patterns can provide spatial information that can elucidate aspects of ecology and behaviour of the species (Powell and Mitchell, 2012). Factors like body size, metabolic requirements, habitat features, foraging behaviour, societal factors, and reproductive behaviour of the species can influence their home ranges (Collen et al., 2011; Sukumar, 2003). Conversely, understanding home ranges can provide possible insights on the all of the above determinants of home range in a species.

From the conservation standpoint, understanding animal home ranges is crucial for addressing contemporary conservation challenges like predicting extinction risks (Collen et al., 2011; Woodroffe and Ginsberg, 1998) and human–wildlife conflicts. In particular, for large mammals like elephants, understanding home range distribution along with within home range habitat selection can be useful in managing human–elephant conflict. As elephants are generalist herbivores with respect to their foraging behaviour and exhibit remarkable behavioural plasticity, they occur in a variety of habitats ranging from wet evergreen forests to semi-arid tropical regions (Natarajan et al., 2016). Elephant home ranges measured across Asia suggest high variability in the estimates ranging from 50-km^2 to 3000-km^2 (Baskaran, 1998; Desai, 1991; Fernando et al., 2008; Joshua and Johnsingh, 1995; Sukumar, 2003, 1985; Williams et al., 2008). With such high levels of variability in elephant home ranges across landscapes, question arises on whether we can objectively predict elephant home ranges.

5.1.1 Mechanistic understanding of home ranges

The mechanistic relationship between body weight and corresponding home range size has been explored for many mammalian species, particularly in the temperate regions where seasonal home ranges tend to be strikingly different (Fagan et al., 2013; Harestad and Bunnel, 2011; Reiss, 1988). McNab (1963) came up with an estimator (a power equation) that estimates home ranges based on body weights. Accordingly, for herbivores, the power equation of McNab was $3.02W^{0.69}$(McNab, 1963). Here W is weight measured in kilograms and the home range is measured in acres. McNab used exponents that were similar to Kleiber's exponent (Kleiber, 1947) in deciphering the relationship between body weight and basic metabolic rate in mammals. Indeed, home range is interplay of animal's metabolic requirement, societal and community-level pressures (intra- and interspecific competition, predation etc) and human-induced modifications (Sukumar, 2003). For Asian elephants, McNab's estimator underestimates home ranges. Swihart et al., (1988) developed an estimator, $4.9W^{1.56}$ to measure home ranges of herbivores. Here the home range is measured in hectares and weight (W) is measured in kilograms. The home range estimates of Swihart et al (1988)'s work relatively better that McNab's estimator. Owen-Smith derived a home range estimator for African elephants, which was derived as $0.0135W^{1.25}$ as described by Sukumar (2003). Here weight is measured in tons and home range is estimated in sq.km. Sukumar (2003) opined that Owen-Smith's estimator works relatively better for Asian elephants. In any case, considering the huge variations in estimated elephant home ranges, it is evident that host of ecological, behavioural and human-induced variables profoundly influence elephant home ranges and therefore, predicting patterns of their home ranges continues to be challenging (Sukumar, 2003).

5.1.2 Estimation of home ranges

Wildlife home ranges can be assessed using many field techniques. Field methods like regularly plotting tracks have been to estimate home ranges of territorial large carnivores (Schaller and Crawshaw, 1980). Using well-maintained re-sighting records of identified individuals, animal home ranges have been estimated (Kumar, 1994; Sukumar, 1985). The aforementioned non-invasive methods have proved invaluable in getting crude outlines of animal home ranges. The advent of radio-telemetry during 1960s had revolutionized the field of spatial ecology enabling investigators to obtain high-resolution real-time information on animal movement, behaviour and subsequent home range patterns (Sukumar, 2003). Radio telemetry studies involve capture, collaring and radio-tracking wildlife using very high frequency (VHF) transmitters. Telemetry unit comprises of VHF transmitter (encased in a belt that will wound on elephants) the emit radio signals (electromagnetic waves) and a receiver unit (along with antenna) that receive the signals (Rabinowitz, 1993). Triangulation and homing in techniques are used to obtain location fixes of animals and manually track them down respectively (Rabinowitz, 1993). Lately, the development of satellite tracking technology has furthered the fields of spatial ecology and animal behaviour by enabling fine-scale data collection (Wittemyer et al., 2019). Modern satellite collars can provide real-time high-resolution data on animal location fixes along with host of other add-ons like activity sensors that record behavioural states of animals in relation to environmental variables (Wittemyer et al., 2019). In satellite tracking, the location fixes are uploaded to satellite and users download data from the servers (Powell, 2000).

The GPS fixes obtained from telemetry collars are analysed to compute home ranges and host of other details pertaining to animal ecology and behaviour (Laver and Kelly, 2008). There are many home range estimators that are currently available. Amongst them, the minimum convex polygon (MCP) approach has been conventionally used to depict animal home ranges (Downs and Horner, 2008; Fleming et al., 2015). Estimation of MCP is not based on any statistical distribution and therefore, it is conceptually simple. The MCP polygon drawn by delimiting smallest polygon connecting peripheral location points with anterior angles less than 180 degrees. The downside of MCP approach includes the influence of outliers on the polygon and that the polygon includes large areas that animal may not use at all. Unlike the MCP, the Kernel Density Estimation (KDE) produces utilization distribution based on location points (Downs and Horner, 2008; Fleming et al., 2015). The KDE estimates probability that an animal be present in any part of its home range using location fixes (Laver and Kelly, 2008). Thus, KDE estimates provide both the size of home range along with the intensity of use (Powell, 2000). In addition to MCP and KDE approaches, there are a host of other estimators such as the Brownian

Bridge Movement Models (BBMM) that delineates movement trajectories and also account for spatial autocorrelation of location fixes, which is highly likely in case of satellite collars that provide high-resolution information (Calenge, 2015). To summarize, there is widespread inconsistency in home range estimation methods with minimal consensus on the most suitable method. Minimizing inconsistency so as to make comparisons meaningful is being advocated (Laver and Kelly, 2008). The choice of estimator depends on its ability to provide biological insights useful for understanding the biology of the animal and in its management. The absolute home range size may not be useful for wildlife manager (Nielsen et al., 2008). Rather the variations in home ranges across landscape and the relative effect of both ecological and human–induced variables explaining such variations would be more relevant for management. There is a general consensus that probabilistic KDE describe home ranges better than MCP (Nielsen et al., 2008). However, the utility of MCP cannot be undermined as it useful for comparing home ranges across landscapes as most of the older studies have used MCP approach for estimating home ranges. Furthermore, MCP provides a crude estimate of area that animals operate, which can be highly relevant for managing species involved in human–wildlife conflicts. The estimates of KDE tend to be comparable across sites and main merit of KDE approach is its ability in detecting core areas (activity centres) and estimating habitat selection. Capitalizing on technological advancements that enable fine-scale tracking of elephants and analysing home ranges using approaches to minimize statistical bias in parameter estimates would be invaluable in relating home range features with spatio-temporal patterns of human–elephant conflict.

In Chhattisgarh, elephants occur over a large area (Chapter-4) with correponding high levels of human–elephant conflict (Chapter-7 & 8). Unravelling elephant ranging behaviour and elucidating patterns on their home range distribution, use of habitats within their home ranges, and movement trajectories in the mosaic landscape would be essential in developing conflict mitigation strategies and conservation plans. In this regard, satellite telemetry can provide fine-scale details on elephant home ranges and associated behaviours. However, collaring elephants is logistically challenging requiring highly skilled personnel, resources and admittedly, carries high amounts of risk to both people involved in the operations and elephants. In Chhattisgarh, the institutional and human resource capacities required for capturing elephants were limited. The elephant capture operations had to be carried out on foot as trained *kumkis* were not available[4]. Due to these considerations, only a limited number of individual elephants can be collared. Alternatively, registration of individual elephants using morphological features and opportunistically monitoring can yield "re-sighting" records that can be used for estimating home ranges (Kumar, 1994; Sukumar, 1985). Such home ranges are crude estimates often constrained by sample size across seasons, but are nevertheless useful.

The objectives entailed in the chapter include (i) estimation of elephant home ranges using different methods along with description of home ranges (ii) assessment of seasonal and monthly differences in elephant home ranges (iii) assessment of home range stabilization (iv) assessment of inter-annual fluctuations in home ranges (v) to describe movement patterns and use of corridors (vi) to compare elephant home ranges with that of other landscapes, and discuss the relevance of understanding elephant ranging behaviour for management of elephants in Chhattisgarh.

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[4] **Chhattisgarh forest department has lately developed a *kumki* unit, which has become effective currently.**

5.2 Methods

5.2.1 Individual identification of elephants

The individual elephants were identified using standard methods based on the morphological features of the elephants (Natarajan et al., 2019). The parameters used for individual identification of elephants have been elaborated in Chapter-4.

5.2.2 Chemical immobilization of elephants

Among the elephants individually identified, a few were selected for collaring based on many considerations. Such considerations included the (i) objectives of the study, (ii) age (iii) reproductive status (so as to avoid capturing cows that are aged, with tiny calves and are in advanced stage of pregnancy) and, (iv) patterns of elephant associations. Radio collaring operations were carried out in different phases. For each phase of the collaring operation, the preparatory activities for collaring were initiated many months in advance. During the project period, realizing that the local capacities to track and follow elephants on foot were low, experienced elephant trackers from Tamil Nadu state in southern India and two experienced trackers from Rajaji tiger reserve, Uttarakhand were brought in to assist in the project. During the course of monitoring elephants on foot prior to collaring, the research team including the trackers became familiar with the terrain condition, which is a prerequisite for executing a safe elephant capture operation. In addition to trackers hired from Tamil Nadu, the local mahouts and trackers were included in the team so as to gain local terrain knowledge and simultaneously train the local trackers.

Senior veterinarian from WII immobilized elephants with assistance from research team, trackers, and the veterinarians of Chhattisgarh Forest Department. I was part of the field team that carried out elephant capture and radio-collaring operations in Chhattisgarh. The immobilization drugs were remotely delivered using

Dan-Inject IM and JM model immobilization equipment. The details of drugs used for collaring elephants are in Table-5.1. The collars with built-in VHF and satellite transmitters that work on iridium technology were procured form M/s. Savannah Tracking, Kenya. The collars were programmed to provide a GPS fix at every one-hour interval. The entire collar unit weighs about 15 Kgs, which is approximately 0.3 to 0.5% of the average body weight of an adult bull and adult cow elephants respectively.

Plate-5.1: Radio collaring of adult tusker in Surguja. Elephant was immobilized with narcotic drugs

Plate-5.2: Radio collaring of adult tusker in Surguja. Elephant was immobilized with narcotic drugs

Plate-5.3: Radio collaring of adult tusker in Dharamjaigarh. Elephant was sedated with a combination of Xylazine and Ketamine

Table-5.1: Drugs used for immobilizing elephants in Chhattisgarh for collaring purposes during the period May 2018 to December 2020

S.No	Elephant ID	Gender & age class	Drugs used
1	BD1	M (*makhna*), >40	Xylazine (Xylaxil) and ketamine (Anaestamin) for sedation and Yohimbine (Yohambin hydrochloride) for reversal
2	GI	F, > 20	Etrophine hydrochloride for immobilization and Diprenorphine hydrochloride for reversal
3	PY	M (tusker), >25	Etrophine hydrochloride for immobilization and Diprenorphine hydrochloride for reversal
4	MH	M (tusker), > 20	Etrophine hydrochloride for immobilization and Diprenorphine hydrochloride for reversal
5	GN	M (tusker), >25	Xylazine (Xylaxil) and ketamine (Anaestamin) for sedation and Yohimbine (Yohambin hydrochloride) for reversal
6	BD2	M (*makhna*), >40	Etrophine hydrochloride for immobilization and Diprenorphine hydrochloride for reversal

5.2.3 Analytical methods

To visualize home ranges MCP was used. To assess home range and concomitant within home range habitat-use, KDE-based Utilization Distribution (UD) was used. The KDE UD contours (isopleths) were defined at kernel 50% (core use), 75% (moderate use), and 95% (intensive use). For smoothing parameter "h" used in estimating KDE, least squares validation cross-validation method (LSCV) method was used across all isopleth levels (Fleming et al., 2015).

Monthly home ranges were calculated (based on 95% UD) and month-wise variations were evaluated using linear regression models with maximum likelihood estimators. The response variable in the models was monthly home ranges (95% UD) measured in km^2, which was assumed to follow a normal distribution. The explanatory variables included individual elephant ID (BD1, BD2, PY, GN, GI), gender (bull/cow), *musth* status (presence/absence) and season (dry/monsoon/winter). Model comparisons were made using information-theoretic approaches by comparing plausible models with intercept-only model (Burnham and Anderson, 2002). The models were compared using Akaike Information Criterion (AIC) values and corresponding AIC weights (Burnham and Anderson, 2002). To compare seasonal difference in range areas, non-parametric Kruskal Wallis tests were used (Sokal and Rohlf, 2012). Descriptive statistics including basic graphs were carried out in excel spreadsheets. The home range estimations were carried out in program R using the package "adehabitatHR" (Calenge, 2015). The visualization and extraction of home range values were carried out in ArcGIS V. 10.6.1. The regression analysis was carried out in program R (R Core Team, 2019).

5.3 Results

5.3.1 Elephant home ranges

A total of 7 elephants were collared during the period 2018–2020 (Table-5.2). Among the 7 elephants, one young cow (around 15 years of age) was collared in Tamor Pingla Wildlife Sanctuary during May 2019. As the collar dropped in two days, it was not included in the list. The elephants were collared in Balrampur (1), Surajpur (3), Tamor Pingla (1), Surguja (1) and Dharamjaigarh (1) Forest Divisions. In additions to elephants collared and monitoring, 93 elephants were individually identified and monitored during the study period (Natarajan et al, 2021). Among them, two groups of elephants namely WE group (Wave Ear as named for matriarch) and TE group (Torn Ear as named for an adult female), were opportunistically, but regularly monitored. The monitoring yielded re-sighting GPS fixes with which home ranges (only MCP estimates) were calculated.

Table-5.2: The details of elephants collared during the study period 2018–2020 is as follows

Elephant ID	Location of collaring	Age class	Monitoring days
BD1	Rewatpur, Balrampur FD	AM, 40+	404
BD2	Duppi, Surajpur FD	-do- (recollaring)	543
GN	Chhal, Dharamjaigarh FD	AM, 30 years	292
PY	Bansipur, Surajpur FD	AM, 30 years	396
GI	Mainpat, Surguja FD	AM, 20 years	623
MH	Surajpur FD	AM, 20 years	15
KM	Tamor Pingla WLS	AF, 15 years	3

* AM = Adult male

Plate-5.4: Elephant BD, adult *makhna* photographed in Surajpur Forest Division

Plate-5.5: Elephant PY, adult tusker photographed in Surguja Forest Division

Plate-5.6: The family herd of GI (GI is the last of the female in the frame with radio collar) photographed in Dharamjaigarh Forest Division

Plate-5.7: Elephant GN, adult tusker photographed in Korba Forest Division

Plate-5.8: The WE family that was monitored intensively during the study period. The adult cow elephant in the left is WE

The estimated home ranges of elephants (both satellite collared elephants and individually monitored) in northern Chhattisgarh during the period June 2018 to December 2020 using MCP and KDE approaches are provided in Table-5.3.

Table-5.3: The estimated home ranges of elephants in northern Chhattisgarh during the period May 2018 to December 2020

Elephant ID	MCP (in Km^2)		KDE (in Km^2)	
	95%	**100%**	**50%**	**95%**
BD1	1171.1	1416.6	26.5	281.7
BD2	939.4	1242.0	31.2	246.3
GN	3582.7	8229.3	72.6	748.9
PY	3862.2	5540.2	85.2	662.9
MH	256.2	290.0	NM	NM
GI	3327.5	4271.9	63.9	605.3
WE$	462.3	NM	NM	NM
TE$	6969.7	NM	NM	NM

**** NM = Home ranges not measured. $The home ranges of TE and WE were estimated based on re-sighting records.***

5.3.1.1 MCP home ranges

The average home range of elephants recorded during the study using 95% MCP approach was 2571.4 km^2 (SD ± 2300.2 km^2, Range: 256.2 – 6969.7 km^2).

5.3.1.2 KDE home ranges

The average home range of elephants recorded during the study using 95% KDE approach was 517.5 km^2 (SD ± 235.3 km^2, Range: 248.5 – 688.7 km^2). The home ranges estimated using 95% UD, measured an average 21.3% (SD±0.03) of the MCP home ranges.

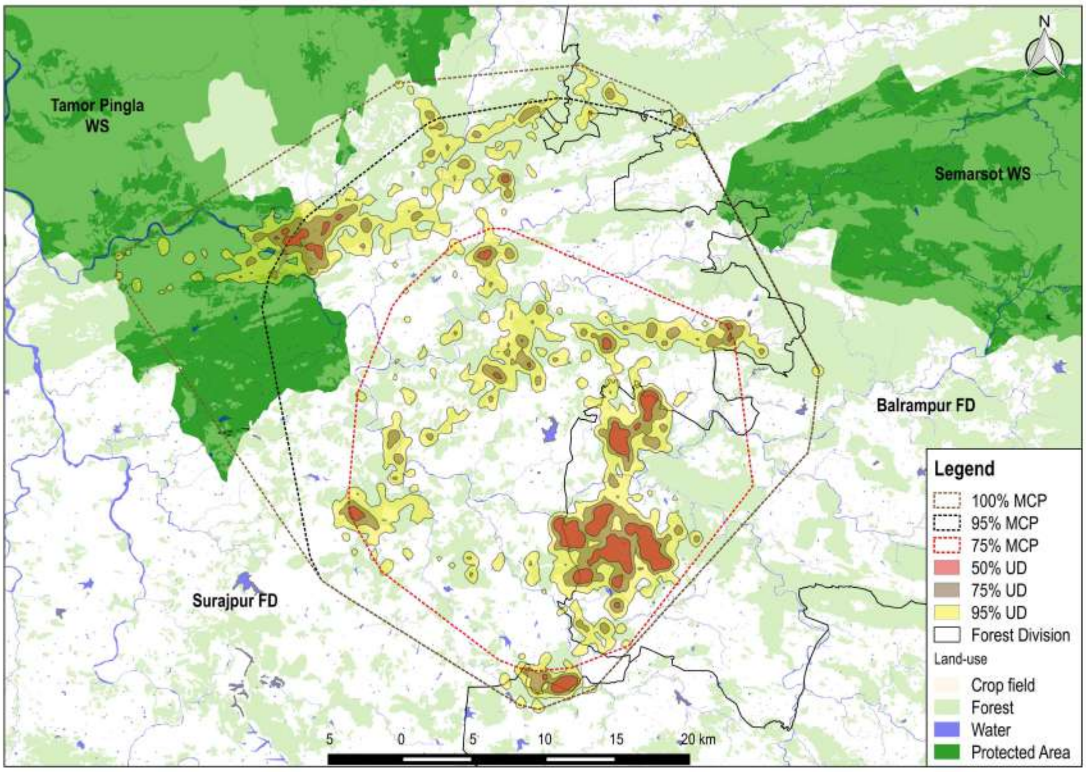


Fig-5.1: Home range distribution of elephant BD1 (adult *makhna*)

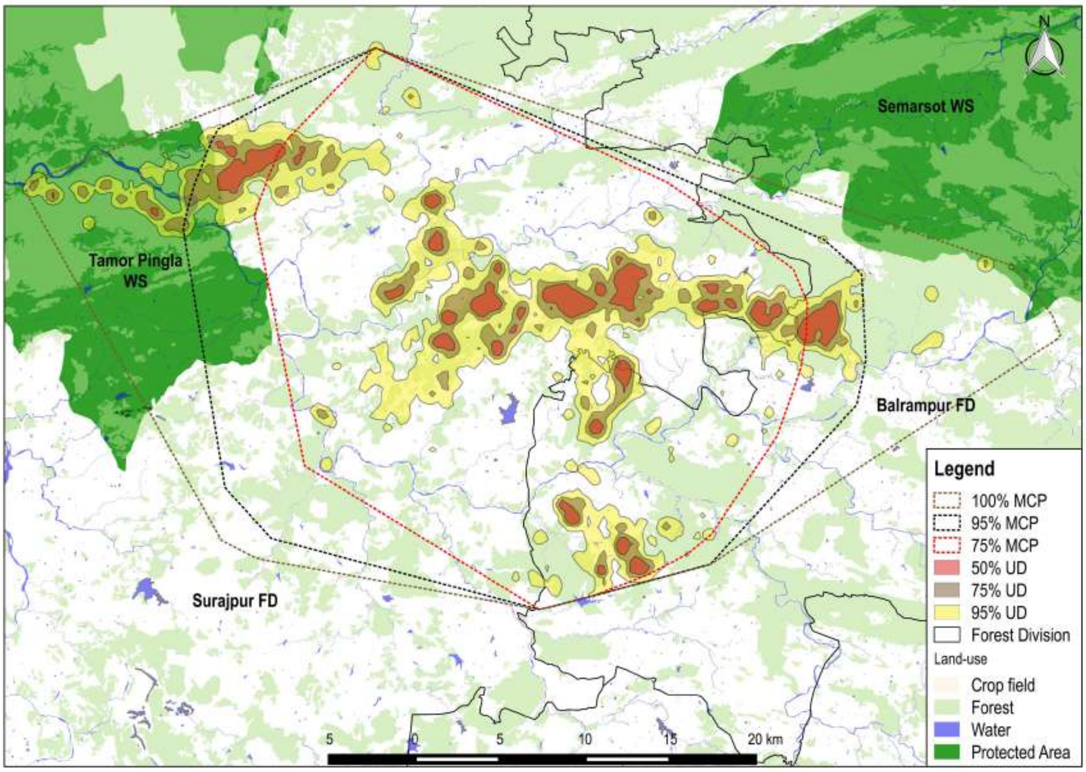


Fig-5.2: Home range distribution of elephant BD1 (adult *makhna*)

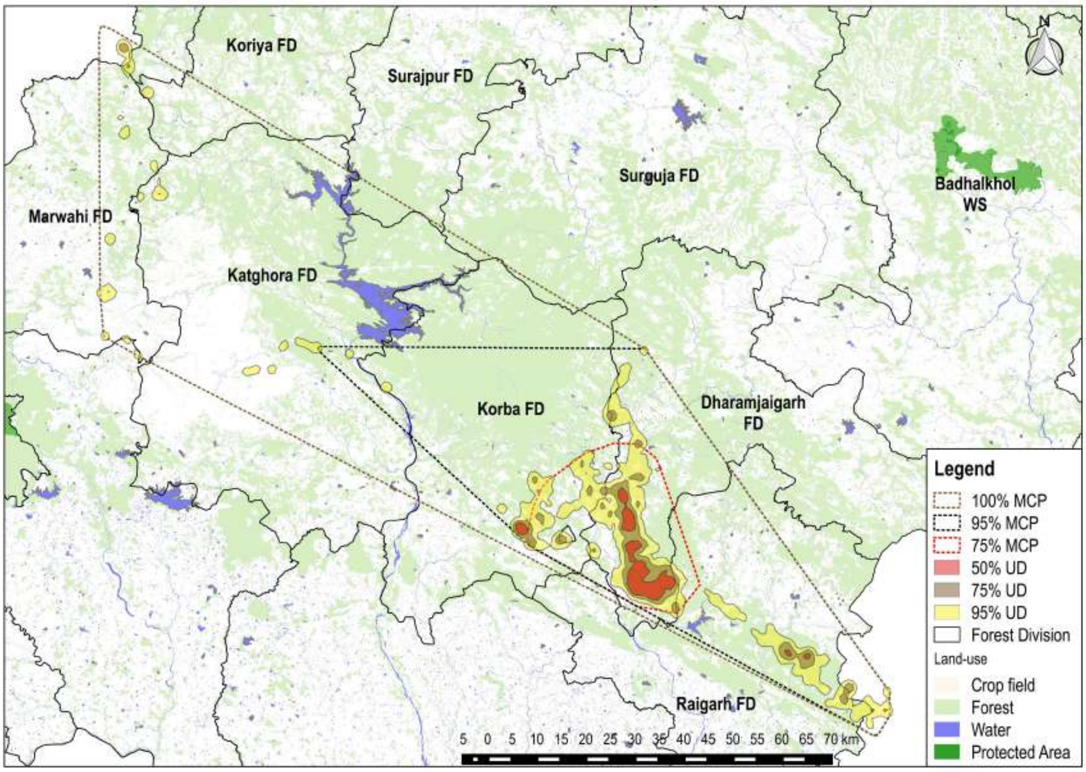


Fig-5.3: Home range distribution of elephant GN (adult tusker)

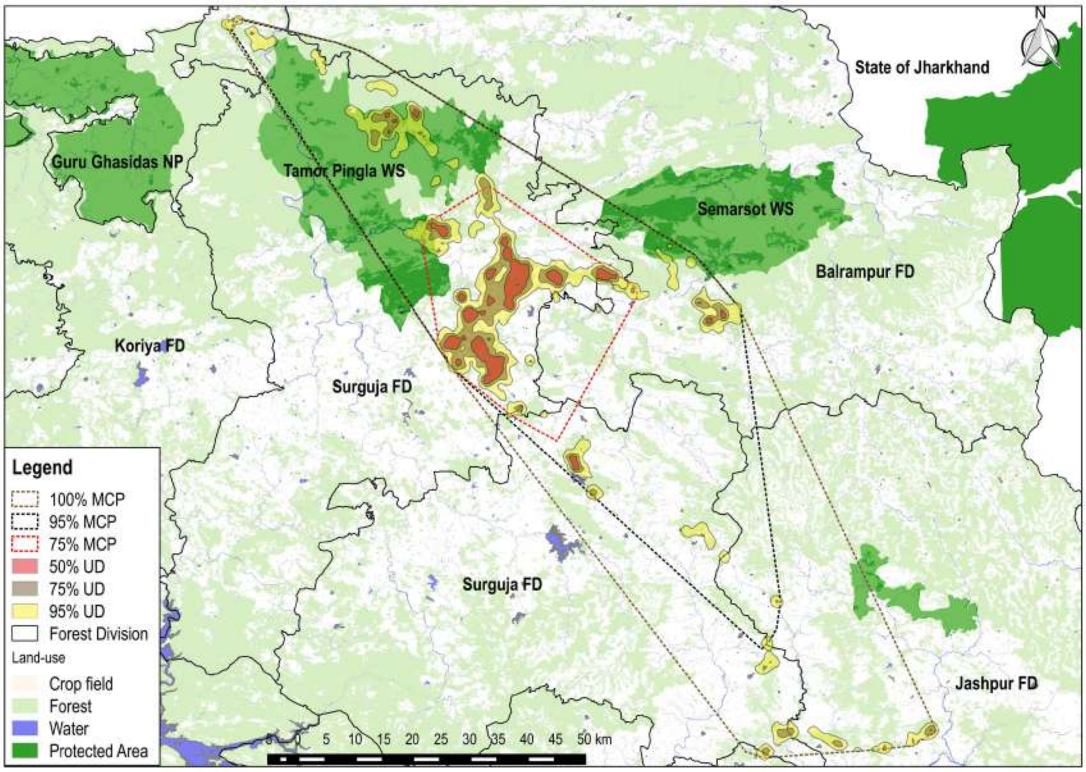


Fig-5.4: Home range distribution of elephant PY (adult tusker)

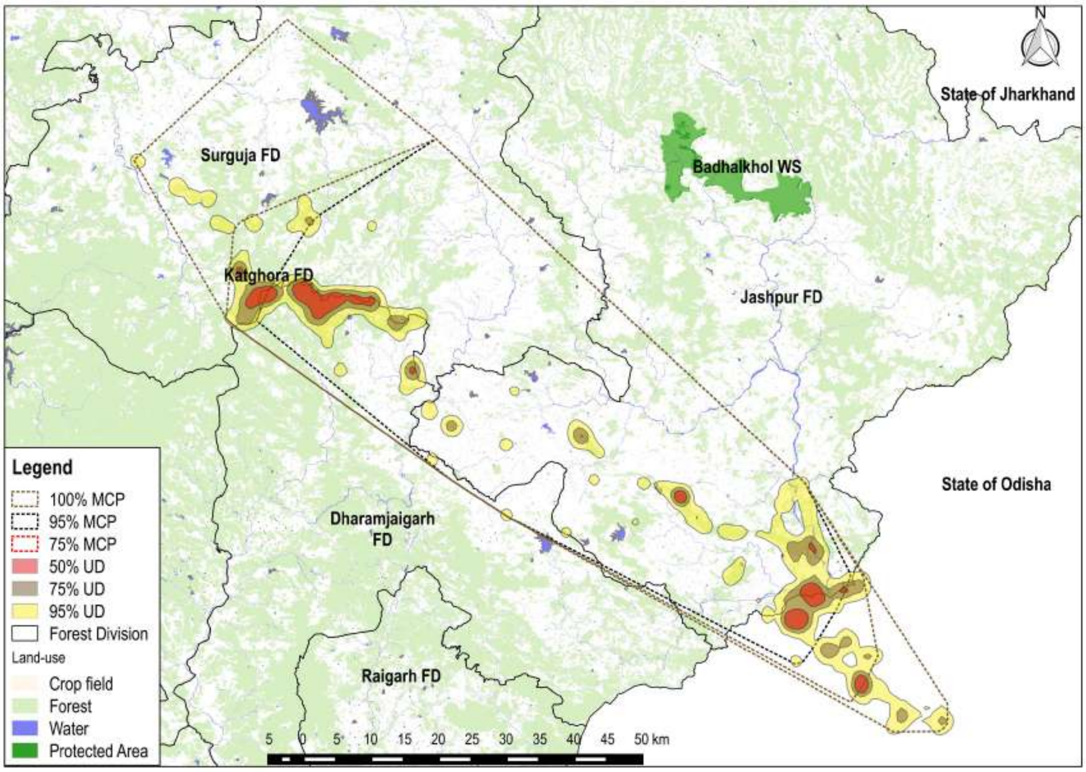


Fig-5.5: Home range distribution of elephant GI (adult cow)

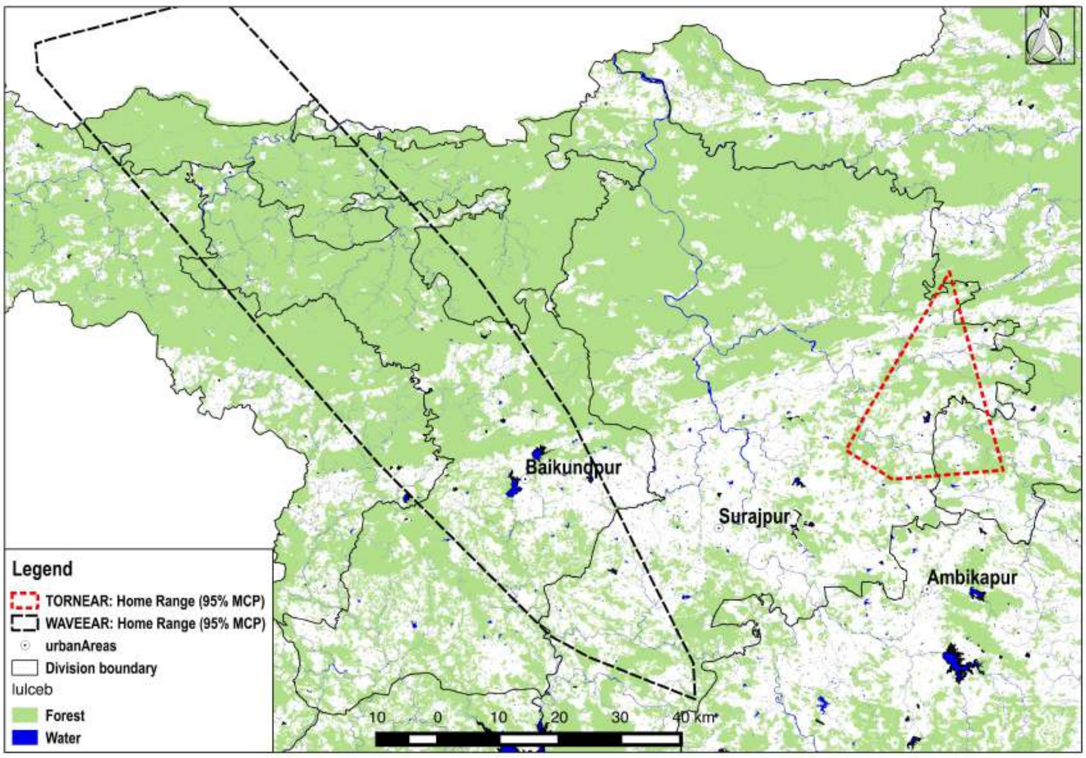


Fig-5.6: Home range distribution (only 100% MCP) of WE and TE herds calculated using "re-sighting" method. Both WE and TE were adult cows

5.3.2 Spatial description of elephant home ranges

The older adult bull *makhna* BD's home range (95% MCP) included 3 Forest Divisions namely Surajpur, Balrampur, and Surguja and also two protected areas namely Tamor Pingla and Semarsot Wildlife Sanctuaries (Fig-5.1 & 5.2). For the latter, only the fringe of the sanctuary was used and the bull did not go into Semarsot wildlife sanctuary. The intensive use area (50% UD isopleth) of the bull was limited to Rajpur range (of Balrampur FD), and parts of Surajpur, Pratappur and Gui forest ranges of Surajpur FD.

The younger adult bull GN's home range (95% MCP) included 4 Forest Divisions namely Raigarh, Dharamjaigarh, Korba, and Katghora Forest Divisions (Fig-5.3). The bull also exhibited "streaking behaviour" [long-distance linear movements with considerable speed as described by Douglas-Hamilton et al (2005)] and traversed to Madhya Pradesh via Marwahi Forest Division (near Achanakmar Tiger Reserve). The latter division was not part of its usual range though. The bull did not use any of the protected areas. Its range also included a part of Sundargarh Forest Division in the state of Odisha. The intensive use area (50% UD isopleth) of the bull was limited to Dharamjaigarh and Chaal forest ranges in Dharamjaigarh FD, Raigarh range of Raigarh Forest Division; Kudumura and Kartala forest ranges in Korba Forest Division.

The younger adult bull PY's home range (95% MCP) included 4 Forest Divisions namely Surajpur, Surguja, Balrampur and Jashpur (Fig-5.4). The bull had also used Tamor Pingla wildlife sanctuary frequently and the fringes of Semarsot wildlife sanctuary. Similar to GN, this bull too exhibited streaking behaviour during *musth* and traversed into Jashpur Forest Division for a few days and returned back to

Surajpur Forest Division. The intensive use area (50% UD isopleth) of the bull was limited to Surajpur and Pratappur ranges of Surajpur Forest Division, Lundra range of Surguja Forest Division and Tamor Pingla wildlife sanctuary.

The younger cow elephant GI's home range (95% MCP) included Surguja, Dharamjaigarh, and Jashpur Forest Divisions in Chhattisgarh, and Sundargarh Forest Division in Odisha (Fig-5.5). The cowherd did not use any of the protected areas. The intensive use area (50% UD isopleth) of the cowherd was limited to Mainpat and Lakhanpur ranges in Surguja Forest Division, Boro range of Dharamjaigarh Forest Division, Pathalgaon range of Jashpur Forest Division and Sundargarh Forest Division in Odisha. The number of elephants in the group was observed to be highly variable. During dry season, when the herd is confined to forested slopes of Surguja and Dharamjaigarh FDs, the number of individuals was observed to range from 9 to 14 individuals. However, during monsoon and winter ranges, the number of individuals in the herd went up to 40.

The herd WE ranged mostly in Surajpur and Balrampur Forest Divisions. During monsoon months, the herd occurred mostly in the forested hills of Gui range in Surajpur FD and Tamor Pingla Wildlife Sanctuary, seldom occurring in human–use areas (Fig-5.6). During late monsoon months and the whole of winter extending to dry season, the herd occurs in Surajpur and Pratappur forest ranges in Surajpur Forest Division and Rajpur range in Balrampur Forest Division. As was the case with GI, the number of individual elephants in WE herd was highly variable (observed range: 6 – 72) indicating significant fission and fusion in the herd. Numerous sub-adult males were observed associating with the herd particularly when the overall number of elephants increased owing to fusion of herds. The herd TE (described later) was observed to intermingle with the WE herd during the winter months.

The herd TE had the largest home range in Chhattisgarh. The herd ranged in Sanjay Tiger Reserve in Madhya Pradesh and Guru Ghasidas National Park in Chhattisgarh (Fig-5.6). The herd also ranged in Koriya, Surguja, Surajpur, and Balrampur Forest Divisions in Chhattisgarh. During winter, the herd intermingled with WE herd and ranged in Surajpur and Balrampur Forest Divisions. The observed number of individuals in the herd varied significantly. Before its fusion with WE herd, the number of individuals in the TE herd ranged from 7 to 14.

5.3.3 Home range stabilization

The cumulative home ranges have been estimated across months using both 95% and 100% MCP and plotted sequentially against tracking duration (Fig-5.7 & Fig-5.8). Generally, for calculating cumulative home ranges, 100% MCP is used. We have used both 100% and 95% MCP estimates as the latter could provide details on major fluxes in cumulative home ranges. With 100% MCP, such fluxes cannot be determined. From Fig-5.7, it is evident that the bulls GN and PY had spike in their home ranges for some months due to streaking behaviour. Such long-distance movements could significantly inflate MCP home ranges.

In general, the time-area curve as depicted in Fig-5.8 indicates that other than BD1 and BD2 (both pertain to the same bull tracked during different periods), the home ranges of other elephants are yet to be wholly defined.

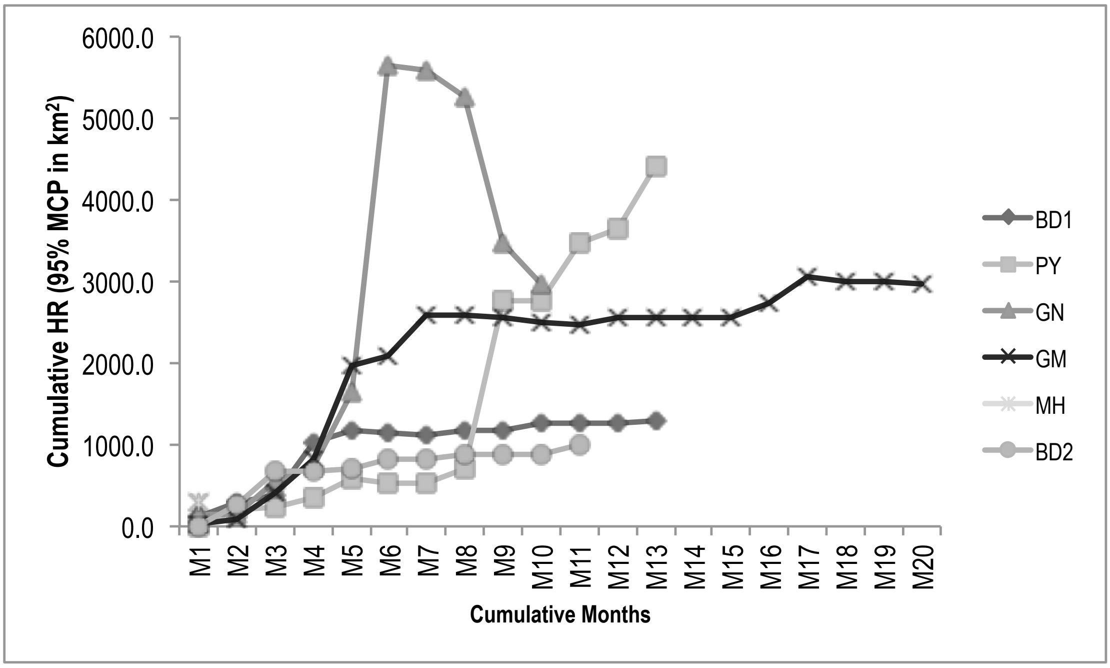


Fig-5.7: Time-area curve indicating cumulative increase in home ranges (95% MCP) of elephants satellite collared in northern Chhattisgarh

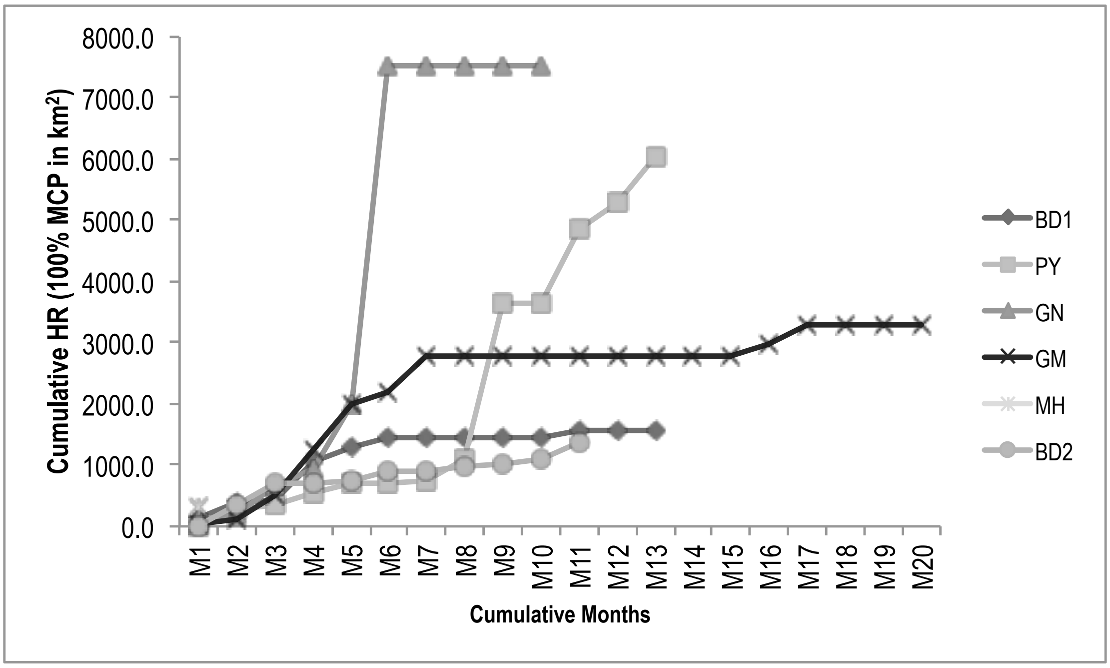


Fig-5.8: Time-area curve indicating cumulative increase in home ranges (100% MCP) of elephants satellite collared

5.3.4 Monthly and seasonal range areas

5.3.4.1 Mean monthly range areas

The average monthly range areas of the collared elephants were 57.9 (SD ± 48.1), 129.9 (SD ± 101.4), 138.4 (SD ± 248.5), and 37.5 (± 46.0) for BD (older bull), PY (young bull), GN (young bull) and GI (young cow in a herd) respectively (Fig-5.9). From Fig-5.9, it is evident that the average monthly range areas of the larger bull BD are lesser than that of the two of the younger bulls PY and GN. The monthly range areas of the young bulls PY and GN were strikingly similar although they occurred in spatially separate areas.

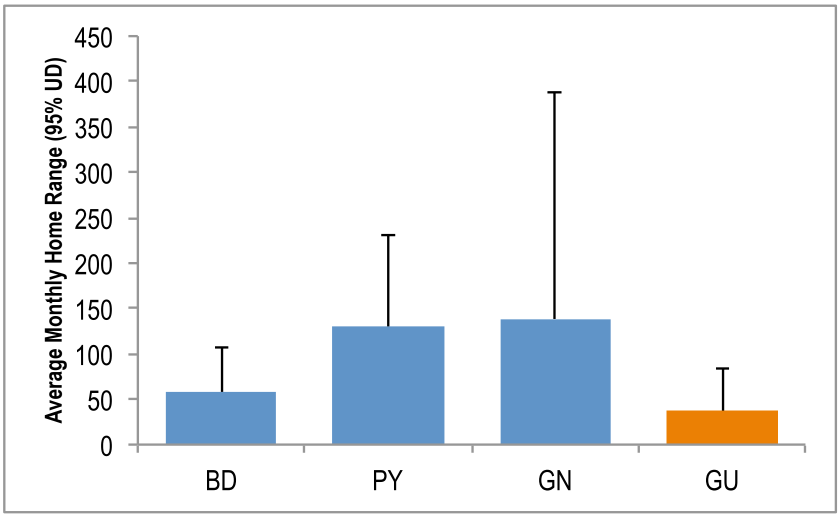
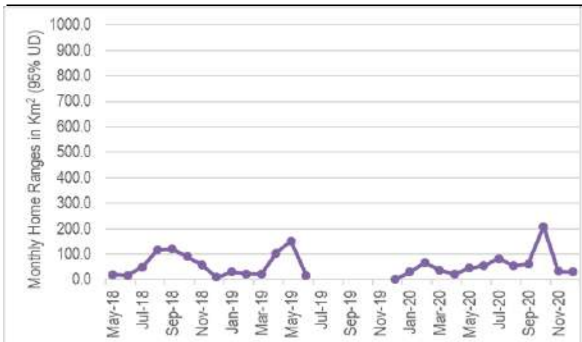


Fig-5.9: Average monthly home ranges (95% UD) of elephants collared in Chhattisgarh. Blue bars: Bull elephant, Orange bar: Cow elephant



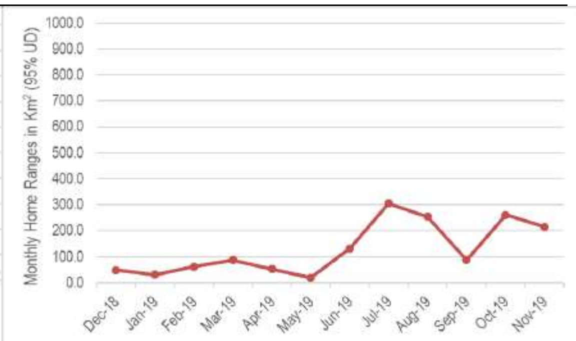


Fig-5.10: Monthly home ranges (95% UD) of BD (including re-collar) (27 months)	Fig-5.11: Monthly home ranges (95% UD) of PY (12 months)

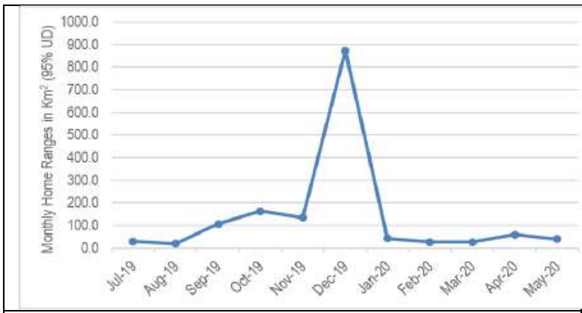
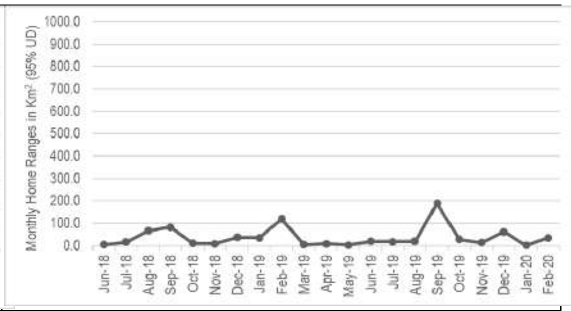
	

Fig-5.12: Monthly home ranges (95% UD) of GN (10 months)	**Fig-5.13: Monthly home ranges (95% UD) of GI (21 months)**

5.3.4.2 Variation in monthly range areas and its determinants

The range areas across months did show considerable variation for all the four collared elephants (Fig-5.10 to 5.13). The monthly variations (as interpreted from the monthly standard deviations) were higher for the young bull GN owing to "streaking behaviour" (Douglas-Hamilton et al., 2005) exhibited by the bull during December 2019 that involved long-distance back and forth movement into Madhya Pradesh along with a female herd of elephants.

Table-5.4: Summary of model selection to assess variations in monthly home ranges of elephants collared and monitored in northern Chhattisgarh during May 2018 to December 2020

Model	AIC	DAIC	R^2	*P*
monthlyHR(UD) ~ individual	876.84	0	0.13	0.03
monthlyHR(UD) ~ gender	878.73	1.89	0.05	0.06
monthlyHR(UD) ~ 1	880.18	3.34	NA	NA
monthlyHR(UD) ~ musthStatus	881.30	4.46	0.01	0.35

monthlyHR: monthly elephant home ranges

Among the three variables modelled to explain variations in monthly range areas (Table-5.4), the effect of individuals (idiosyncrasy of each individual elephant) emerged significant ($P = 0.03$). The monthly home range of the adult bull *makhna* BD was larger than cow herd Gautami [β =-20.5(SE ± 32.5), CI = -85.2 – 44.4], but relatively smaller than that of the young bulls Ganesh [β = 80.5 (SE ± 39.9), CI = -0.8

– 160.1] and Pyare [β = 71.9 (SE ± 38.7), CI = -5.4 – 149.1]. The other chosen variables of gender and *musth* status were only weakly informative in explaining the monthly variations in the elephant range areas.

5.3.5 Seasonal home ranges

The year was divided into three seasons namely '*dry*' (March – June), '*monsoon*' (July – September) and '*winter*' (October – February) and range areas (measured as 95% UD) were calculated for all the three seasons for the satellite-collared elephants (Table-5.5). The dry season ranges of elephants were significantly lower than ranges during the monsoon and winter seasons (KW chi-squared = 6.02, df = 2, P = 0.04). The dry season range is only about 28.8% (SD±22.05%) of the annual ranges for all the elephants collared and monitored. For the cow elephant GI, the dry season range of 25.5 km^2 is just 5% of its annual range. The monsoon and winter ranges of elephants are comparatively much higher (Table-5.5).

Table 5.5: Seasonal range size estimates (95% UD) for satellite collared elephants in northern Chhattisgarh (only for elephants with longer tracking duration)

S.No	Elephant ID	Home Range (95% UD) in km^2	Range size (95% UD) in km^2		
			Dry	Monsoon	Winter
1	BD1	281.7	95.5	135.4	215.1
2	BD2	246.3	156.4	275.2	159.6
3	GN	748.9	151.4	132.3	931.0*
4	GI	605.3	25.5	291.1	275.0
5	PY	662.9	149.6	626.8	377.0

*Since this is a 95% cumulative UD, outliers will be removed across seasons. Thus, when number of months increase, outliers considered during earlier months' home range estimation would be removed.

5.3.6 Seasonal range overlap

The seasonal extent of overlap of range areas is provided in Table-5.6. For the older big bull (BD), the seasonal range overlap was over 50% for all the seasons. For the younger adult bulls GN and PY, the average overlap was less than 18% for all seasons. For the adult cow GI from the herd, the overlap was 17.9% for monsoon and winter ranges and 6.4% for monsoon and dry season ranges. The range areas of the cow GI were completely different for dry and winter seasons.

Table 5.6: Seasonal range overlap (estimated based on 95% MCP) of satellite collared elephants in northern Chhattisgarh

S.No	Elephant ID	MW	MD	DW
1	BD1	44.9%	38.3%	46.9%
2	BD2	56.8%	69.0%	68.6%
3	GN	9.9%	25.2%	9.4%
4	GI	17.9%	6.4%	0%
5	PY	20.7%	8.1%	26.5%
	Average	**30.04%**	**29.4%**	**30.2%**

MW: Monsoon/Winter, MD: Monsoon/Dry, DW: Dry/Winter

5.3.7 Inter-annual variations in home ranges

The inter-annual comparison in home ranges was made for two of the collared elephants for which data was available for two different years. For the elephant BD (adult bull *makhna*, > 40 years), the overlap in ranges for the period 2018-2019 and 2019-2020 was 73.5%. For the female herd GI, the overlap in ranges for the period 2018-2019 and 2019-2020 was 56.5%.

5.4 Discussion

Using both telemetry and re-sighting-based approaches, elephant home ranges were estimated for five bulls and three female herds in Chhattisgarh during the period May 2018– December 2020. The results and discussions presented in the thesis pertain to this period only. The WII continued the study beyond December 2020 as well and continued to monitor collared elephants besides collaring additional individuals.

5.4.1 Elephant home ranges in Chhattisgarh

The home ranges estimated in the study using MCP approach were higher than Kernel UD estimates. On an average, the (95%) Kernel UD estimates were less than 22% of the (95%) MCP estimates. This indicates that a large fraction of areas within MCP home ranges were unused by elephants. In fragmented landscapes, animal home ranges would encompass patches embedded in unused areas resulting in inflated MCP home ranges (Powell and Mitchell, 2012). While 95% Kernel UD estimates may reflect the actual range area of elephants, the areas outside of intensive habitat use that elephants use for crop foraging and movement between patches may not reflect in the UD ranges. Therefore, from management point of view, understanding both MCP and UD ranges would be useful, as MCP can be viewed as the geographic space in which animals occur, and the UD ranges represent use of habitats within the geographic space (Moorter et al., 2016).

The elephant ranges in Chhattisgarh often encompass multiple Forest Divisions and Protected Areas and also span across neighbouring states. The home range estimates (95% MCP) of elephants in Chhattisgarh were in general higher than elephant home ranges reported from other landscapes (Table-5.7). I would urge caution in interpreting elephant home range comparisons across landscapes. The home range comparisons often do not account for terrain complexities. A relatively small 2-dimensional elephant home range in the hilly region may actually be comparable with a larger home range in the flatter region. Therefore, spatial distribution of home ranges that includes the underlying terrain factors, habitat quality including productivity, and competition (both intra-specific and inter-specific) may determine the extent of elephant home ranges (Sukumar, 2003). As elephant home ranges in Chhattisgarh are distributed in the mosaic of forest patches embedded in agricultural areas, they are predictably large. Elephant home ranges being large in Chhattisgarh corroborates with the findings of other studies from fragmented landscapes (Sukumar et al., 2003; Singh, 2006).

Table-5.7: Estimated elephant home ranges (using either 95% or 100% MCP) from different landscapes across India

S.No	Landscape	Sex	Home Range (in Km^2)	Method	Fragmentation	Source
1	Buxa, North Bengal	Female	696	Telemetry	High	(Sukumar et al., 2003)
2		Female	293			
3		Female	701			
4		Female	695			
5		Bull	180			
6		Bull	179			
7		Bull	444			
8	Rajaji, Uttarakhand	Bull	407	Telemetry	Low	(Williams, 2005)
9		Bull	188			
10		Bull	254			
11		Female	183			
12		Female	326			
13		Female	306			
14		Female	251			
15	BR Hills / Sathyamangalam	Female	240	Re-sighting	Low	(Sukumar, 1985)
16		Female	250			
17		Bull	320			
18		Bull	170			
19		Bull	215			
20	Mudumalai, Western Ghats, TN	Female	232	Telemetry	Low	(Desai, 1991)
21		Female	111			
22		Female	265			
23		Bull	199			
24		Bull	243			
25		Bull	168			

S.No	Landscape	Sex	Home Range (in Km^2)	Method	Fragmentation	Source
26	South Bengal	Female	3368	Re-sighting	High	(Singh, 2006)
27	Mudumalai, Western Ghats, TN	Female	464	Telemetry	Low	(Baskaran and Desai, 1996)
28		Female	382			
29		Female	288			
30	Hosur, Eastern Ghats, TN	Female	302	Re-sighting	Low	(Kumar, 1994)
31		Female	224			
32		Bull	876			

5.4.2 Shift in home range across years

Repeated use of the same areas is known to confer fitness benefits to animals owing to familiarity of areas, knowledge about microhabitats, and threats. Such recurrent use of areas will eventually result in consistent home ranges as animals begin to obtain and store cognitive maps of the landscape. Thus, animals tend to exhibit fidelity to home ranges (Powell, 2000; Powell and Mitchell, 2012). Conversely, fidelity to areas can be used to infer animal home ranges. The function of spatial memory helps in keeping home ranges intact (Fagan et al., 2013; Moorter et al., 2016, 2009; Ranc et al., 2020). Elephants – both African and Asian exhibit considerable fidelity to their home ranges (Baskaran, 1998; Goldenberg et al., 2018; Kumar, 1994). However, elephants may alter movement and shift ranges in response to novel pressures. For example, in Samburu, East Africa, loss of adult females in the clans led to major range shifts (Goldenberg et al., 2018). Range shifts or unstable home ranges often manifest through drifts (if the shift is gradual) or displacements (if the shift is drastic) away from previously used areas (Moorter et al., 2009). In Chhattisgarh, time-area curve of home ranges plotted against months indicates that other than the older bull BD, the home ranges of other individuals remain relatively less defined. The inter-annual shift in home ranges was minimal for BD, but high for the herd GI (inter-annual home range comparisons were not possible for other elephants due to inadequate data). Thus, longitudinal monitoring of elephants would be required to confirm if the observed range areas are indeed set elephant home ranges. The synergistic effects of elephant home ranges being distributed in fragmented habitats, and range shifts caused by exploratory behaviour make elephant home ranges in Chhattisgarh as one of the largest amongst those estimated in India across other landscapes (Table-5.7).

The "optimal foraging theory" in ecology (Sutherland, 1983) could potentially explain elephant movement patterns, home range and habitat use in relatively intact, but limited habitats (where not much of empty niches are left to be exploited). However, in "unlimited habitats" (large extents of fundamental niches that can be exploited), elephant space use may follow the predictions of the theory of "ideal free distribution" (IFD). IFD theory predicts that animals are free to move between patches to maximize their fitness benefits (Fretwell and Lucas, 1970). In northern Chhattisgarh, elephant range is expanding in patchwork of forests embedded in agricultural lands and inter-patch movement doesn't seem a constraint – at least in the present. Elephants as such have evolved high mobility, which in combination with behavioural plasticity in patch selection (Chapter-6) is facilitating their range expansion in Chhattisgarh. Whether elephants accrue long-term fitness benefits from such range expansion as indicated by IFD remains to be tested and seems unlikely as well. However, the range expansion observed in Chhattisgarh presents the most overriding management challenge.

5.4.3 Monthly and seasonal home ranges

The monthly ranges (as measured in 95% UD) were relatively smaller for the older adult bull BD and the female herd GI, but considerably larger for the young bulls GN and PY. The observed monthly variations in range use were best explained by individual idiosyncrasies, which possibly override the effect of other variables like gender and even *musth* status in bulls. In a comparatively larger population of elephants, the dominant bulls in *musth* may exhibit 'roving strategy' of traversing long in search of potential mates across different clans (Baskaran, 1998; Keerthipriya et al., 2020). Consequently, the *musth* range of bulls tends to be very large compared to their non-*musth* ranges (Joshua and Johnsingh, 1995). In Chhattisgarh, there are few female herds as the overall population itself is small. The older and dominant adult bull BD came into *musth* precisely during the first week of August during 2018, 2019 and 2020. The bull remained in *musth* for three months, till November. This period coincides with fusion of herds in Surajpur and Balrampur districts when paddy starts ripening. Observations show that BD associates with the large herd during this period. More samples from across different landscapes would be required to confirm if large and dominant bulls time their *musth* during clan congregations so as to maximize mating opportunities with minimal cost of traversing. The younger bulls GN and PY had a shorter duration of *musth* lasting about a month. The bull PY exhibited 'streaking behaviour' during *musth* and traversed extensively moving from Surajpur division to Jashpur division closer to Jharkhand border. PY's *musth* was recorded during November during 2018 and 2019 when groups started getting relatively smaller. The bull GN's *musth* was recorded during the month of August during 2018 and 2019. Its association with the herds during *musth* was not recorded during the study.

With respect to seasonal range areas, the dry season ranges of elephants were significantly lower than the monsoon and winter ranges. For the female herd GI, the dry season range was just 5% of its overall home range. During dry season, the herd comprising about 9 – 14 elephants remained in 25-km^2 of forested habitat along the slopes of Mainpat in Surguja and Dharamjaigarh forest divisions. These slopes drop down from the Mainpat plateau and support luxuriant vegetation including several species of browse plants and perennial springs flowing down from the plateau even during dry season. This indicates that habitat quality in some of the forest patches – particularly those that are large and contiguous with minimal of human interference can potentially support elephants in the landscape. Thus, dry season ranges of elephants could serve as a surrogate for habitat quality (Sukumar, 2003, 1989). Habitat management efforts in Chhattisgarh can benefit from understanding habitat quality – in terms of fodder and water resources in GI's dry season range. The advent of monsoon and subsequent winter seasons mark the availability of standing crops in the landscape. During monsoon and winter months, elephants range areas measure over 50% of their annual range as crop foraging in Chhattisgarh is widely scattered and not concentrated to few sites (Chapter-7).

With respect to seasonal overlap in home ranges, for the adult bull *makhna* BD, there was high overlap in range areas across the three seasons. This was not the case with the younger bulls (GN and PY) and for the female herd GI. For the female herd GI, there was an exclusive dry season range. Exclusive seasonal ranges have been observed in elephants occurring in habitats that exhibit high seasonal variations in resource availability (Baskaran, 1998). In landscapes where elephants have included significant human–use areas in their home ranges the natural season-induced resource pressures may be negated by access to food and water in agricultural fields.

This is probably the case with BD that occurs in human–dominated areas almost throughout the year with minimal of seasonal variations in the home range distribution.

5.4.4 Use of corridors by elephants

Identifying and restoring corridors is often a cornerstone in conservation of wildlife populations in highly fragmented habitats. Corridors may facilitate daily and seasonal migrations and also periodic dispersal of animals to maintain population and genetic connectivity. Corridors are easy to identify within landscapes where the difference between habitat and non-habitat is clear (Johnsingh et al., 2006; Menon, 2017). However, in areas where the difference between habitat and non-habitat is diffuse, as is the case in northern Chhattisgarh, identifying corridors can be challenging. Here the elephant landscape is a hinterland of forest patches interspersed with settlements and agriculture. Stark differences in the overall structure as well levels of human occurrence between forests and non-forests do not exist in the rural areas, as agriculture is still highly marginal and seasonal in most areas. Thus, the landscape appears to offer minimal resistance for elephants to move, especially in the cover of the night. There are numerous forest patches, scrubland, forest plantations and uncultivated fallow lands that could serve as daytime habitats for elephants. Night-light in the landscape continues to be minimal compared to many other states in the country, which are more economically developed. These conditions may facilitate free movement of elephants in Chhattisgarh. To illustrate, the GI herd's movement trajectory (both onward and return) from Dharamjagarh FD to Sundargarh FD in Odisha did not follow the identified structural corridor, but followed a different route outside of forests through crop fields. Thus, defining and maintaining elephant corridors in Chhattisgarh would require a data-driven approach (Vasudev et al., 2021) but also be extremely challenging in terms of management. It must be remembered that "corridors" should not serve to perpetuate elephant-human conflicts.

Box-1: The status of the elephants monitored during 2017-2020

1. The elephant GN (adult tusker) collared during July 2019 and monitored till May 2020 with collar was electrocuted on 18/06/2020 in Behramar, Chaal range of Dharamjaigarh Forest Division, Chhattisgarh. The bull was electrocuted in a settlement in a illegally tapped direct power supply. Two monthly prior to its electrocution, the bull's collar ripped off during May 2020 due to weak belting.

2. The bull MH (adult tusker) collared during May 2019 and monitored for a short duration of two weeks was found dead during May 2020 inside the forests. The carcass was putrefied and thus, the exact cause of its death was not ascertained. Because the bull was dead far from the village, electrocution was ruled out.

3. The female herd WE's matriarch CGF003 was found dead near a water hole in Ganeshpur beat of Pratappur range of Surajpur Forest Division on 10/06/2020. The exact cause of death was not ascertained. However, during the period (June 2020), there were series of elephant deaths in Chhattisgarh indicating a possibility of local disease outbreak. At the time of the death of CGF003, local authorities suspected deliberate poisoning as one of the possible reasons of death.

4. Another identified old female of WE group CGF004 was found dead in Ganeshpur beat of Pratappur range of Surajpur Forest Division on 09/06/2020. The cow had a well-developed fetus. As was the case with CGF003, the exact cause of the death was not established. Opinions varied between deliberate poisoning and disease outbreak.

5. During the period 2018-2020, the death of a few juvenile elephants and also adult cows were recorded due to both natural and unnatural causes.

5.4.5 Elephant dispersal patterns

In most large mammals, females are philopatric, and are concerned with securing resources and ensuring offspring safety, while males disperse to maximize their reproductive fitness (Greenwood, 1980). Contrarily, 'environmental dispersals' can occur due to resource saturation and mediated by density dependent mechanisms (Sinclair et al., 2006). For the past few decades, elephants in the East-central region have been faced with deteriorating habitat conditions as cautioned by many authors (Singh et al., 2002; Singh, 2002; Singh and Chowdhury, 1999). This apparently had triggered major redistribution of elephants across the entire East-central region marked by frequent immigrations or dispersals. In general, the dispersal distance of mammals is related to its home range size (Bowman et al., 2002). The larger the home range, the greater the distance dispersed (Bowman et al., 2002). Thus, the observed large home ranges are one of the major reasons for long-distance dispersal of elephants in Chhattisgarh. During the period of study, a few such long-distance dispersals were anecdotally recorded. Some of them include:

i. During September 2018, a herd of elephants dispersed into Bandavgarh tiger reserve (BTR) in Madhya Pradesh from Chhattisgarh. Among the elephants that dispersed, 8 individuals photo-captured earlier in Korba, Koriya, Katghora and Dharamjaigarh forest divisions in Chhattisgarh. As on April 2022, the herd still occurs in and around BTR.
ii. During August 2018, a herd of five elephants that were earlier identified from Surguja FD dispersed into buffer zone of Sanjay tiger reserve in Madhya Pradesh. This herd comprised of an adult cow, sub-adult cow, two sub-adult bulls and a juvenile bull. Owing to conflict reasons, the Madhya Pradesh

forest department captured all the five individuals and housed them in captivity. The juvenile bull died immediately after the capture.

iii. During the year 2020, two young bulls reportedly from Odisha dispersed into Mahasamund in Chhattisgarh and then onwards traversed widely covering the forest divisions of Rajnandgaon, Dhamtari, and Gariyaband in Chhattisgarh, Gondia district in Maharashtra and reached Kanha tiger reserve, Madhya Pradesh. One of the two bulls was electrocuted in Balaghat district of Madhya Pradesh and the other bull was captured and moved to captivity by Madhya Pradesh forest department.

iv. During August 2018, an adult cow and a sub-adult bull photocaptured in Surguja Forest Division dispersed into Korba Forest Division. The sub-adult bull was electrocuted.

v. Wildlife-SOS had collared a female elephant from a herd of 22 elephants during September 2018 in Mahasamund forest division, Chhattisgarh. (I was also part of the collaring operations). This herd dispersed into Gadchiroli forest division in Maharashtra (Swaminathan et al., 2021).

Other similar unrecorded elephant dispersal events in the landscape were plausible. From the above, it is evident that many elephant immigration events ended-up as failed dispersals if the small-population paradigm (Channell and Lomolino, 2000) is invoked. Further to this, such dispersals also result in heightened human–elephant conflict. Therefore, monitoring elephant dispersals would be critical in the landscape.

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CHAPTER-6

PATCH USE AND HABITAT SELECTION BY ELEPHANTS

6.1 Introduction

Asian elephants have evolved physiological and behavioural adaptations to occur in a wide spectrum of tropical habitats ranging from arid-scrub to moist evergreen forests (Desai, 1991; Sukumar, 2003). The tropical forested habitats of Asian elephants undergo seasonal fluxes in the resource distribution (Natarajan et al., 2016). For example, in the deciduous forests, the nutritive value including crude protein content and palatability of edible grasses increase during rains, and decrease thereafter (Ahrestani et al., 2012; Sukumar, 1989). Similarly, seasonal fruits that constitute an important part of elephant diet may be available only for a short period of time (Sekar and Sukumar, 2013; Sivaganesan, 1991). In the relatively drier tracts, surface water and pre-formed water sharply decline during dry season (Natarajan et al., 2016). These natural seasonal rhythms in resource availability drive differential use of habitats by elephants (Baskaran, 1998; Natarajan et al., 2016; Sukumar, 1989). In addition to environmental, biotic influences like inter-clan dominance hierarchies and resultant competition can result in differential habitat selection by elephants (Desai, 1991). Furthermore, in addition to natural factors, human impacts on the habitat can exert an overriding influence in determining spatial distribution of elephants (Desai and Baskaran, 1996).

Elephant–habitat interactions have been extensively researched in Asia as the topic is of immediate relevance for the management (Desai and Baskaran, 1996; Jathanna et al., 2015; Natarajan et al., 2016; Sivaganesan, 1991; Sukumar, 1989;

Williams, 2005). From these studies, general patterns and major determinants of elephant habitat selection can be inferred. Nonetheless, site-specific information is often acknowledged to be crucial to better understand and manage elephant habitats particularly in light of elephants' behavioural plasticity that can override generalist predictions. Wildlife–habitat relationships can be examined at different spatial and temporal scales (Morrison et al., 2012). Among the host of metrics used in assessing wildlife–habitat relationships, habitat selection is one of the most widely used. Habitat selection by animals is a hierarchical process that involves behavioural decision-making aimed at increasing fitness benefits (Krausman, undated manuscript). Habitat selection can be assessed using several approaches that collectively compare habitat-use by animals with resources available for them (Manly et al., 2002). Johnson (1980) provided a framework elucidating "four orders of selection" based on hierarchical classification to study habitat selection. The four orders include the first-order selection is defined as selection of geographic range among the available options, the second order is defined as selection of home ranges within the geographic range, the third order is defined as habitat-use within home ranges, and the fourth order pertains to selection of micro-habitats at finer spatial scales (Johnson, 1980).

The chapters 4 & 5 of the thesis have already dealt with first order and second order habitat selection by elephants in Chhattisgarh. In this chapter, I examine the third order habitat selection by assessing resources within the elephant home ranges. Akin to the clarity provided by Johnson (1980) on the orders of habitat selection, Thomas and Taylor (1990) suggested three sampling designs relevant for assessing wildlife–habitat relationships. Among the three sampling designs, under design III, use of habitat within home ranges is compared with the availability of resource units within habitats (Manly et al., 2002). Using this framework, the aim of this chapter is to assess patterns of habitat selection by elephants in northern Chhattisgarh. Additionally, habitat-use by elephants across different seasons has been assessed and implications for management were discussed.

6.2 Methods

Seven elephants were immobilized and fitted with GPS satellite collars programmed to provide location fixes at one-hour interval (elaborated in Chapter-5). The collared elephants were monitored during the period May 2018 to December 2020, for different durations. This includes a bull that was collared twice as the collar deployed initially fell off. Among the seven collared elephants, only five elephants provided data for longer duration (>250 days), for which home ranges were estimated (elaborated in Chapter-5). Among the five elephants, GI (adult cow) is a female herd and the others (BD1, BD2, PY and GN) were all bulls.

Home ranges were estimated using both MCP and Kernel UD approaches. By combining the 100% MCP areas of five satellite collared elephants BD1, BD2, GN, GI and PY, the sampling measuring 18,194-km^2 frame was created in GIS. Within the sampling frame, 1-km^2 grids that serve as spatial sampling units, were overlaid. The grid size selection was based on the combined potential impact of the environmental variables, which were readily available at 1-km^2 resolutions. Habitat selection by elephants was assessed following "use" vs "availability" approach. The collar GPS fixes falling within the grid indicate "use". The extent of environmental variables used in the models indicates "availability". The environmental variables used in the models included (1) extent of open forest in the grid (2) extent of moderately dense forest in the grid (3) extent of very dense forest in the grid and, (4) extent of rivers in the grid. The variables open forest; moderately dense forest and very dense forest were extracted from the forest cover layer of the Forest Survey of India available at 30-m resolution (FSI, 2019).

In addition to habitat selection by elephants, the proportional use of forest, crop fields and other habitats was descriptively evaluated across three different seasons. The seasons included dry (March to June), monsoon (July to September) and winter (October to February). The variables of forest cover, agriculture, still water, rivers, urban and rural built-up were extracted from 10-m resolution land-use land-cover layer developed by NRSC–IIRS, Nagpur for northern Chhattisgarh.

Habitat selection by elephants was assessed using generalized linear models (GLM) by quantifying the influence of potential explanatory variables on the response variable. The response variable in the models, the number of GPS location fixes in each grid was assumed to follow a Poisson distribution (Bolker, 2008). However, because elephant MCP home ranges encompassed areas that elephants did not use, there were many zero entries that caused over-dispersion of the counts in the response variable. Over-dispersion in the response variable is a violation of assumptions of Poisson distribution that assumes population mean equivalent to its variance. Therefore, I used negative binomial regression that accounts for over-dispersion of counts during the modelling process itself. Model selection was done based on information-theoretic approaches by comparing plausible models with intercept-only models (Burnham and Anderson, 2002). The variable significance and ranking were done using P-values (indicating significance) and *Z* scores of each variable, wherein higher relative scores indicate better explanatory power of the variable. The regression analysis was carried out in program R (R Core Team, 2019) using the package MASS (Venables and Ripley, 2002).

6.3 Results

6.3.1 Seasonal habitat-use patterns

During dry season (March to June), elephants have spent an average of 81.2% (±10.6) of their time in the forests, while 14.1 %(±8.5) of time was spent in the crop fields and about 4.7% (±3.1) of time was spent in other areas. The other areas indicate rivers and streams, water holes and vicinity of settlements. Unlike the bulls, the female herd of GI spent the dry season completely within forests, seldom venturing into human–use areas (Table-6.1). This pattern was observed for the family herd of GI for two years of 2019 and 2020.

During monsoon (July to September), elephants have spent an average of 79.9% (±3.7) of time in the forests and about 16% (±3.2) of time in the crop fields. Even the female herd of GI, spent about 13.6% of time in the crop fields unlike the dry season (Table-6.1). During the winter months (October to February), the time elephants spent in the crop fields were highest at 19.1% (±5.5). Concurrent elephant use of forests was about 76% (±5.3), which was comparatively lesser than the dry and monsoon months. Similar to monsoon, the GI herd spent about 13.8% of time in the crop fields (Table-6.1).

Table-6.1: Seasonal use of forests, crop fields and other habitats by satellite collared elephants in Chhattisgarh during May 2018 to December 2020.

EleID	Forest (in %)			Agriculture (in %)			Others (in %)		
	Dry	Mon	Win	Dry	Mon	Win	Dry	Mon	Win
BD1	74.8	79.2	69.6	20.7	18.0	26.2	4.5	2.8	4.2
BD2	76.8	84.0	78.0	19.6	11.5	19.0	3.6	4.5	3.0
PY	73.2	78.2	71.2	18.6	17.7	22.9	8.2	4.1	5.9
GN	81.7	75.0	79.6	11.2	19.0	13.7	7.1	6.0	6.7
GI (cow)	99.2	83.2	81.9	0.5	13.6	13.8	0.3	3.2	4.3
Average (± SD)	**81.2 (10.6)**	**79.9 (3.7)**	**76.0 (5.3)**	**14.1 (8.5)**	**16.0 (3.2)**	**19.1 (5.5)**	**4.7 (3.1)**	**4.1 (1.3)**	**4.8 (1.4)**

Dry: Dry season (March – June) Mon: Monsoon (July – September), Win: Winter (October – February)

6.3.2. Habitat selection patterns

Within their home ranges, elephants predominantly selected forested habitats over other major land-use forms like agricultural crop fields. The variable Rivers did not emerge significant in explaining the observed variations in elephant habitat selection (Table-6.2). Among the three categories of forests classified by Forest Survey of India (FSI, 2009), elephants selected open forests over moderately dense and very dense forests (Table-6.3).

Table-6.2: Summary of model selection results to explain habitat selection by elephants in Chhattisgarh using negative binomial regression

Model	AIC	DAIC
HabSel~MDF+OF+VDF+Riv	27611	0
HabSel~OF	27735	124
HabSel~VDF	27741	130
HabSel~MDF	27752	141
HabSel~1 (Intercept only)	27762	151
HabSel~Riv	27763	152

HabSel: Habitat selection by elephants. MDF: Moderately dense forests, OF: open forests, VDF: very dense forests, Riv: Rivers and streams

Table-6.3: Parameter estimates including those of forest types and rivers included in the negative binomial regression models to explain elephant habitat selection patterns

Variable	Estimate (±SE)	95% CI (lower & upper)	Z	*P*
Intercept	-0.08 (0.09)	-2.7 – 0.10	-0.92	0.35
Moderately dense forest	1.17 (0.13)	0.91 – 1.44	8.96	<0.001*
Open forest	2.29 (0.21)	1.85 – 2.73	10.60	<0.001*
Very dense forest	2.25 (0.27)	1.73 – 2.81	8.25	<0.001*
Rivers and streams	7.15 (1.98)	2.91 – 12.0	3.60	0.0003*

* indicates significant *P* values

6.4 Discussion

6.4.1. Seasonal habitat-use patterns

During all the three seasons of dry, monsoon, and winter, elephants have spent over 75% of time in the forests and about 14 – 19% of time in the crop fields. Exception to this was by GI herd, which spent the dry season almost entirely in the forests. In the tropical deciduous forests, dry season is characterized by low primary productivity and dried up surface water sources (Natarajan et al., 2016). Thus, the ability of the habitat to support elephants in such dry conditions should be an essential metric of assessing habitat quality. Sukumar (1985) opined that dry season habitat represents the 'best available habitat' for elephants. Therefore, the dry season range of GI herd may represent the best of habitats available for elephants in northern Chhattisgarh. Not only did elephants spent the entire dry season of about 4 months within forest without venturing into human-use areas, their body condition also did not show any drastic decline (Chapter-4). GI's dry season range was spread about 25.5 km^2 of mixed deciduous forests located along the Mainpat slopes in Surguja and Dharamjaigarh forest divisions (Chapter-5). Identifying habitats similar to that of GI's dry season range and improving habitat conditions in such habitats would be an important strategy to increase residence time of elephants inside the forests in Chhattisgarh. Unlike the GI herd, the bulls (BD1, BD2, PY and GN) spent considerable time in the crop fields even during dry season when standing crops were sparse in the landscape. This indicates that even if standing crops remain unavailable at the landscape-scale, bulls could still sneak in and forage on vegetables (like cucumber and water melon), pulses and grains grown in a small scale near the settlements.

In northern Chhattisgarh, the paddy (*Oryza sativa*) is sown after the onset of seasonal monsoon during June and July months. Paddy harvest is done during October – November. In Surguja, after paddy is harvested, the annual crop of sugarcane (*Saccharum officinarum*) attracts elephants (Chapter-7). Sugarcane harvest is usually completed by March after which the fields remain fallow till monsoon sets in. Thus, during monsoon and winter months, elephants start spending considerable time in the crop fields. Even the female herd GI spent over 13.5% of time in the crop fields during monsoon and winter months indicating that standing crops attract elephants regardless of inherent habitat quality of forest patches.

6.4.2 Landscape-level habitat selection

Overall, within their home ranges, elephants have predominantly selected forests over other land-use categories. This is intuitive as forests are the primary habitats of Asian elephants and use of other forms of land-uses in the environment would be conditional on availability of forest cover (Ram et al., 2021). The reports of elephants occurring in plantations, groves, and thickets of weeds in wetlands without any forest cover (eg Srinivasaiah et al., 2019) should thus represent exceptionally erratic and ephemeral scenarios. In the study area, elephants did not use urban areas and the industrial mining areas, as these are clearly non-habitats for elephants. Thus, elephants occasionally entering urban areas as had happened on few occasions in Surguja are clearly anomalous, and possibly a result of haphazard and unplanned elephant drive operations. While elephants avoided urban areas, they did occasionally use rural settlements sometimes damaging houses to raid stored grains resulting in acute human–elephant conflict.

In the combined MCP home ranges of the five collared elephants, the total extent of moderately dense, very dense and open forest was around 4783 km^2, 587

km^2 and 3153 km^2 respectively. Among these three broad forest types as classified by the FSI, elephants selected open forests more than the moderately dense and very dense forests. The 'open forests' as classified by the Forest Survey of India (FSI, 2019) are those with crown density ranging from 10 to 40%[5]. Particularly in Surguja, forest patches categorized as open forests are typically small, embedded in human-use areas, and are under continuous resource use by local communities in the form of fodder for livestock, fuel wood, and variety of non-timber forest products. Fragmentation and degradation of these forest patches occurred long since before even contemporary elephant use began. Thus, it is flawed to correlate current human–elephant conflict in Chhattisgarh with contemporary habitat conditions within the state.

Plate-6.1: Dense strands of Sal (*Shorea robusta*) coppice in Surajpur providing cover for elephants. A bull in musth is seen foraging in the Sal patch

[5] Forest Survey of India classifies forests of India into four major types based on crown cover namely 1) very dense forests (crown density > 70%), moderately dense forests (crown density 40 to 70%), open forests (crown density 10 to 40%) and scrub (crown density < 10%)

Plate-6.2: Herd of elephants resting in the Sal patch. Typical daytime scene inside forest patches. Few elephants can be seen lying down and few of the rest in standing position itself.

Unlike other landscapes where intact elephant habitats suffered fragmentation and degradation jeopardizing elephant populations (Puyravaud et al., 2019; Singh and Chowdhury, 1999), paradoxically, elephant range expansion in northern Chhattisgarh has been occurring in the mosaic of fragmented 'open forests' interspersed in human–use areas. Elephant selection of the relatively patchy open forests in human–dominated areas presents a conundrum that is critical to elucidate in light of human–elephant conflict. The 'open forests', as classified by FSI, although poor in the crown density, constitutes predominantly of strands of Sal (*Shorea robusta*) coppice interspersed with secondary vegetation comprising a few browse species for elephants (Annexure-1). This is particularly the case in Surguja region. Thus, the term 'open forests' may be a misnomer in the context of elephant management as they provide dense cover throughout the year. Given that the elephants extensively forage on cultivated crops in the vicinity of forest patches using latter as daytime refuges (Chapter-7), it is plausible that elephants select forest patches not only based on inherent patch characteristics, but also by the potential foraging opportunities in the human–use areas surrounding the forest patches. In addition to fodder and shade provided by open forests, the majority of them being Sal-dominated patches have surface water throughout the year. The on-going management interventions like water conservation and augmentation, and achieved by constructing water holes and check-dams had also increased the surface water availability in these forest patches.

Another important feature of the patchy forests in northern Chhattisgarh is the low inter-patch distance. The average inter-patch distance recorded in Surguja, Surajpur and Jashpur forest divisions in the landscape was < 1 km. In landscapes where inter-patch distances and the resistance for movement are high, elephants may remain in patches for longer period of time (personal observation from Eastern Ghats). However, when inter-patch distance is low, elephants' residence time in the patch can be low as they can easily switch between patches. These are possible reasons explaining elephant use of open forests significantly more than moderately dense and very dense forests.

6.4.3 Ecological perspectives on elephant habitat selection

Patch-use dynamics by wildlife has always remained an important theme of inquiry from both spatial ecology and animal behaviour perspectives. While many theoretical frameworks exist to understand patch use by wildlife, the ecological theory of "marginal value theorem" (MVT) provides a coherent economic analysis of costs and benefits of being in a patch (Charnov, 1976; Nonacs, 2001). The MVT proposes that to maximize energy intake, animals should remain in a patch till the net gain decreases as inferred by examining the 'a curve of diminishing returns' (Nonacs, 2001). Although MVT was not explicitly tested in the study, invoking predictions of MVT, it appears that elephants may take foraging and patch exit decisions based on the perceived profitability of being in the patch. In other words, elephants would remain in the patch until the returns from the patch is decreased to marginal values. As there are several hundred patches of forests throughout northern Chhattisgarh, elephants seemed to have evolved a strategy of switching easily between forest patches to subsist on whatever browse left in the patch during the day and foray in human–use areas during the night. However, it is noteworthy that in human–dominated areas, elephant use of patches may also be strongly influenced by human responses. Thus, elephants might exit a 'good quality' patch if people offer resistance to local elephant occupancy. Furthermore, the fitness benefits of optimal patch-use indicated by MVT seems unlikely in northern Chhattisgarh due to human–induced direct and indirect threats. Direct threats to elephant populations include conflict-related mortalities and chronic stress of occurring in human–dominated areas. The indirect threat may include long-term consequences of ingesting pesticide-laden crops, which is shown to potentially cause endocrine disruption, cardiovascular problems, and impair even basic metabolic functions like thermoregulation in mammals (Köhler and Triebskorn, 2013).

6.4.4 Elephant habitat selection: Management perspectives

The small and isolated patches of open forests are important source of livelihood for local communities that are predominantly forest-dependent tribes (Chapter-9). Thus, the local communities would certainly continue to use these forests. Curtailing their use can only further strain the possibilities of co-existence between elephants and people, and such restrictions wouldn't augur good for elephants too as small and isolated patches of forests cannot qualify as viable elephant habitat. Even the moderately dense and very dense forests that occur patchily without connectivity wouldn't be viable elephant habitats. Therefore, management should aim to reduce elephant use of patchy forests in human-use areas and simultaneously increase elephant use forests that are interconnected with relatively minimal human interface. The interconnected forests of Tamor Pingla Wildlife Sanctuary along with forests of Surajpur and Balrampur forest divisions in Surguja region are an example. Improving habitat conditions by carrying out activities like water provisioning, raising fodder plantations (of bamboo *Dendrocalamus strictus* and other edible grasses) and others in the patchy open forests is counter-productive and would result in perpetuating human–elephant conflict. Instead, habitat-improvement activities should be concentrated in the moderately dense and very dense forests with a clear aim of attracting and retaining elephants in such areas.

Given that elephants exhibit selection for foraging opportunities in human–use areas, reducing their use in patchy open forests is going to be challenging. Nevertheless, since the year 2019 elephants have started using Tamor Pingla Wildlife Sanctuary with increased frequency following improvement in habitat conditions (this included water augmentation and grassland creation). Thus, the long-term strategy of harbouring elephants in the identified relatively intact habitats should be pursued.

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CHAPTER-7

PATTERNS AND DETERMINANTS OF CROPLAND–ELEPHANT CONFLICT

7.1 Introduction

Biodiversity-rich tropical forests provide numerous ecosystem services like soil protection, nutrient cycling, moisture retention, and watershed functions that directly benefit local communities (Myers, 1988). However, the downside of living along forests includes negative interactions between people and wildlife that sometimes escalate into conflict situations (Woodroffe et al., 2005). In the forest–agriculture eco-tones of the tropical countries, cropland–wildlife conflict is a major challenge for conservation. Many mammals of the Order Primates, Artiodactyls and Proboscides forage on cultivated crops (Hill, 2018). Amongst them, crop foraging by elephants presents a convoluted challenge: While the species is endangered and requires public support for conservation, these animals can cause loss of crops, property, and occasional human lives (Sukumar, 2003). Adding to the complexity is the ability of elephants to learn behaviours associated with crop foraging, which can be culturally transferred to conspecifics through social learning. Justifiably, cropland–elephant conflict continues to be a major area of applied research due to its direct relevance in Asian elephant conservation.

Within Asia, India harbours the largest population of nearly 30,000 elephants in an area of about 125,000 km^2 of diverse tropical habitats (Project Elephant Division, Government of India, 2020). There are stringent legal provisions and institutional mechanism to protect elephants and their habitats in the country (Bist, 2006; Rangarajan et al., 2010). In general, elephants imbue cultural affinity in India due to which targeted retaliatory killings remain few relative to other range countries in Asia (Sukumar, 2003). Nevertheless, human–elephant conflict, primarily in the form of crop losses and human fatalities continues to escalate with potential long-term ramifications for elephant conservation (Rangarajan et al., 2010). Notwithstanding the numerous proximate reasons elucidating the causation and development of crop foraging behaviour in elephants (eg Sukumar, 2003), ultimate reasons postulated to explain the phenomenon include (i) use of cultivated crops as fall-back food to offset scarcity arising from direct and tacit forms of habitat loss (Balasubramaniam et al., 1995; Desai and Baskaran, 1996) (ii) as part of optimal foraging strategy (Pyke, 1984) since crops may be a concentrated source of food, which elephants can exploit to maximize time (Chiyo et al., 2011; Sukumar, 1991), (iii) as a strategy to overcome nutrient deficiencies in elephants' regular diet (Osborn, 2004; Sukumar, 1990; Williams et al., 2001), and (iv) as a male strategy to gain reproductive advantage through better expression of *musth* that confers competitive edge in male-specific agonistic interactions (Chiyo et al., 2011; Hollister-smith et al., 2007; Hollister-Smith et al., 2008; Sukumar, 1991). Elephants feed on cultivated crops almost exclusively during night, likely due to perceived 'landscape of fear' (Troup et al., 2020) as crop foraging entails considerable risks (Goswami et al., 2014; LaDue et al., 2021). However, in humanized landscapes characterized by high interspersion of natural forests and agriculture, observations show that both males and females forage crops (Datye and Bhgawat, 1995; Singh et al., 2002). The phenomenon of both males and female elephants foraging crops seems particularly acute in landscapes witnessing large-scale immigration of elephants into humanized areas, out of their home ranges (Daniel et al., 2008; Datye and Bhgawat, 1995; Singh et al., 2002). While there could be complex set of underlying reasons triggering such dispersals, habitat saturation owing to habitat loss, isolation of populations, and local over-abundance could be overriding factors (Barua and Bist, 1995; Daniel et al., 2008). Regardless of the drivers, managing dispersing population of elephants presents a complex challenge (Daniel et al., 2008).

The state of Chhattisgarh located in the East Central region of India harbours an elephant population, which has expanded its range from the neighbouring states of Odisha and Jharkhand since the year 2000 (Pandav et al., 2019). Historically, elephants occurred in Chhattisgarh, but were presumed to have become locally extinct during 1920s. The contemporary elephant range in Chhattisgarh continues to expand in humanized areas with concomitant increase in human–elephant conflict (Nigam et al., 2021). Chhattisgarh Forest Department that manages wildlife and forests in the state had paid an *ex gratia* of approximately US $ 6.47 million towards crop and property losses caused by elephants during the period 2009 to 2021 (Project Elephant, Government of India, 2020). There are less than 250 elephants (Project Elephant, 2020), but their distributional range is spread over 17,500 km^2 of mosaic landscape that is rural and predominantly under tribal occupation. Furthering the efforts towards conflict mitigation in Chhattisgarh would require strategies stemming from knowledge of both ecological and social underpinnings of human–elephant interactions at multiple spatial scales. However, management interventions towards addressing human–elephant conflict continue to be reactive and often, decisions emanate from subjective evaluations. To streamline conflict mitigation efforts, and invoke preventive management strategies, objective assessment of aspects of human–elephant conflict, such as quantifying crop losses and identifying their drivers would be important.

A challenge facing quantification of crop losses and identifying drivers is that the variables could be scale-dependent (Songhurst and Coulson, 2014). Therefore, making assessments at different ecologically relevant spatial resolutions would be crucial to disentangle the effects of drivers of conflict. Given this, we evaluated the patterns of crop losses at two spatial scales during different datasets. The landscape-scale assessment, which covers most of the elephants' range in Chhattisgarh, could be relevant for formulating policy-level interventions such as creating perspective plans and in defining the appropriate approach for mitigating human–elephant conflict. The fine-scale assessment, which was carried out in one of the major conflict hotspots in Chhattisgarh was aimed at unravelling patterns of crop loss and their determinants that can guide in preparation of site-specific management plans. Specifically, we (i) assessed the variations in the intensity of crop loss by elephants at the landscape-scale and identified the potential spatial correlates (ii) quantified crop losses by elephants, evaluated potential differences among elephant social groups, identified vulnerable temporal window of crop losses and assessed the spatial determinants of crop loss occurrence at finer spatial scales. The variables used to explain variations in the spatial patterns of crop losses by elephants have been provided in Table-7.1.

Table 7.1: Variables used in assessment of crop losses by elephants

S.N	Variable	Scale of influence	Measurement (at the grid level)
1	eleUse	LL	Categorical variable (of categories high, medium, low and sporadic) depicting intensity of habitat use by elephants at the level of forest range.
2	extFor	LL	Extent of forest (all forest types) and other natural habitats measured in km^2
3	extAgr	LL & FL	Extent of agricultural field measured in km^2
4	forPatch	LL	Count of discrete forest patches
5	distRiv	LL & FL	Euclidean distance from grid centroid to nearest river (>4^{th} order)

S.N	Variable	Scale of influence	Measurement (at the grid level)
6	MSI	LL & FL	Mean shape index depicting shape complexity of the forest patches. Relatively higher scores indicate higher complexity
7	builtArea	LL	Extent of built-up area measured in km^2
8	nigLight	LL	Mean density of night illumination
9	MPAR	LL	Mean perimeter to area ratio of forest patches
10	extSett	FL	Extent of settlement measured in km^2
11	forEdge	FL	Measure of frontage (in kilometer) of the forest patches
12	distFor	FL	Euclidean distance from the grid centroid to nearest forest patch
13	dist Road	FL	Euclidean distance from the grid centroid to nearest main road

* The response variables are "intensity of crop loss" at the landscape-scale and "probability of occurrence of crop-loss" at fine-scale. LL = landscape-scale; FL = fine-scale

7.2 Materials and methods

7.2.1 Study area

Northern Chhattisgarh is part of the Central Highlands in the Indian Peninsula comprising of rugged hills, flat hilltops and forested plains (Forsyth, 1871; Rodgers and Panwar, 1988). More than 50% of the landscape is forested (FSI, 2019). The altitude ranges from 400 -1200 m with an average annual rainfall of 800 - 1600 mm received during the months of July to September. The major river catchments in northern Chhattisgarh include Rihand, Mahaan, and Kanhar of the Gangetic basin and Hasdeo, Gej, Ib and Maand of the Mahanadi basin. There are also numerous man-made water bodies including the village ponds throughout the landscape. Paddy (*Oryza sativa*) is staple food crop and hence widely cultivated along with seasonal vegetables, local variety of pulses, maize (*Zea spp*), wheat (*Triticum aestivum*) and sugarcane (*Saccharum offinarum*) in relatively well-irrigated tracts. The forests are predominantly of Sal (*Shorea robusta*) dominated moist and dry deciduous formations

(Champion & Seth, 1968). The forests in the central Indian plateau are reportedly rich in earthly minerals like coal and iron ore (FSI, 2019). Consequently, numerous mineral mines dot the landscape. Northern Chhattisgarh is predominantly rural with population density of 150 persons per km^2 (Directorate of Census Operations, 2011). Over 55% of the local populace is forest-dependent tribal communities, comprising of communities like Kunwar, Baiga, Gond, Pando, Kudako, Pahari Korwa, and Oraon (Areendran et al., 2011). The estimated elephant population of northern Chhattisgarh is around 250 (Project Elephant, Government of India, 2020).

The landscape-level assessment of crop losses by elephants was carried out in 10 forest divisions namely Surguja, Surajpur, Balrampur, Jashpur, Manendragarh, Koriya, Katghora, Korba, Raigarh and Dharamjaigarh in two forest circles of Surguja and Bilaspur (Fig-7.1). The landscape also includes four protected areas namely Guru Ghasidas national park (1411 km^2), Tamor Pingla (543 km^2), Semarsot (430 km^2) and Badhalkol wildlife sanctuaries (104 km^2) where elephant occurrence is reported.

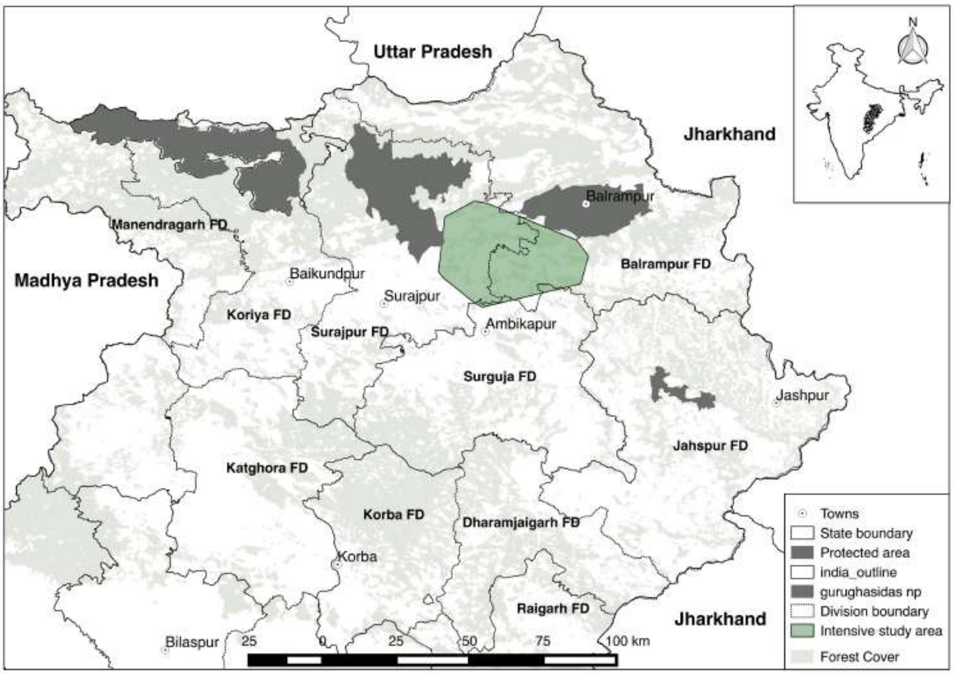

Fig-7.1: Study area map showing the fine-scale study area and the overall landscape

Fine-scale assessment of crop losses by elephants was conducted in a subset of larger landscape (henceforth 'intensive study area') with reported high levels of human–elephant conflict, located in the inter-junction of three forest divisions in Surguja circle namely Surguja, Surajpur and Balrampur. As part of long-term research project by Wildlife Institute of India, Dehradun, we have been monitoring elephants using satellite telemetry and individual-based approaches in Surguja circle, which helped us in demarcating the geographic bounds of the intensive study area. The demarcation was also based on logistical familiarity and local information network. In the demarcated area, crop loss incidences recorded during field surveys were mapped in GIS to create a polygon (following minimum convex polygon approach). The intensive study area measures 1200 km^2, which constitutes 450 km^2 of forests (Fig-7.1).

7.2.2 Crop loss data

7.2.2.1 Secondary data

For landscape-level assessment of crop loss intensity, we collated crop loss records from 10 forest divisions and four protected areas in Surguja and Bilaspur circles for the period 2015 to 2020. We mapped those records in GIS at the village level and calculated average number of crop loss days for each village. We preferred the metric mean crop loss days to mean crop incidences, as the former is sensitive in capturing "intensity of crop loss" and less vulnerable to statistical non-independence unlike crop loss incidences, which could be correlated.

7.2.2.2 Primary data

The fine-scale assessment of crop losses was carried out in the intensive study area during February 2019 to February 2020. Two of the project field assistants from local villages (enumerators henceforth) and a researcher were trained in identifying elephant signs and recording crop loss information in the field. The enumerators coordinated with the forest guards, local villagers and carried out site visits (usually on the next day of the damage) to record crop type, GPS location, stage of damage, number of elephants involved and their gender, wherever appropriate. The villagers were forthcoming in assisting our enumerators in recording reliable data. A measuring tape was used to record the length and width of the crop loss area in meters unit. Locating crop loss sites was not difficult due to simultaneous behavioural monitoring of elephants on a regular basis using satellite collars (Nigam et al., 2021) and individual-based approaches (Natarajan et al., 2019) from the year 2017 onwards. Due to this, we reasoned that modelling imperfect detection (Goswami et al., 2015) was not required in the intensive study area.

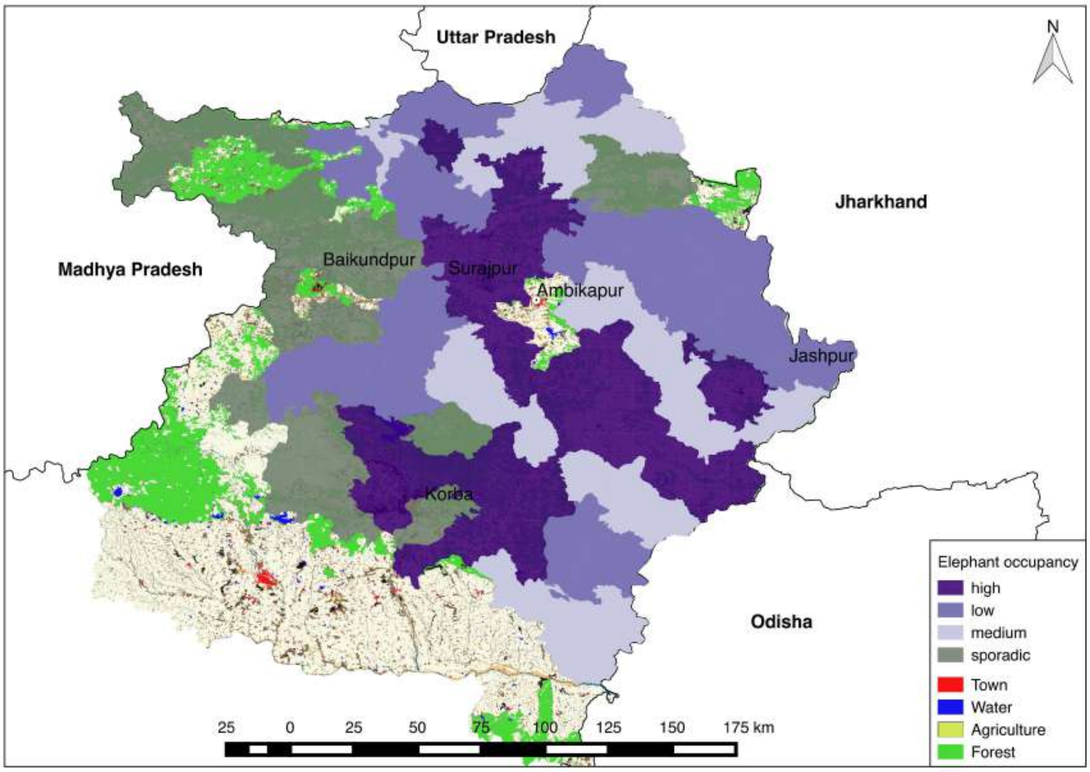

Fig-7.2: Elephant habitat-use at the level of forest ranges

7.2.3 Data analysis

For the landscape-level assessment of crop loss intensity by elephants, we overlaid 4 km^2 grids across the entire elephant range in northern Chhattisgarh. At 4 km^2, the grids were large enough to accommodate an independent crop loss incident and also amenable for evaluation of potential covariates. The grids with no reported crop losses were excluded from analysis resulting in a total of 1126 grids in the sampling frame. For each grid, we calculated the mean number of crop loss days. If there were multiple villages within the grid, we calculated the overall mean number of crop loss days pooled across villages. We used linear regression models to evaluate the effect of explanatory variables on intensity of crop losses by elephants. The response variable in our models was the average crop loss days within the grid during the period of assessment. The response variable was assumed to follow a Gaussian distribution, and prior to analysis we scaled it with a natural logarithm to deal with potential skews in the distribution. Among the explanatory variables used in the models, intensity of habitat-use at the range-level was mapped based on field observations and cross reference of forest department's daily elephant monitoring report for the period 2017–2020 (Fig-7.2). The variables extent of forest cover, agriculture, and built-up areas; MSI, MPAR, and distance to river were extracted from 10-m resolution land-use land-cover (LULC) imagery developed by National Remote Sensing Centre, Nagpur, Maharashtra (NRSC, www.nrsc.gov.in). Information on night-light was extracted from visible light data available for India.

For fine-scale assessment of probability of crop loss by elephants we overlaid on 1-km^2 grids in the intensive study area. The chosen grain size was relatively fine to capture variation in crop loss occurrence. Grids smaller than this could potentially result in auto-correlation of crop loss incidences. Grids with 100% forest cover with no crop fields were eliminated leaving 1076 grids in the sampling frame. The response variable, presence (1) or absence (0) of crop loss incidences was assumed to follow logistic regression. The explanatory variables of distance to settlement, extent of forest edge, distance to forest and distance to river additionally used in logistic regression were computed from NRSC LULC imagery

The continuous explanatory variables used for both landscape-level and fine-scale analyses were scaled with Z score transformation to facilitate interpretation of model coefficients (Zuur et al., 2009). The model comparisons were made using information-theoretic approaches by evaluating AIC values and relative AIC weights of the plausible models in the candidate set with intercept-only model (Burnham and Anderson, 2002). We compared the *Z* scores and confidence intervals of the model-averaged regression coefficients to rank explanatory variables in the relative order of influence on the response variables. For the top ranking binomial regression models, we calculated the receiver-operating curve (ROC) value indicating model fit with cut-off values of 0.7 and above considered a reasonably good fit (Sitati et al., 2003).

The extent of crop loss recorded from the intensive study area was presented in hectares. To assess the difference in magnitude of crop loss between solitary elephants and groups ($\geq$ 2 elephants), we used Kruskal-Wallis chi-square test (Sokal and Rohlf, 2012). We urge caution in interpretation of elephant groups, which would comprise both family units as well as all-male groups. However, the frequency of occurrence of all-male groups was comparatively lower. Furthermore, even if all-male groups occurred within forest patches in which family groups also occurred, the recorded crop losses were assigned to groups. We used Pearson's correlation test to assess potential correlation between magnitude of crop loss and number of elephants

(Sokal and Rohlf, 2012). Further, to compare the severity of loss among the cultivars foraged by elephants, we estimated severity index (S_i) for each crop calculated as:

$$S_i = C_e / C_d$$

Whereby, C_e is the extent of loss of a particular crop (in hectares) and C_d is the total number of elephant forage days recorded for the crop. We performed the statistical analyses in Program R (R Core Team, 2019). The GIS variables were extracted using ArcGIS v10.6.

7.3 Results

7. 3.1 Landscape-level intensity of crop loss

During the period 2015–2020, 1426 villages from 10 forest divisions and four protected areas in northern Chhattisgarh reported crop losses by elephants. Based on the reported intensity of conflict, four major conflict hotspots were identified (Fig.7.3). We evaluated 15 linear regression models to examine the influence of explanatory variables on crop loss intensity caused by elephants (Table-7.2). No significant collinearity was observed between the explanatory variables (variance inflation factor, VIF < 4). Among the candidate list, the top two models (ΔAIC < 2) provided comparable support. As they were nested, we carried out model averaging to obtain parameter estimates (Table-7.3). The explanatory variables in the top models included elephant habitat use (eleUse), extent of agriculture (extAgr), extent of forest area (extFor), number of discrete forest patches within the grid (forPatch), and distance to nearest river (distRiv). Among the predictors, intensity of habitat use by elephants had the best support from the data – crop loss intensity was high in areas that were used intensively by elephants in comparison to areas with low ($\beta = -0.68$, SE = 0.09, $P < 0.001$), medium ($\beta = -0.61$, SE = 0.08, $P < 0.001$), and sporadic ($\beta =$

−0.74, SE = 0.12, $P < 0.001$) habitat use by elephants. The intensity of crop loss was low in areas that were largely agricultural fields without forest cover ($\beta = -0.10$, SE = 0.05, $P < 0.05$). Furthermore, intensity of crop loss by elephants was high in grids with relatively high forest cover ($\beta = 0.12$, SE = 0.05, $P < 0.01$) and contained more forest patches ($\beta = 0.07$, SE = 0.03, $P < 0.005$). Proximity to river had a positive effect in explaining spatial variation, but was only weakly informative ($\beta = 0.02$, SE = 0.04, $P = 0.67$).

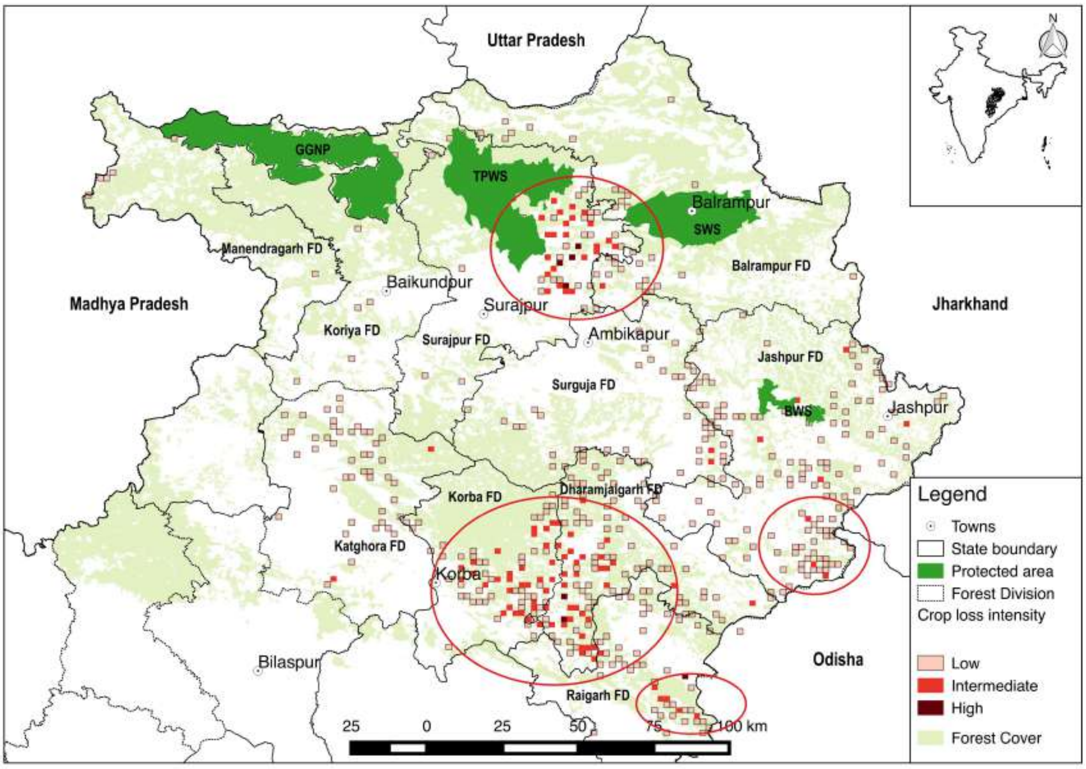

Fig-7.3: Intensity of crop loss by elephants at the landscape-scale in northern Chhattisgarh

Table-7.2: Summary of model selection results explaining spatial variation in intensity of crop losses caused by elephants at the landscape-scale

Model	AIC	ΔAIC	ω	Deviance	R^2
CLintensity~eleUse+extAgr+extFor+forPatch	3395.1	0	0.605	1323.2	0.12
CLintensity~eleUse+extAgr+extFor+distRiv +forPatch	3397.0	1.9	0.244	1323.0	0.12
CLintensity~eleUse+extAgr+extFor+distRiv +MSI+forPatch	3398.6	3.5	0.110	1322.5	0.12
CLintensity~ eleUse+extAgr+extFor	3400.9	5.8	0.033	1332.4	0.12
CLintensity ~ eleUse+extFor	3403.9	8.8	0.008	1338.3	0.11
CLintensity ~ eleUse	3441.9	46.8	0.000	1386.6	0.08
CLintensity ~ extFor	3487.4	92.3	0.000	1451.6	0.03
CLintensity ~ extAgri	3496.7	99.7	0.000	1463.6	0.03
CLintensity ~ forPatch	3515.8	120.7	0.000	1488.6	0.01
CLintensity ~ distRiv	3516.3	121.2	0.000	1489.3	0.01
CLintensity ~ MSI	3518.0	122.9	0.000	1491.5	0.00
CLintensity ~ builtArea	3522.7	127.6	0.000	1497.8	0.00
CLintensity ~ 1 (intercept only)	3523.4	128.3	0.000	1501.3	NA
CLintensity ~ nigLight	3525.2	130.2	0.000	1501.2	0.00
CLintensity ~ MPAR	3525.3	130.2	0.000	1501.2	0.00

CLintensity = Intensity of crop loss recorded in the grid

Table-7.3: Parameter estimates including those of elephant habitat use, extent of agriculture, extent of forest area, number of forest patches, and distance from the river as included in the top models that explain intensity of crop losses

Variable	Estimate	SE	95% CI (lower)	95% CI (upper)	*Z*	*P*
Intercept	0.36	0.06	0.240	0.485	5.79	< 2e-16***
eleUse-low	-0.68	0.09	-0.844	-0.507	7.86	< 2e-16***
eleUse-medium	-0.61	0.08	-0.771	-0.447	7.37	< 2e-16***
eleUse -no	0.01	0.78	-1.524	1.548	0.02	0.98
eleUse -sporadic	-0.74	0.12	-0.972	-0.501	6.13	< 2e-16***
extAgr	-0.10	0.05	-0.194	-0.003	2.03	0.042*
extFor	0.12	0.05	0.021	0.216	2.38	0.017*
forPatch	0.07	0.03	0.022	0.124	2.79	0.005**
distRiv	0.02	0.04	-0.058	0.090	0.43	0.666

* Indicates significant P values

7.3.2 Fine-scale patterns of crop loss

7. 3.2.1 Characteristics of crop loss

We recorded 363 incidences of crop foraging by elephants from 60 villages (that include small settlements as well) in the intensive study area for the 13-month period (February 2019 – February 2020). The measured extent of crop loss by elephants was 12.4 hectares comprising of 10 different crops (Fig.7.4). Amongst them, loss of sugarcane was highest (5.81 hectares, n = 214 days), followed by paddy (3.5 hectares, n = 64 days), maize (1.73 hectares, n = 23 days), and wheat (0.68 hectares, n = 42 days). The losses pertaining to other crops were relatively minimal. Amongst the top four crops, severity of losses due to elephants was relatively high for maize (Si = 0.08); followed by paddy (Si = 0.05), sugarcane (Si = 0.03), and wheat (Si = 0.02). Elephant-related crop losses were spread out throughout the year due to availability of sugarcane, an annual crop in the landscape (Fig-7.5). The period of losses pertaining to cereals and maize mirrored local crop cultivation cycles. They were foraged predominantly damaged during mature stages, whereas sugarcane suffered elephant-related crop losses during mature and vegetative stages (Table 4). The extent of crop loss was positively correlated with number of elephants (Pearson's r = 0.51, t = 11.25, P < 0.001). Further, crop losses caused by elephant groups were higher than losses caused by solitary elephants (Kruskal Wallis χ^2 = 305.78, df = 237, P = 0.001).

Plate-7.1: Elephants feeding on paddy in Udaipur range of Surguja Forest Division

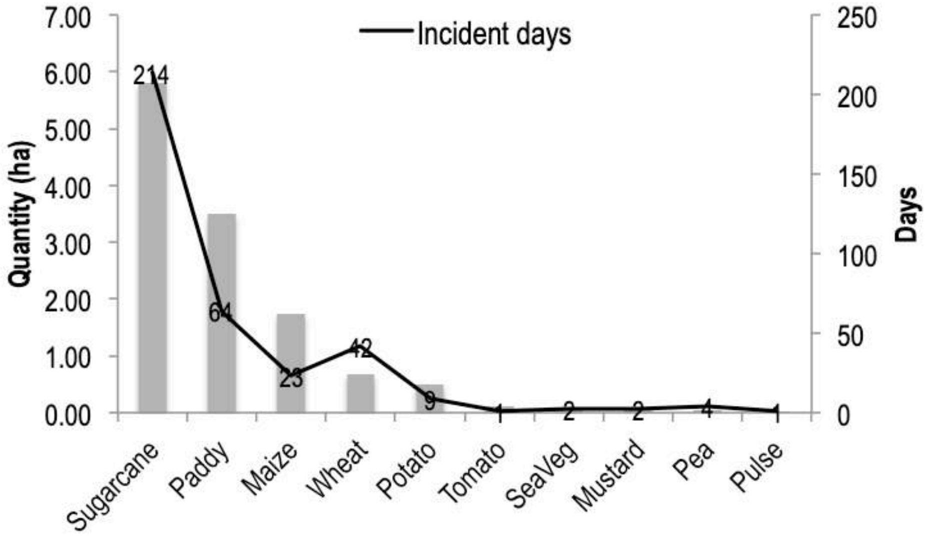

Fig.7.4: Quantity of cultivars foraged by elephants in Surguja, Chhattisgarh along with the recorded number of crop loss days for the period February 2019 – February 2020

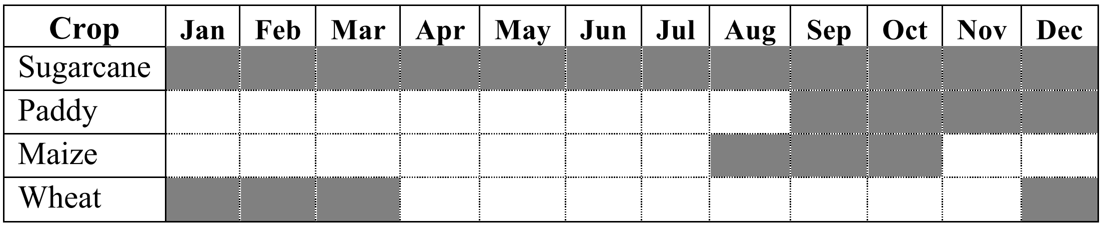

Fig-7.5: Period of loss of top four cultivated crops by elephants recorded in Surguja, Chhattisgarh during February 2019 – February 2020

Table-7.4: Phenophase of top four cultivated crops foraged by elephants in Surguja

Crop	Incidences	Phenophase of crops
Sugarcane	214	57% mature, 43% others
Paddy	64	94% mature, 6% others
Maize	33	91% mature, 9% others
Wheat	42	83% mature, 17% others

7.3.2.2 Spatial patterns of crop loss occurrence

We evaluated 10 binomial regression models to examine the influence of explanatory variables on the probability of crop loss occurrence by elephants in Surguja (Table-7.5). Collinearity between explanatory variables was not significant (VIF < 4). In the candidate list of models, the top three models (ΔAIC < 2) included the explanatory variables distance to road (distRoad), distance to forest (distFor), mean shape index (MSI) of the forest patch, and total edge (forEdge) of the forest patches. The fit of the top models in explaining the variability in the response variable was considered adequate (ROC = 0.71). As the top three models were nested, they were model averaged for obtaining parameter estimates (Table-7.6).

The explanatory variable, distance to main roads best explained the observed variations in response variable, whereby, the probability of crop loss by elephants increased with increasing distance from the main roads (β = 0.53, SE = 0.12, P < 0.001). Further, probability of crop loss by elephants was high in grids having forest patches with relatively high MSI values (β = 0.39, SE = 0.14, P < 0.007). Furthermore, there was high probability of crop loss by elephants in grids that were closer to forest patches (β = -0.29, SE = 0.20, P < 0.135) although the regression coefficients were only weakly informative (Table 6). The forest edge measured in the grid had a weak effect on the observed probability of crop loss by elephants (β = -0.12, SE = 0.16, P = 0.46).

Table-7.5: Summary of model selection results explaining probability of crop loss by elephants in Surguja, Chhattisgarh

Model	AIC	ΔAIC	ω	Deviance	LogLik
CLprob ~ distRoad+distFor+MSI	725.7	0.0	0.439	717.7	-358.8507 (df=4)
CLprob ~ distRoad +MSI	726.1	0.4	0.350	720.1	-360.0735 (df=3)
CLprob ~ distRoad + distFor + MSI +forEdge	727.1	1.4	0.210	717.1	-358.5853 (df=5)
CLprob ~ distRoad	745.3	19.6	0.000	741.3	-370.6602 (df=2)
CLprob ~ MSI	757.7	32.0	0.000	753.6	-376.8308 (df=2)
CLprob ~ distFor	759.1	33.4	0.000	755.1	-377.5677 (df=2)
CLprob ~ forEdge	768.2	42.5	0.000	764.2	-382.1143 (df=2)
CLprob ~ 1 (intercept only)	779.1	53.4	0.000	777.1	-388.5518 (df=1)
CLprob ~ extSett	779.1	53.4	0.000	775.1	-387.5713 (df=2)
CLprob ~ extAgri	779.2	53.5	0.000	775.2	-387.6202 (df=2)

CLprob = Probability of occurrence of crop losses in the grid

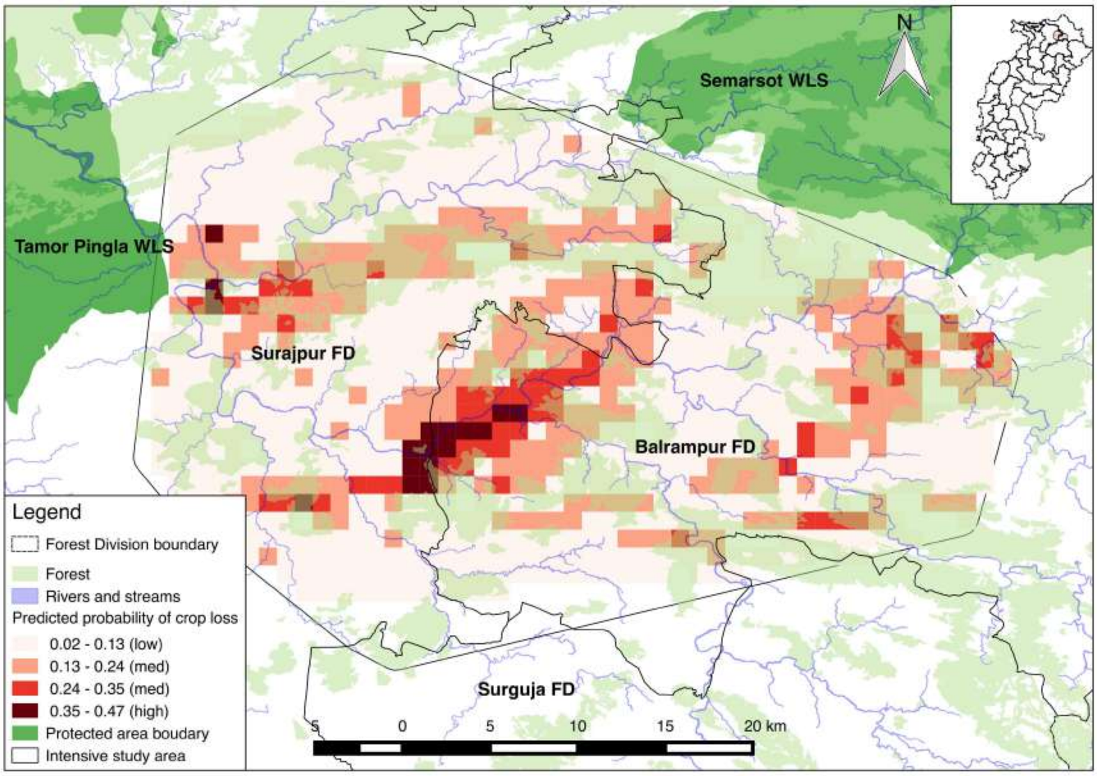

Fig-7.6: Predicted probability of crop loss in Surguja

Table-7.6: Parameter estimates including those of distance to road, distance to forest, mean shape index of the patch and total edge as included in the top models that explain probability of crop losses by elephants

Variable	Estimate	SE	95% CI (lower)	95% CI (upper)	*Z*	*P*
Intercept	-2.24	0.12	-2.47	-2.01	19.42	<2e-16 ***
distRoad	0.53	0.09	0.35	0.71	5.71	<2e-16 ***
distFor	-0.29	0.20	-0.68	0.09	1.49	0.135
MSI	0.39	0.14	0.11	0.67	2.70	0.007 **
forEdge	-0.12	0.16	-0.43	0.20	0.72	0.469

* Indicates significant *P* values

7.4 Discussion

7.4.1 Landscape-level patterns of crop loss

It is ironic that a relatively small population of about 250 elephants had caused crop losses in 1426 villages across 10 forest divisions in northern Chhattisgarh during 2015–2020. During this period, Chhattisgarh forest department paid US$ 6.4 million as *ex gratia* relief towards elephant-related crop, and property losses (Project

Elephant, Government of India). In comparison, the state of Karnataka, which harbors the largest elephant population in India (about 6000 elephants as per Project Elephant, 2020) paid *ex gratia* relief of US$ 6.5 million during 2014 – 2019 (Project Elephant, Government of India). Thus, the *ex gratia* paid by Karnataka was only slightly above Chhattisgarh values despite harboring elephant populations that are 93% higher than that of Chhattisgarh. This indicates that human–elephant conflict in Chhattisgarh is disproportionately high with respect to its elephant population. The observed anomalous phenomenon is possibly owing to combined effects of large elephant home ranges that are distributed in fragmented mosaic of habitats (Pandav et al., 2019), and concurrent range elephant expansion resulting from exploratory behaviour (Nigam et al., 2021).

At the landscape-scale, intensity of habitat-use by elephants best explained the observed variations in intensity of crop losses. Our findings contradict Pozo et al., (2018), who in case of African elephants suggested that elephant space-use might not be a good predictor of crop losses. The contradiction is important to elucidate in light of elephant behavioural ecology. In polygynous social mammals, natural selection favors risk-aversive strategy in females as observed in case of elephants (Chiyo et al., 2011; Sukumar, 2003, 1991). This generally preempt female herds from foraging crops as it entails considerable risks to the group. However, when natural elephant habitats saturate due to myriad forms of threats like fragmentation and corresponding losses, even female herds might start foraging crops (Datye and Bhgawat, 1995; Desai and Baskaran, 1996). Desai and Riddle (2015) suggest that such initial exposure to crop foraging either due to opportunistic or compelling reasons can become habitual over time. Moreover, crop foraging can rapidly spread across elephant clans even if the behaviour is mal-adaptive (*i.e.* not in the best interest of genes), as construed from accelerated rate of conflict-induced elephant mortalities (Goswami et al., 2014; LaDue et al., 2021). In light of such unnatural mortalities and potential impacts of ingesting agricultural pesticides, assessment of long-term effects of crop foraging on elephant populations appears imperative. As both males and female elephants forage crops in northern Chhattisgarh, elephant space-use emerged as a strong predictor of crop losses.

Amongst the other explanatory variables, the extent of forest cover and forest patches showed a positive effect, whereas extent of agriculture had a negative effect on intensity of crop loss by elephants. These results seem intuitive, as elephant herds cannot occur in completely agricultural landscapes that lack forest cover.

7.4.2 Fine-scale patterns of crop loss

In the intensive study area, although elephants foraged about 10 species of cultivated crops, losses were substantial only for sugarcane, paddy, maize, and wheat. Among these four crops, quantitatively, sugarcane was the most damaged; followed by paddy, maize, and wheat. The severity of maize and paddy losses due to elephants was higher than sugarcane and wheat. Elephants foraged cereals and maize predominantly during relatively mature stages as reported by others (Gubbi, 2012; Sukumar, 2003). As the temporal window of damage was narrow for the cereals, concerted crop protection efforts for few weeks could bring down losses substantially. Furthermore, seasonal barriers like mobile fences (that can be dismantled after use) with active community participation can be experimented in select hotspots. The option of seasonal barriers is particularly relevant to Chhattisgarh as high fragmentation preclude use of permanent barriers like trenches. Sugarcane suffered elephant-related losses throughout the year, and it has seemingly increased the duration of cropland–elephant conflict in Surguja. The idea of cultivating alternative crops (that are less edible for elephants) has been widely suggested (Gross et al., 2016; Neupane et al., 2017). While it is the political economy that drives farmer choice of crops, alternative-cropping strategies wouldn't work in fragmented areas as elephants have evolved long-distance movement and can easily switch crop foraging sites.

Among the explanatory variables, the observed variations in probability of crop loss occurrence by elephants were best explained by distance from main roads. We found that in areas that were far from main roads, probability of crop loss by elephants was high. Plausible explanations for this include higher detection rate of elephants and better vigilance along the roads in the humanized areas. Ironically, while road network inside natural elephant habitats can be a serious conservation concern, in the mosaic of agricultural fields and settlements outside forests, road network could help in monitoring elephant conflict. In Surguja, there are range-level rapid response teams comprising of forest staff and village volunteers equipped with multipurpose vehicles that patrol main roads and village roads during the evening and night hours to check elephant movement and prevent ingression into agricultural fields, whenever possible. To make it more systematic, mapping local road network and developing “conflict monitoring circuits” would be useful for monitoring conflict in high conflict areas. In Surguja, main roads have less traffic as compared to many other states. Yet, they seem to serve as psychological deterrents for elephants, which can potentially be further exploited to create virtual barriers.

When elephants occur in human–dominated areas, they may use natural forest patches as daytime refuges (Graham et al., 2010). We found higher probability of crop loss by elephants in the proximity to forest patches. Although the regression coefficients were weakly informative, we would urge caution in carrying out habitat improvement activities like water augmentation in small forest patches as they could become day-time elephant refuges. Instead, efforts to improve habitat conditions should target larger forest patches that exist the landscape where it is desirable to sustain elephants. In addition to forest proximity, shape parameters of forests like their frontages can be important correlate of crop losses by elephants (Gubbi, 2012). We found that the effect of forest edge on the observed probability of crop loss by elephants was weak; MSI values of the forest patches had a relatively strong effect. As MSI implies shape complexity that takes into account parameters like area, perimeter, and core of the patch, it appears that elephants select patches that are relatively complex.

7.4.3 Limitations

In our assessment, although the environmental variables explained variations in both intensity of crop loss at the landscape-scale and probability of crop loss by elephants in the intensive study area, we concur with Campomizzi et al., (2008) that prediction power of wildlife-habitat assessments including conflict assessments could improve if behavioural variables can be accounted. For example, the direct observations made on radio-collared elephants in Chhattisgarh indicate significant spatial displacement (moving across forest patches) by elephants in response to both conspecific attraction and avoidance. Such displacements were a norm rather being exceptions and would be difficult to explain using environmental variables. Furthermore, in social animals there could be "conformist behaviours" wherein space-use can simply mirror what was learnt from elders (Whitehead, 2010). For example, raided history can be an important predictor of crop loss regardless of the effect of other environmental variables (Songhurst and Coulson, 2014). In addition to elephant behavioural variables, responses of local farmers and management can also be strong determinants of spatial patterns of crop losses by elephants. This calls for carrying out systematic long-term monitoring of elephants in humanized areas using simple, but robust measures of human–elephant conflict that forest staff on duty can collect.

7.4.4 Management implications

The contemporary range expansion of elephants in the forest-agriculture interface in Chhattisgarh and concurrent crop losses and other forms of conflict necessitate landscape zonation for better management. The envisaged plan should identify elephant conservation and conflict management zones using existing information on human–elephant conflict, elephant occurrence, and also predict possible range expansion using robust niche-modelling approaches. Elephant range expansion outside of these zones, in predominantly human-dominated areas need to be limited by demarcating and gradually enforcing boundaries using natural geographic features (like major rivers) and man-made barriers like road and railway network. Elephant immigration into areas with low forest cover would end up as failed dispersals resulting in conflict with no conservation prospects for elephants as witnessed in case of elephant dispersal into Andhra Pradesh (Daniel et al., 2008). The zonation exercise is not specific to Chhattisgarh, but whole of East Central region as elephant home ranges studied in Chhattisgarh are distributed across two or more states (Nigam et al., 2021). The zonation of landscape would be conditional on prioritizing elephant conservation zones and keeping them safe from threats of mineral mining and infrastructure development so that elephant conservation prerogatives are not compromised. In particular, the mineral mining in East Central region has been identified as inimical to elephant conservation as it trigger human–elephant conflicts by saturating natural elephant habitats (Singh and Chowdhury, 1999).

At finer spatial scales, management priority would be to prevent spread of conflict outside of the current high-conflict zone (Fig.5) and aim to gradually increase duration of elephant occurrence within large forested complex comprising of Tamor Pingla wildlife sanctuary, Guru Ghasidas national park and connected forests in Surajpur and Balrampur forest divisions. As the area to perimeter ratio of forest patches is high, utility of permanent barriers would be minimal. Therefore, portable barriers can be tactfully experimented to limit elephant distribution within the current conflict zone.

Impetus is often placed on coming up with 'out of the box' ideas to mitigate human–elephant conflict. However, building on simple methods that field staff and local villager can understand seems to be a better strategy rather than seeking a proverbial 'silver bullet' for conflict mitigation. As even moderately effective interventions like daily conflict monitoring, developing early-warning mechanism, timely payment of *ex gratia* relief, and strategic use of barriers can significantly contribute in reducing the impact, strengthening them and the expertise thereof assumes a greater priority. Amongst these measures, institutionalizing elephant monitoring through well-trained field teams with enhanced technical capacity to deal with exigency would be an important long-term investment towards conflict resolution efforts. From elephant conservation standpoint, addressing human–elephant conflict is crucial as high levels of conflict-induced mortality can render elephant populations stochastic.

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CHAPTER-8

AN ASSESSMENT OF SPATIAL OCCURRENCE AND PATTERNS OF HUMAN FATALITIES DUE TO ELEPHANTS

8.1 Introduction

Conservation of large mammals in human–dominated landscapes rests on tacit reconciliation between recovering and sustaining at-risk wildlife populations, while managing human–wildlife conflicts (HWC) within socially tolerable limits (Woodroffe et al., 2005). In biodiversity-rich, densely populated Asian countries, the paradox of prioritizing conservation and concomitantly advancing conflict resolution is exemplified in management of species like tiger (*Panthera tigris*), Asiatic lion (*Panthera leo*), elephant (*Elephas maximus*) and others. Globally, these species have high existence values owing to their charisma and endangerment. However, their acceptance by local communities for conservation becomes a challenge especially when there are negative interactions (Jhala et al., 2019; Karanth et al., 2020; Sukumar, 2003). The local communities bearing costs of human–wildlife interactions often tend to be poor and socially disadvantaged (Bandara and Tisdell, 2003; Ram et al., 2021). From their perspective, HWC could impose both direct and indirect costs (Barua et al., 2013; Thondhlana et al., 2020). Such direct costs may include loss of cultivated crops, livestock, property, and occasional human casualties. The indirect costs of conflict were hard to measure and may include fear-related stress, compromised health, reduced mobility affecting education and livelihood, debts, and transaction costs involved in getting compensation for losses (Barua et al., 2013; Thondhlana et al., 2020). Although only few interactions between people and wildlife result in human deaths, those incidences are regarded as the most acute form of HWC (Gulati et al., 2021). Loss of human lives can result in societal ramifications when breadwinners are lost leading to marginalization of families and creation of demographic orphans affecting their school education and social insecurity. Thus, HWC-related human fatalities can potentially convert interface zones of human-wildlife co-occurrence into frontiers of fear. From conservation standpoint, loss of human lives due to HWC can trigger pre-emptive and retaliatory killing of wildlife, and may elicit biophobic responses in local communities resulting in animosity towards conservation. Therefore, from both wildlife conservation and human welfare considerations, developing strategies to reduce life threats to local people is crucial for inspiring their participation in conservation.

Amongst the diversity of wild mammalian species that occur in Asia, animals that cause frequent crop and livestock losses, and occasionally endanger human lives trigger fear amongst people. Tiger, Asiatic lion, leopard (*Panthera pardus*), sloth bear (*Melursus ursinus*), one-horned rhino (*Rhinoceros unicornis*), gaur (*Bos gaurus*), wild buffalo (*Bubalis bubalis*) and elephant (*Elephas maximus*) and some of the major mammalian species that have been incriminated to result in human wild animal conflict. Although incidences of human fatalities due to sloth bears and leopards are spatially widespread, incidences involving elephants are relatively high and are politically sensitive too. In India, which harbours the largest Asian elephant population, over 500 human lives are lost to HEC every year (Rangarajan et al., 2010). Ironically, HEC is a major threat facing elephant conservation as they trigger local resentment and opposition to conservation efforts (Natarajan et al., 2021b). Annually, an estimated 100 – 150 elephants die in India due to unnatural reasons (Rangarajan et al., 2010). As remnant elephant habitats in India and other range countries in Asia are embedded in human-use areas with long interfaces, garnering local support for elephant conservation depends on reducing the threats to human lives in the first place. Elephant-related human fatalities can be due to an interplay of landscape configuration (Ram et al., 2021), behavioural ecology of elephants (Sukumar, 2003), and demographic and livelihood aspects of local communities (Naha et al., 2019; Ram et al., 2021). Thus, minimizing life threats to humans in landscape matrices comprising of forests interspersed human-use areas is complex, and requires a multi-pronged approach integrating aspects of social sciences along with tenets of animal behaviour and ecology.

Comprehensive assessment of human fatalities due to HEC remains few. The frontline staffs at the helm of field management often lacks resources and requisite training to collect objective information that can be quantitatively analysed. Further, as such incidences are often unforeseen, reliable eyewitnesses are rare making it difficult to conjecture the circumstances surrounding an incident. Consequently, narratives on elephant-related human fatalities tend to be dramatic, exaggerated and thus, less informative for the management. Efforts to characterize wildlife attacks on human beings had often relied on secondary information like Forest Department records (Acharya et al., 2016); interview of victims' families (Rajpurohit and Krausman, 2000) and analysis of news reports. These assessments can be useful to understand spatio-temporal trends, but may lack fine-scale details required to address the problem holistically. In areas where HEC-related human fatalities are recurrent, there is pressing need to objectively and accurately record information on incidences and underlying reasons.

The East-central region in India is one of the four major elephant bearing regions in the country. This region suffers disproportionately high HEC accounting for over 50% of all HEC-related human fatalities in India despite harbouring only 10% (around 3000) of the elephant population (Project Elephant Division, 2020). Chhattisgarh is one amongst the elephant range states in the east-central region where HEC is acute with over 60 human lives lost annually although the state harbours a relatively small elephant population of 250 – 300 elephants. The elephant population in Chhattisgarh was estimated to be around 250, most of which occur in north and northcentral regions of the state (Project Elephant Division, 2020).

Elephants have recolonized Chhattisgarh only about three decades ago from the neighbouring states of Odisha and Jharkhand after being reportedly absent for over 8 decades (Pandav et al., 2019). Thus, HEC in Chhattisgarh continues to be emergent problem with continuous expansion of elephant ranges. Here, considering the moral, social and political compulsions, the overarching priority of wildlife management has been to try and minimize human fatalities due to HEC.

Based on the above, the aim of this study was to (i) examine the relative influence of select variables on the spatial occurrence of human fatalities due to HEC at the landscape-scale encompassing the entire elephant range in northern Chhattisgarh (ii) characterize the incidences of HEC-related human fatalities to elucidate patterns and circumstances surrounding human fatalities by elephants. We hypothesized that at the landscape-scale, intensity of crop losses by elephants, house-damage by elephants, extent of forest cover, distance from streams and rivers, mean elevation, terrain ruggedness, extent of human settlements and extent of cultivated crops would be important factors influencing probability of HEC-related human fatalities.

8.2 Materials and methods

8.2.1 Study Area

Our study was carried out in north and north-central Chhattisgarh covering the districts of Raigarh, Korba, Jashpur, Balrampur, Koriya, Surajpur and Surguja administered under nine forest divisions in two forest circles of Surguja and Bilaspur (Fig-8.1). Forest cover with seasonal and sporadic elephant occupancy in north and north-central Chhattisgarh spans around 17,500 km^2 (approximate and indicative). The forests are patchy, and interspersed with agricultural and human settlements. The landscape is part of the “central table-land” in the Indian Peninsula comprising of rugged hills, flat hill tops and forested plains (Forsyth, 1871; Rodgers and Panwar, 1988). More than 50% of the landscape in northern Chhattisgarh is forested (FSI, 2019). The altitude ranged from 400–1200 mm. Rainfall ranged from 800 – 1600 mm, mostly received during the monsoon months of July to September. The remnant natural forests comprise of Sal (*Shorea robusta*) - dominated moist and dry deciduous formations (Champion and Seth, 1968). The forests in Central Indian plateau are rich in earthly minerals like coal and iron ore (FSI, 2019) and mineral mining and associated infrastructure development, has caused loss and further fragmentation of natural forests in the landscape (Areendran et al., 2011). Further, due to sustained local biomass-removal pressures, the remnant forest patches has suffered varied levels of degradation.

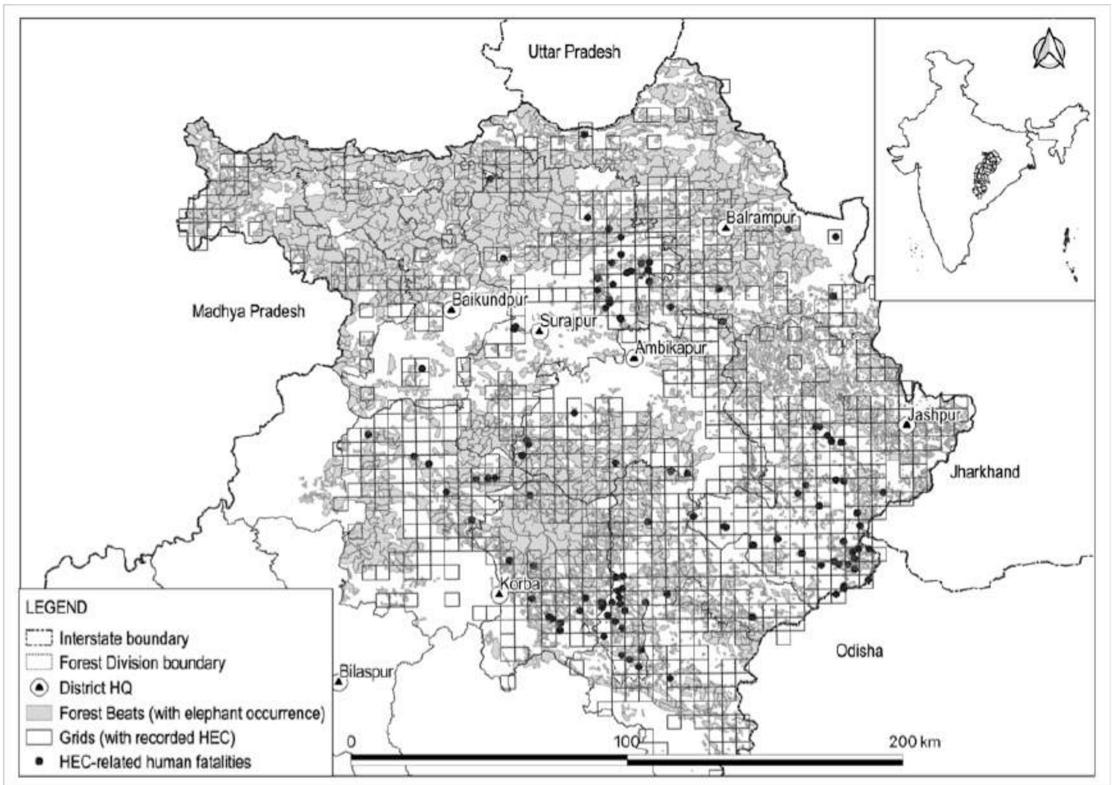

Fig-8.1: Locations of human fatalities due to elephants recorded during the study

Northern Chhattisgarh is predominantly rural with a population density of 150 persons per km^2 (Directorate of Census Operations, 2011). Over 55% of the local populace are tribal comprising of communities like Kunwar, Baiga, Gond, Pando, Kudako, Pahari Korwa, Oraon, and others (Areendran et al., 2011). Tribal communities depend on forests for firewood, seasonal fruits, edible saprophytes, medicinal plants, honey and fodder for livestock. Paddy (*Oryza sativa*) is widely cultivated during monsoon while sugarcane (*Saccharum officinarum*) is cultivated in the relatively well-irrigated tracts. Cultivars like paddy, sugarcane, wheat (*Triticum aestivum*), maize (*Zea spp*), local millets, and vegetables suffer elephant-related losses.

8.2.2 Field surveys and secondary data

We collected information on human fatalities during August 2017 to April 2020. We used two datasets for the analysis. Dataset used for making spatial predictions of occurrence of human fatalities comprised of both the primary data directly recorded in the field by visiting incident sites; and secondary data obtained from the forest department for the incidences for sites that were not visited. For the second objective of characterizing human fatalities to elucidate fine-scale patterns and circumstances, only the primary data collected directly in the field was used. Primary data collected entailed visiting sites of human fatalities within two days of the incident to record site variables (habitat type, distance from the forest, crop availability, and other micro-habitat details), victim particulars (age, gender, ethnicity, physical condition, and possible activity of the victim during the incident), elephant details (sex, group size and presence of identified groups), which were deciphered based on the signs and in few cases through opportunistic direct observations recorded by tracking elephants. Further, as part of long-term elephant monitoring program in Chhattisgarh, we satellite collared and followed few elephants making it easier for us to categorize elephants involved in conflict situations. Additionally, we recorded qualitative information aimed at understanding circumstances associated with human fatalities through informal interviews with the forest department staff, field elephant monitoring teams, and local villagers.

We categorized into gender and different age groups based on a priori assumptions about relative vulnerability of different age groups to elephant encounters. The victim age groups comprised of children1 (< 4 years), children2 (5 – 14 years), adult1 (15–24), adult2 (25–54), and old (>55 years). The time of the day was classified based on daylight availability and general human time-activity patterns including morning (5:00 to 8:00 AM), day (8:00 AM to 4:00 PM), evening (4:00 PM to 7:00 PM) and night (7:00 PM to 5:00 AM). Season of the year comprised of dry (March to June), monsoon (July to September) and winter (October to February) based on average temperature and rainfall patterns. Based on field evidences, we categorized elephants into males (including solitary bulls and all-male groups) and breeding herds (typically family units comprising of adult females and offspring).

8.2.3 Model structure and data analysis

We overlaid 4-km^2 grids across the entire elephant range in northern Chhattisgarh. Grid size was based on the average size of forest patches that elephants regularly use in the relatively patchy tracts of the landscape. We excluded grids that had no reported incidences of HEC (crop & house loss and human fatalities) from the analysis. We used generalized linear models (GLM) to quantify the effect of explanatory variables on spatial occurrence of human fatalities due to elephants. The response variable in the models was the presence or absence of reported human fatality in each grid, which was assumed to follow a logistic distribution. The explanatory variables quantified include distance to nearest river, extent of built-up area, human population density, extent of forest, extent of agricultural crops, extent of house damage caused by elephants, and habitat-use by elephants. Intensity of habitat-use by elephants was measured as a categorical variable (of categories high, medium, low and sporadic) at the forest range level. The variable intensity of house damage by elephants obtained from forest department records for a 5-year period (2015 to 2019) coinciding with our assessment. For few forest divisions, only three-years of forest department data were available. This however did not affect the values assigned to the grids as only average values per grid were used as metric for 'intensity of house damage' by elephants. The variables of forest cover and built-up were extracted from

10-m resolution land-use land-cover imagery developed by National Remote Sensing Centre, Nagpur, Maharashtra (NRSC, www.nrsc.gov.in). The variable of distance from main roads (including all metaled roads) was calculated as Euclidean distances from the centroid of the grid to the nearest road in GIS. Human population density was derived from USGS population data for tropical countries. We used the pre-existing stream layer developed by WII for central India using DEM and Survey of India topographic maps, and computed Euclidean distance from the grid center to the nearest 4th order streams and above.

We assessed multi-collinearity between variables using variance inflation factor (VIF) and included variables with VIF < 2 (Bolker, 2008). Following (Burnham and Anderson, 2002), we used an information theoretic approach for model selection and compared plausible models with an intercept-only model. We compared Akaike Information Criterion (AIC) values and AIC weights of the models in the candidate set (Burnham and Anderson, 2002; Johnson and Omland, 2004). We assessed the fit of the top models using receiver operating characteristic curve (ROC) values. The ROC values range from 0.5 to 1.0 and values above 0.7 indicating reasonably good fit (Sitati et al., 2003). To assess the relative influence of the explanatory variables in the potential top models, we examined the slope estimates of the variables along with their confidence intervals and compared the Z scores.

Primary data recorded in the field was used to compare possible differences in frequency of human fatalities between victim gender, age-class and ethnicity; differences in periodicity of human fatalities across different time-intervals of the day and seasons of the year, and differences between elephant social groups using Pearson's Chi-square tests (Sokal and Rohlf, 2012). For calculating the expected values of gender, age-class and ethnicity to perform hypothesis tests, we used census data of Chhattisgarh (Directorate of Census Operations, 2011). Elephant demography data was obtained from Chhattisgarh Forest Department based on 2017 elephant census to compare the difference in frequency of incidences between male elephants and breeding herds. As per Pandav et al (2019), satellite collared elephants in Chhattisgarh, on an average spend over 20% of time in human-use areas. This was used to compare relative frequency of human fatalities by elephants inside and outside of forests.

We a priori expected that there could be spatio-temporal autocorrelation in the HEC-related human fatalities. Because the secondary data obtained from the forest department lack precision on location, time of incident and other details, we assessed spatio-temporal autocorrelation of incidences based on primary data. We used Moran's I statistic that uses inverse weights between geographic point locations to assess possible clustering (Crawley, 2007) and carried out a permutation test for Moran's I statistic using Monte Carlo simulation (Bivand and Wong, 2018). We used auto-correlation function plot to visually assess temporal autocorrelation between incidences (Crawley, 2007).

We performed regression, test statistics and correlation tests in Program R (R Core Team, 2019). Projection of human fatality incidences and extraction of geographic information system (GIS) variables at the grid level were carried out in ArcGIS v 10.6.

8.3 Results

A total of 130 incidences of human fatalities due to HEC were reported by the Forest Department during the period August 2017 to April 2020 in northern Chhattisgarh comprising of Surguja and Bilaspur forest circles. Of the total reported cases, we responded to 61 cases of human fatalities.

8.3.1 Spatial occurrence of human fatalities due to elephants

We evaluated 16 binomial regression models using different covariate structures to examine the influence of explanatory variables on the response variable (Table-8.1). The explanatory variables did not have multi-collinearity issues (VIF < 2.5 for all the variables). (Johnson and Omland, 2004) suggest that regression models with ΔAIC < 7 lend support from the data. In the candidate set of 15 models, the top 4 models received similar support with ΔAIC < 6.2 (Table-8.1). Therefore, we model-averaged the top 4 models to obtain parameter estimates of the explanatory variables (Table-8.2).

Intensity of habitat use by elephants emerged as the best predictor of the observed variation in the occurrence of human fatalities. In areas of high habitat use by elephants, the probability of human fatality was higher compared to areas of medium, low and sporadic habitat use by elephants (Table-8.2). Distance to roads emerged as an important predictor in explaining the observed spatial patterns of human fatalities. Relatively high number of human fatalities due to elephants have occurred close to the roads and reduced with distance away from roads (Table-8.2). Furthermore, probability of human fatality due to elephants was high in areas where the MSI of forest patches were relatively high. Furthermore, in areas of high frequency of house damage by elephants, the probability of human fatalities due to elephants was high (Table-8.2). The extent of agricultural area and forest cover within the grid were only weakly informative (Table-8.2). The variables of human population density, extent of built-up area, and distance from the rivers did not receive adequate support from the data. The ROC of the top model was 0.807 indicating good fit and explanatory power of the variables used in the models.

Table-8.1: Summary of model selection to assess spatial occurrence of human fatalities due to HEC in Chhattisgarh

Model	AIC	ΔAIC	AIC weight	Deviance
incident~AG+HD+ELEUSE+MSI+ROD	1069.1	0.0	0.414	1053.2
incident~HD+ELEUSE+MSI+ROD	1069.2	0.1	0.411	1055.2
incident~AG+FOR+HD+ELEUSE+MSI+ROD	1071.1	2.0	0.155	1053.1
incident~ELEUSE+MSI+ROD	1075.3	6.2	0.019	1063.3
incident~ELEUSE+ROD	1090.7	21.6	0.000	1080.7
incident~ELEUSE	1109.7	40.6	0.000	1101.7
incident~ROD	1170.5	101.4	0.000	1166.5
Incident~HD	1188.9	119.8	0.000	1184.9
incident~MSI	1199.0	129.9	0.000	1195.0
incident~AG	1199.3	130.2	0.000	1195.3
incident~FOR	1201.4	132.3	0.000	1197.4
Incident~1 (Intercept only)	1203.1	134.0	0.000	1201.1
incident~PD	1203.8	134.7	0.000	1199.8
incident~BLT	1204.4	135.3	0.000	1200.4
incident~RIV	1204.7	135.6	0.000	1200.7

Incident, presence or absence of occurrence of human fatality; ROD – Euclidean distance between grid and the nearest road, HD, intensity of house damage by elephants in the grid; AG– percentage of crop fields in the grid; BLT – percentage of human settlement in the grid; FOR – percentage of forest cover in the grid; RIV, Euclidean distance from the grid to the nearest stream of 4^{th} order and above; MSI: Mean shape index; ELEUSE: Intensity of habitat use by elephants

Table-8.2: Parameter estimates of the variables in the model averaged top models to assess spatial occurrence of human fatalities due to HEC in Chhattisgarh

Variable	Estimate	SE	95% CI (lower)	95% CI (upper)	*Z*	*P*
(Intercept)	-3.82	0.15	-4.11	-3.53	25.8	< 2e-16 ***
AG	0.17	0.13	-0.09	0.42	1.29	0.19
HD	0.12	0.04	0.05	0.19	3.26	0.00111**
ELEUSE-low	-1.43	0.27	-1.95	-0.91	0.27	1.00e-07 ***
ELEUSE-medium	-1.87	0.36	-2.56	-1.17	5.24	2.00e-07 ***
ELEUSE-sporadic	-2.47	0.46	-3.38	-1.56	5.31	1.00e-07 ***
MSI	0.41	0.10	0.21	0.60	4.09	4.32e-05 ***
ROD	-0.71	0.15	-1.01	0.40	4.59	4.40e-06 ***
FOR	0.03	0.18	-0.32	0.39	0.19	0.84647

ROD – Euclidean distance between grid and the nearest road, HD, intensity of house damage by elephants in the grid; AG– percentage of crop fields in the grid; FOR – percentage of forest cover in the grid; MSI: Mean shape index; ELEUSE: Intensity of habitat use by elephants. * indicates significant *P* values

8.3.2 Characteristics of human fatality incidences due to elephants

To characterize human fatalities due to elephants, only primary cases (n = 61) were used. More men died in comparison to women (χ^2 = 4.73, df = 1, P = 0.02) with significant proportion of victims being adults (χ^2 = 29.88, df = 4, P < 0.01). Deceased were predominantly from tribal communities (χ^2 = 10.45, df = 1, P < 0.01). Human deaths were significantly higher during night (χ^2 = 15.63, df = 3, P < 0.01) and throughout the year with no marked seasonal differences (χ^2 = 2.10, df = 2, P = 0.34). Although human fatalities occurred both inside and outside the forests, deaths were significantly higher outside (χ^2 = 24.45, df = 1, P < 0.01). Of the total 25 cases of human fatalities that occurred inside the forests, 44% (n = 11) occurred when the victims went to forests for collecting forest produces. About 32% (n = 8) occurred when the victims were commuting in the forest roads or trials either on foot or in two wheelers. A small fraction of incidences occurred when the victims went to forests for herding livestock (12%, n = 3) or simply watching elephants (12%, n = 3). Of the total 36 cases of human fatalities that occurred outside the forests, about 47% (n = 17) occurred in crop fields and 47% (n = 17) occurred in and around human settlements. Two incidences occurred in roads outside the forests.

Bull elephants were more involved in human fatality incidences than breeding herds (χ^2 = 35.78, df = 1, P < 0.01). There was evidence for some level of spatial clustering of incidences (Moran's I = 0.29, P < 0.01). Temporal autocorrelation between the days of human fatalities was significant at lag-1 (Fig-8.2).

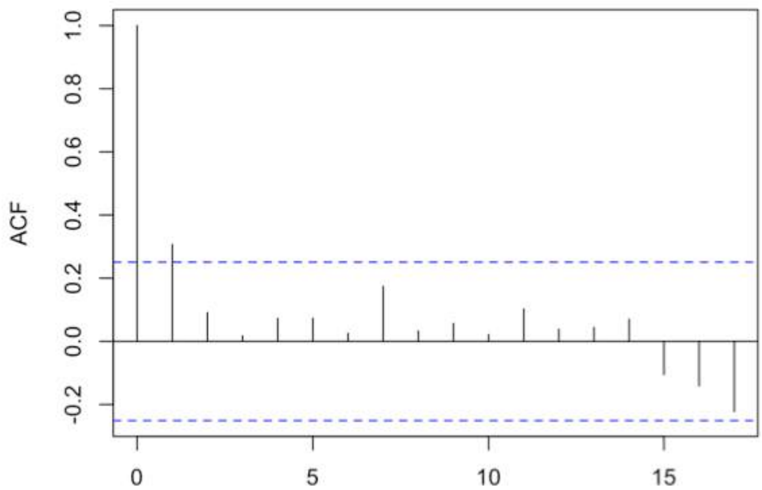

Fig-8.2: Temporal autocorrelation of the dates of human fatality due to elephants in Chhattisgarh. At lag-1, the autocorrelation between the dates of human fatality incidences is significant

8.4 Discussion

8.4.1 Spatial occurrence of human fatalities

Our assessment demonstrates that in northern Chhattisgarh, probability of occurrence of human fatalities corresponds with areas of high habitat use by elephants. About 70% of reported human fatalities occurred in areas where habitat-use by elephants was relatively high (Fig-8.3). Intuitively, in the mosaic of human–dominated patchy landscapes with high level of elephant habitat-use, the frequency of interactions between elephants and people would be high (Ram et al., 2021). Outside the areas of high habitat-use by elephants, nearly 30% of human fatalities have occurred in areas of intermediate and low habitat-use by elephants. This presents a unique challenge for management, as those incidences would be difficult to foretell owing to sporadic elephant movement.

Our results further suggest that probability of human fatalities was high along the main roads. In northern Chhattisgarh, forests are interspersed with villages, settlements, and crop fields with numerous roads passing through the mosaic landscape. Elephants regularly cross these roads, particularly during the low light hours when moving between forest patches. Elephants may also use man-made trials and roads with less traffic for their directed movement (Natarajan et al., 2016). Local people too actively use these roads throughout the day for regular commuting. There were many fatal human encounters with elephants while commuting on roads. In particular, villagers walking, cycling or commuting on motorcycles during late in the evening are particularly vulnerable. Sudden encounters between elephants and people on roads can trigger fright response in both, which sometimes could elicit fatal attacks on people by elephants.

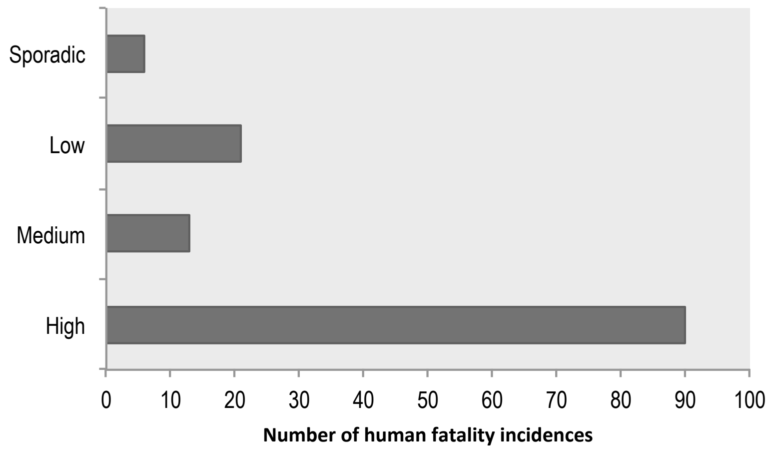

Fig-8.3: Human fatalities due to elephants in different intensities of elephant habitat-use

Our results also indicate that in forest patches with higher MSI have high probability of elephant-related human fatality. Higher MSI values are indicative of shape complexity, which translates into higher perimeter to surface area with relatively long interface areas that predispose frequent interactions with people (Gubbi, 2012). This is the plausible explanation for probability of human fatalities being high in forest patches with high MSI.

Furthermore, the probability of elephant-related human fatalities was high in areas that reported frequent house damages by elephants. House break-ins by elephants is widespread in Chhattisgarh and may be related to easy access of stored grains and salt (personal observation).

Plate-8.1: Group of elephants approaching a house to raid stored grains in Balrampur district

Plate-8.2: A sub-adult bull that entered a settlement in Surajpur district

During the period 2015 – 2019, a total of 6916 incidences of house damage by elephants were reported from across 11 Forest Divisions and 2 Protected Areas (Tamor Pingla Wildlife Sanctuary and Guru Ghasidas National Park) involving 748 villages (including settlements) (Source: Chhattisgarh Forest Department). House break-ins by elephants create abject fear among local communities as it invariably occurs during the night hours leaving inhabitants of the house dumbfounded and helpless. Houses in the landscape were typically fragile mud-walled huts with flimsy tile-roofs, which elephants can easily push down. Low resistance offered by people towards elephants while breaking houses could embolden elephants, habituate them resulting in cultural transmission of the behaviour to other elephants too (Moss, 2012). Akin to elephants, brown bears (*Ursus arctos*) in Asia too are known for house break-ins resulting in huge economic losses and injuries (Dai et al., 2019; Worthy and Foggin, 2008). In case of bears, the problem would possibly remain with few individuals. However, in case of elephants the behaviour can rapidly spread across population and thus, presents even greater challenge to manage.

Plate 8.3: A house damaged by elephants in Surajpur district

8.4.2 Characteristics of human fatality incidences

Of the 61 primary cases of human fatalities recorded in the field, most of the victims were men – a pattern consistent with other elephant ranges too (Sukumar, 2003, 1985). This was owing to gender division of labour wherein men were mostly engaged in activities like guarding crop fields during night, driving away elephants, and travelling during low-light hours. As adult men were invariably the principal earning members of the families, losing them can be financially devastating for families with negative feedback on children's education (Thondhlana et al., 2020). Further, preponderance of HEC victims belonging to tribal communities could reflect their livelihood aspects that were predominantly agricultural and forest dependent in comparison to other communities that were entrepreneurial. Tribal communities in the landscape depend on forests for livelihood, and collect a number of non-timber forest products, fuel wood, and fodder across all seasons. This was likely a reason for lack of seasonal differences in human fatalities as interactions between people and elephants could occur throughout the year. High fraction of human fatalities occurred outside the forests. In relatively intact elephant habitats, human fatalities were often higher inside the forests where elephants mostly occurred (Sukumar, 2003). In such areas, crop damage by elephants was often limited to a predictable zone of agricultural fields juxtaposed forests (Gubbi, 2012; Williams et al., 2008). In Chhattisgarh, most human deaths have occurred outside forests. This was likely due to undefined elephant home ranges and convoluted landscape mosaic of forests interspersed with settlements with significant movement of elephants outside of forests (Chapter-5). Outside forests, human fatalities occurred in both agricultural fields and around human settlements.

Plate-8.4: High fraction of elephant-related human fatalities were due to young males that are difficult to monitor in human-use areas

The preponderance of involvement of elephant bulls in human fatality incidences corroborates with reports from other landscapes too (Ram et al., 2021). Bull elephants can range widely and often unpredictably through human-use areas (Keerthipriya et al., 2020). Further, dispersing young bulls might lack social buffering of the herds making them excitable during interactions with people. In spite of the problem, monitoring young elephant bulls in human–dominated areas is a challenge. Even use of advanced satellite tracking technology can be limited to only a few individuals. Behavioural ecology bull elephants in human-dominated areas remain less understood and calls for long-term investigation.

8.4.3 Ecological perspectives on human fatalities by elephants

Wildlife-related human causalities are often correlated with proximate behavioural stimuli like stress, physiological status, and instantaneous human disturbances (Naha et al., 2019). However, it is essential to consider (i) cumulative proximate causes and (ii) evolutionary roots of behavioural responses of the animals towards people. These two considerations would be important to identify appropriate long-term conflict mitigation strategies. The cumulative proximate causes indicate that the accumulation of negative interactions between people and elephants can reach a tipping point culminating into animal's aggressive response. (Howard and Herroro, 2005) expounded on provoked and unprovoked attacks by animals on people. This classification can be quite subjective as the seemingly 'unprovoked' attacks could simply be accumulative of negative responses crossing threshold levels of tolerance.

In addition to proximate reasons, the ultimate drivers of aggressive response of wildlife towards people may stem from evolutionary relationships. Elephants (and their extinct forms) and people share an evolutionary relationship of prey and predators respectively (Sukumar, 2003). As suggested by (Frid and Dill, 2002), in systems where people have hunted animals over evolutionary times, even presence of people without any apparent threat can rarely be synonymous to predation stimuli that could elicit defence–offence strategies.

Thus, in landscapes where human–elephant coexistence is envisioned, minimizing the overall frequency of negative interactions by promoting spatio-temporal avoidance mechanisms between people and elephants would be critical. Conflict-related mortalities of both elephants and people can render co-occurrence in shared landscapes difficult even if larger public far-off from the field favours co-existence.

8.4.4 Management perspectives on elephant-related human fatalities

As high fraction of human fatalities due to elephants has occurred in areas of high habitat-use by elephants, institutionalizing elephant monitoring by actively involving village volunteers would be important. It also emerges that strengthening community-based early-warning systems by broadcasting elephant location details could help in minimizing the frequency of negative interactions between people and elephants, particularly in common places like roads, bus-stands etc (Kumar and Raghunathan, 2014). With regard to the problem of house damage caused by elephants, till long-term solutions aimed at discouraging elephants from approaching houses are advanced, experimenting seasonal barriers to prevent elephants from entering human dwelling areas would be critical. Such barriers need to be ingeniously designed with high efficiency and cost effectiveness so that local communities can be incentivized to invest on them. Ideally, aberrant elephant behaviours like damaging houses; kitchens and ration shops should be identified early and rectified through aversive conditioning or other appropriate strategies before it spreads into many individuals. While negative conditioning of free ranging elephants is not an easy proposition, non-lethal approaches aimed at instilling fear in elephants to desist from damaging houses can be cautiously experimented duly considering the legal requirements. To perpetuate human–elephant coexistence in a landscape, healthy fear of people among animals may be essential to promote avoidance behaviour in animals with an overarching aim of reducing interactions between both the species.

Further, as our results indicate spatio-temporal autocorrelation in incidences, onset of a human fatality incident should result in enhanced monitoring and vigilance by the forest department in anticipation of more incidences, particularly for the first few days following an attack.

While the aforementioned deal with symptoms of HEC, the long-term objective of the management should be to address the ultimate causes. In the east-central region, integrity of elephant habitats was compromised for mineral mining, infrastructural development and food production. Sustained threats to elephant habitats can reduce their carrying capacity triggering elephant dispersals into sub-optimal and unviable habitats (insular and smaller relative to elephant home ranges) resulting in heightened conflict with people. For east-central region and Chhattisgarh in particular, implementing ecologically sound land-use policies prioritizing elephant conservation over infrastructure and mineral mining development in identified elephant habitats would be vital to minimize elephant displacement. Alongside, monitoring elephant dispersals and limiting their range expansion into unviable habitats would be essential to minimize the zone of HEC.

8.4.5 Methodological limitations

Developing predictive models to determine spatial patterns of human–wildlife conflict is important for management, but remains a challenge (Hoare, 1999). Even with relatively large multi-species dataset on large felids, (Packer et al., 2018) could not get a strong inference on patterns of human attacks. (Sitati et al., 2003) developed spatially explicit regression models to predict crop losses by African elephants in Kenya, but couldn't extend the models to explain human casualties. In this study, we obtained broad correlates of human fatalities with some level of statistical credence. The explanatory power of the models can be significantly improved possibly by including two of the important variables namely human and elephant behavioural variables. Human fatality is an outcome of physical interaction between elephants and the human victim in different contexts and circumstances.

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CHAPTER-9

HOUSEHOLD PERCEPTIONS OF RISK TOWARDS ELEPHANTS AND ATTITUDE TOWARDS CONSERVATION IN SURGUJA

9.1 Introduction

The synergy of global change and human–induced alterations to natural habitats are exerting sustained pressures on myriad wildlife species with challenges to survival (Pimm and Raven, 2000). Without major conservation interventions, several species of plants and animals may face threat of local extinction (Ceballos et al., 2017, 2005; Ceballos and Ehrlich, 2002). Among the various conservation efforts urgently required, generating favorable public opinion and garnering the support of local community stakeholders are paramount (Bandara and Tisdell, 2003; Woodroffe et al., 2005). However, gaining support for conservation can become a challenge when conflict-related costs pit local communities against wildlife (Gillingham et al., 2003; Ravenelle and Nyhus, 2017; Woodroffe et al., 2005). Co-existence between wildlife and local communities can get further strained when human lives are lost during conflict situations (Woodroffe et al., 2005). Promoting co-existence in human–dominated mosaic landscapes characterized by high human–wildlife interface rests on effective and timely resolution of human–elephant conflicts aimed at allaying fears, offsetting losses as possible following empathetic and inclusive management approach. Conflict resolution entails technical approaches driven by ecological underpinnings of the species and landscape concerned, along with societal factors like stakeholder perception and consequent attitudes (Dickman, 2010; Dickman et al., 2011; Guerbois et al., 2012). Local attitudes towards conservation could be shaped by myriad factors like perceived risks to life and livelihood; past experiences, benefits gained from conservation, expectations and local religious and cultural belief systems (Dickman, 2010; Peterson et al., 2010).

Asian elephants, *Elephas maximus*, typify the challenges facing conservation of endangered species in human–dominated landscapes. Although revered for cultural reasons and range countries attach high conservation values, human–elephant conflict can render managing elephant populations and their habitats difficult. Areas of acute human–elephant conflict (HEC henceforth) are often rural affecting marginal communities. India harbors over 60% of extant wild Asian elephants, and HEC is widely acknowledged as one of the major threats facing elephant conservation in the country (Blake and Hedges, 2004; Gubbi et al., 2014; Rangarajan et al., 2010). In areas where HEC is recurrent, local communities may start perceiving elephants as a direct threat to life, livelihood, and food security (Barua et al., 2013). In India, the remnant elephant ranges areas are small, isolated and have long human–interfaces with frequent human–elephant interactions. There are also landscapes where HEC has started surfacing quite recently and show increasing trends. In those landscapes managing HEC can be far more challenging due to the following reasons (Daniel et al., 2008). (i) The institutional capacities to deal with HEC would be low due to inadequate exposure and prior experience. (ii) Awareness levels of local communities would be very low. (iii) Often, suitable habitats for elephants may not be available.

Chhattisgarh in the East-Central region has emerged as conflict hotspot grappling with crop losses, house break-ins by elephants and increasing HEC-related human fatalities (Nigam et al., 2021; Pandav et al., 2019). The communities affected by HEC in the state are predominantly socially disadvantaged tribes, who depend on forests for energy, food, medicine and income needs. As illustrated by Struebig et al.,

(2018) in case of evaluating coexistence between people and tigers in Sumatra, understanding household behaviour and resource use by local communities can be invaluable in devising conflict mitigation strategies aimed at minimizing interactions between people and elephants. Furthermore, as involvement of local communities is inevitable for successful implementation of conservation and conflict mitigation initiatives (Natarajan et al., 2021), evaluating attitudes towards elephant conservation could be useful to identify thrust areas that can bridge the gap between wildlife management and local communities. With these aims, we assessed local villagers' farm and off-farm activities that potentially increase the likelihood of contact with wild elephants, and discuss management options to reduce negative interactions with elephants in Surguja, Chhattisgarh. Further, we quantified attitudes towards of local communities towards elephant conservation and deliberate on the drivers of such attitudes.

9.2 Methods

9.2.1 Household surveys

We conducted our surveys during the period 20th March 2018 to 01st June 2018. We prepared a 5-page questionnaire containing 51 questions that focused on (1) respondents' household and demographic details, (2) off-farm activities, (3) resource dependence on forests, (4) activities that increase the likelihood of contact with elephants and (5) attitudes towards elephant conservation and HEC. We explained the purpose of our survey and obtained prior verbal consent from the respondents before administering the questionnaires. We selected households based on access and readiness of the respondents to participate in the survey. Village communities in Surguja are endogamous as well as homogenous. Therefore, instead of increasing sample size of respondents within settlements, which would be redundant, we tried to maximize spatial coverage, and representation by interviewing respondents from different settlements. Two interviewers from Surguja with interest in conservation and familiarity of local language (Surgujia) and communities were trained and accompanied by LN (N. Lakshminarayanan) for conducting interview surveys.

9.2.2 Attitude scores and likelihood of encounters with elephants

To quantify individual attitudes of respondents towards elephant conservation, seven questions from the interviews were used. Following Suryawanshi et al., (2014), score of (-1) was assigned for negative response, (0) for neutral or no response, and (1) for a positive response for each question and cumulative scores per individual were calculated. The scores could range between (-7) (if all the responses are negative) and (+7) (if all the responses are positive). A positive cumulative score would indicate favorable attitude towards elephant conservation and negative score, otherwise. Seven explanatory variables that could potentially influence respondents' attitude towards elephant conservation were included in the regression models (Table-9.1). The variables extent of crop and house damage by elephants in the villages was collated from Forest Department records. Other independent variables used in the regression models were recorded during the interviews. The variable 'cumulative dependence' used in the models was calculated by adding the responses pertaining to use of forest resources by the respondents.

Linear regression models were built to evaluate the effect of independent variables on the response variable (attitude scores calculated for respondents using interview responses). Candidate set of 9 regression models were built (Table-9.2) and information theoretic approach was followed for model selection (Burnham and

Anderson, 2002). The statistical analysis was performed in Program R (V. 3.6.2) (R Core Team, 2019).

Table-9.1: Variables selected to model respondents' attitudes towards elephant conservation

Variable	Name in regression model	Measurement	Expected influence on attitude towards conservation
Frequency of crop damage by elephants at the village level	Crop Loss	Sum total of elephant crop raiding incidences reported in the village for the period 2015-2018	Relatively high frequency of crop raiding will negatively influence attitudes
Frequency of house breaking by elephants at the village level	House Damage	Sum total of elephant house breaking incidences reported in the village for the period 2015-2018	Relatively high frequency of house breaking by elephants will negatively influence attitudes
Elephant related human fatality at the village level	Human Fatality	Occurrence of human fatalities due to elephants during the period 2015-2018	Human fatality at the village level will negatively influence attitude
Extent of dependence on forests	Dependence	Cumulative score. Calculated by adding forest-based resources used/collected by respondents	Respondents highly dependent on forests will have positive attitude
Satisfaction on ex-gratia compensation payment paid by Forest Department	Compensation	Dichotomous response of whether or not the respondent is satisfied with compensation received from Forest Department for the crop losses	Respondents with low levels of crop compensation will have relatively high levels of negative attitude
Age of respondent	Age Group	Self-reported age of respondents classified old, very old, adult, teen and young	Old and very old respondents will have negative attitude
Education and literacy	Education	Self-reported education status (educated/not-educated)	Respondents not educated would be more dependent on forests and land and would perceive elephants a direct threat to livelihood

To assess the relative likelihood of households' activities that predispose encounters with elephants, for each activity, we quantified the number of people engaged that particular activity, and number of people reporting encounters with elephants while doing it. We used Chi-Square goodness-of-fit-test to test if the likelihood of encountering elephants differed significantly between the self-reported activities (Sokal and Rohlf, 2012). For significant difference, we calculated odds ratio to rank activities in the order of relative risks.

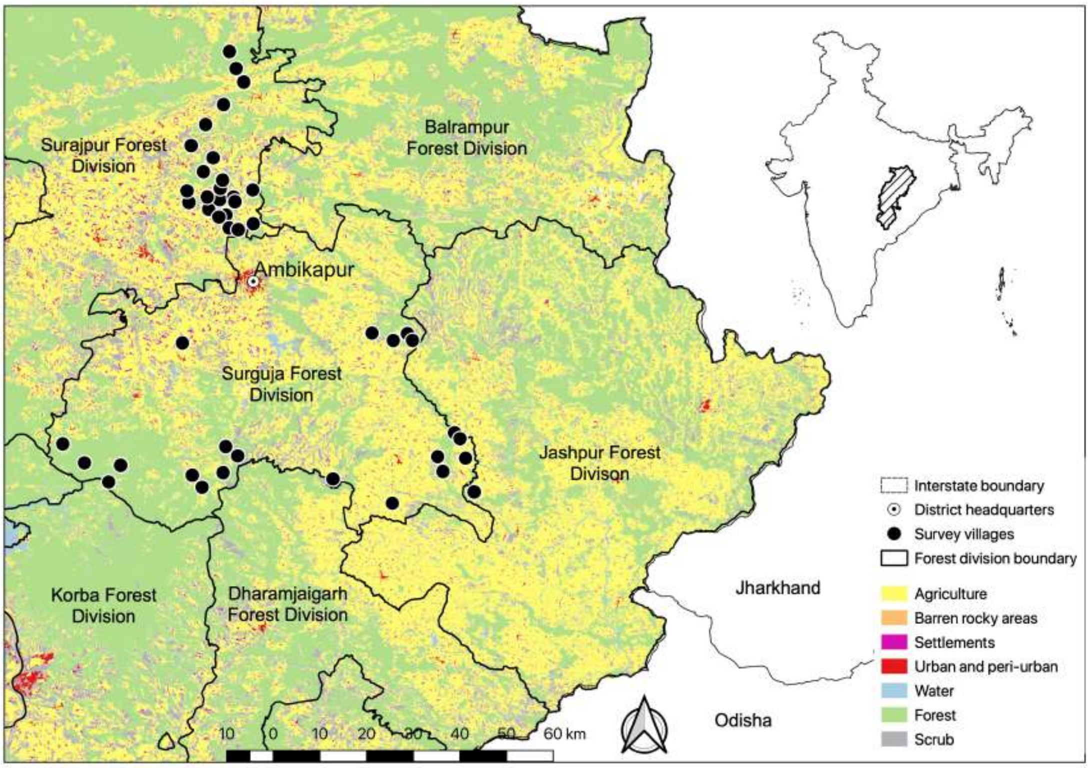

Fig-9.1: Location of villages surveyed in Surguja and Surajpur districts in northern Chhattisgarh

9.3 Results

9.3.1 Household characteristics, agricultural practices and forest dependence

A total of 180 individuals from 51 settlements [mean = 3.5 (±1.3)] were interviewed (Fig-9.1). About 29% (n=52) of respondents were women. The respondents were predominantly adults, with a mean age of 36 ± SD 13, (range = 16 to 80 years) and mostly tribal (92%, n =166). Over 23% (n = 42) of respondents were Gonds (a forest-based tribal community distributed in the Central Indian states of Chhattisgarh, Maharashtra and Madhya Pradesh). Over 56.5% (n = 115) of respondents had basic primary education (56.5%, n = 115) and a small fraction of them (3.8%, n = 7) were college graduates too. The primary occupation of the respondents was agriculture (96%, n = 173) and allied farm-based activities. Over 96% (n = 170) of respondents' own livestock, which are mostly grazed in the forests (66%, n = 117) and taken to water bodies inside the forest for watering (78%, n=123). About 99% (n = 179) of respondents collect a variety of minor forest products from the forests for their own bonafide use, sale in local markets, and to government contractors as daily wage laborers (Table-1).

9.3.2 Attitudes towards elephant conservation

The mean (±S.D) attitude score of households towards conservation was -1.2 (± 1.9), Range = -6 – 4. The best model explaining respondents' attitudes towards elephant conservation had two variables namely, satisfaction towards compensation received from the Forest Department for elephant-related crop losses and respondents' cumulative dependence on forests (R^2= 0.39, p < 0.01, Table-2). Respondents satisfied with compensation paid by the forest department elicit relatively favorable attitudes towards elephant conservation (β =2.28 ± 0.26, p < 0.01). Compensation paid by forest department had the highest explanatory power on respondents' attitudes (R^2= 0.36, p < 0.01). Respondents with self-reported relatively high-level of dependence on forests elicit favorable attitudes towards conservation (β =0.176 ± 0.05, p <0.01). However, the independent explanatory power of the variable was relatively low (R^2= 0.10, p < 0.01).

Table-9.2: Model selection results: Effect of independent variables on cumulative attitude scores towards elephant conservation

Model	AIC	DAIC	R^2	P
CumScore ~ Compensation + Dependence	601.10	0	39.88	<0.01*
CumScore ~ Compensation	608.49	7.39	36.20	<0.01*
CumScore ~ CropLoss	707.24	106.14	0.40	0.41
CumScore ~ Dependence	744.21	143.11	10.30	<0.01*
CumScore ~ HouseDamage	751.68	150.58	0.54	0.33
Intercept only model	761.40	160.30	NA	NA
CumScore ~ HumFatality	761.20	160.10	1.28	0.13
CumScore ~ Education	763.63	162.53	0.06	0.73
CumScore ~ Age	767.44	166.34	1.27	0.68

CumScore = cumulative attitude score, CropLoss = Crop loss incidences in the village, Compensation = satisfaction towards compensation paid by FD, Dependence = Extent of dependence on forests, CulArea = Cultivated area owned by respondent, HouseDamage = elephant-related house damage incidences in the village, Age = Age of the respondent, Education = Education status of the respondent

9.3.3 Activities that increase likelihood of elephant encounters

Most of the respondents we interviewed reported interactions with wild elephants during different spheres of their daily activities. The likelihood of encountering elephants differed significantly between the five self-reported activities of respondents (χ^2 = 290.2, df = 4, $P < 2.2e^{16}$). Amongst the activities that increase the likelihood of contact with elephants, the odds of suddenly encountering elephants is highest, as well as significant while passing through narrow forest roads and trials (Table-9.3). NTFP (non-timber forest produce in India) and firewood collection from the forest emerge as second and third significant activities that increase the likelihood of sudden encounters with elephants (Table-9.3). The odds of encountering elephants while working in the crop fields adjacent to forests and herding livestock in the forest were not significant (Table-9.3).

Table-9.3: Odds ratio of activities that increase the likelihood of encounters between people and elephants in select villages in Surguja

Activity	# Resp. doing	# Encountering elephants	# Not encountering elephants	Odds	Ln (Odds)	SE (Odds)	Back transform	95% CI	Lower CI	Upper CI	Significance
PASS	178	172	6	28.67	3.36	0.41	1.51	2.96	25.7	31.64	Yes
NTFP	179	163	16	10.19	2.32	0.26	1.29	2.54	7.64	12.73	Yes
FIRE	175	140	35	4.00	1.39	0.18	1.20	2.36	1.63	6.37	Yes
CROP	173	62	111	0.56	-0.58	0.15	1.17	2.29	-1.74	2.86	No
LVS	124	38	86	0.44	-0.82	0.19	1.21	2.38	-1.94	2.82	No

PASS: Passage through forest, NTFP: Non-timber forest produce collection, FIRE: Firewood collection, CROP: Working in crop fields next to forests, LVS: Livestock grazing.

9.4 Discussion

9.4.1 Attitudes towards conservation

The mean attitude scores of households interviewed in Surguja towards elephant conservation were negative. This differs from findings reported from Kaziranga landscape in Assam, Northeast India, where Vasudev et al., (2020) reported that stakeholders' attitude towards elephant conservation was positive. The possible reasons for the difference in attitude are important to elucidate: Although Chhattisgarh supports only 250 to 300 wild elephants (Chapter-3) – a mere 1% of India's wild elephant population, it loses over 60 human lives annually (Chapter-8), which constitutes about 15% of HEC-related human fatalities reported in India. Thus, per-captia human deaths with respect to elephant population are disproportionately high in Chhattisgarh. Wildlife-related human fatalities, particularly those involving large mammals can create abject fear, trauma and antipathy amongst local communities towards wildlife (Desai and Riddle, 2015; Sukumar, 2003; Woodroffe et al., 2005), which possibly is the case in Surguja. Further, wild elephants have been integral part of Kaziranga landscape for time immemorial, and consequently, local communities reportedly believe that elephants have intrinsic rights to exist regardless of HEC (Vasudev et al., 2020). In contrast, elephants became locally extinct in Chhattisgarh during 1920s and their re-colonization began only two decades ago (Chapter-3). Therefore, in the living memory of local communities in Chhattisgarh, elephants may be relatively “new”.

Attitudes towards conservation can be shaped by numerous factors like economic benefits, cultural attachment, and past personal and societal experiences with the species (Bandara and Tisdell, 2003). Our results demonstrate that *ex gratia* payment of Forest Department towards elephant-related crop and property losses elicit favorable attitudes. Chhattisgarh forest department presently provides *ex gratia* to victims of HEC at the rate of US$ 300 per hectare of standing crop damaged by elephants; US$ 1300 (upper limit) for house damage and US$ 8000 to the kin of a human victim of HEC. *Ex gratia* payment towards wildlife-related losses is a stopgap arrangement, intended to assuage affected people for their immediate losses to reduce animosity (Bulte and Rondeau, 2005; Madhusudan, 2003; Ravenelle and Nyhus, 2017). The process of filing for *ex gratia* claims is cumbersome and involves heavy paperwork (Madhusudan, 2003). This delay in getting compensated, albeit meagerly could lead to delay, despair and resentment amongst stakeholders (Barua et al., 2013; Gubbi, 2012). Nonetheless, from management perspective, budgeting for HEC-related losses is difficult as conflict is not easily predictable. Ironically, without budgetary allocations, it is difficult to pay ex gratia on time. Further, issues like poor literacy among farmers; difficult logistics, inadequate staff, graft, false claims and favoritism may hinder the process of paying compensation.

Regardless of these practical challenges, for poverty-stricken local communities in northern Chhattisgarh with an average monthly income of less than

US$ 60, timely monetary relief to losses is indispensable. Without such reliefs, affected families that are already impoverished would suffer from debts. Therefore, streamlining the process of filing, assessing, and providing compensation through technological innovation, such as developing mobile-based applications that field staff can use to reliably survey crop damage would be beneficial. In Surguja, because elephants range over a vast tract of mosaic landscape comprising of forest patches embedded in human-use areas, HEC primarily occurs in revenue villages outside the jurisdiction of forest department. It is a paradox that forest department is solely managing HEC in such landscapes. Involvement of district administration (which manages general administration of a district in India) and state agricultural department in HEC management is imperative. Hitherto, these departments in most areas remain aloof to the problem of HEC. With an active involvement of district administration and agricultural department, it is easier to implement schemes like Pradhan Mantri Fasal Bima Yojana (Prime Minister's crop insurance scheme) – federal Government's crop insurance scheme (https://pmfby.gov.in) in villages that suffer recurrent conflict.

The second variable in our model that influences household attitudes towards elephant conservation is forest dependence by households. Households with a relatively high level of dependence on forests elicit favorable attitude towards conservation. As suggested by (Dickman, 2010), households with high level of dependence on forests may perceive elephant-related risks as occupational hazards since the risks are often undertaken voluntarily. In Surguja, households collect a variety of minor forest products that provide income benefits as well. Getting such direct benefits may arouse positive attitudes towards conservation in general (Gillingham et al., 2003).

9.4.2 Interactions with elephants and risk perceptions

Many households reported encountering elephants during low-light hours in forest roads and trials while returning back to their dwelling places from place of work. This corroborates with detailed analysis of human fatalities as well (Chapter-8). Further, although income benefits from forest produce collection elicit favorable attitude towards conservation, NTFP collection increases the likelihood of sudden encounters with elephants and other wild animals like sloth bears (*Melursus indicus*) (Rajpurohit and Krausman, 2000).

Plate 9.1: NTFP collection such as collection of *tendu* (*Diospyros melanoxylon*) is a major source of income for local communities

Our results demonstrate that risk of encountering elephants during firewood collection is lower than that of NTFP collection or commuting through forest roads. This is likely the result of villagers collecting firewood from forest edges than interiors, as head-loads of wood cannot be carried for long distances unlike minor forest produces, which may require traversing forest interiors. Regardless of risk severity, implementing centrally sponsored scheme to provide clean cooking fuel to poor communities, Pradhan Mantri Ujjwala Yojana (https://pmuy.gov.in), in HEC hotspots might help in reducing firewood dependence and also frequent interactions with elephants.

9.5 Conclusion

In landscapes where HEC is emergent, such as Surguja, it might take time for the local communities to fully understand the risks involved in co-existence with elephants. Our results indicate that empathic approach by actively involving local communities and risk sharing (providing *ex gratia* is a risk-sharing strategy) can improve local attitudes towards conservation. While developing positive attitudes and willingness to share space with elephants are essential in habitats that are viable for elephant conservation, nurturing co-existence may be depend on developing institutional mechanisms to deal with HEC whenever it escalates. Furthermore, our results also hint at possibilities of engaging with local communities to modify farm and off-farm practices to minimize negative interactions with elephants.

Although urban class favors elephant conservation, it is often rural stakeholders who profoundly influence elephant survival in shared landscapes (Bandara and Tisdell, 2003). Therefore, evolving participatory HEC management approaches, by involving local communities in conflict resolution is pivotal, as they would gain firsthand experience, which can trickle into community at large. As human developmental activities continue to fragment natural habitats interface between elephants and people would inevitably increase. Consequently, cautious co-existence with socially manageable levels of HEC appears inevitable for conserving elephants due to their large home range needs. While co-existence with elephants is easy to advocate, implementing it in the field hinges of fine-scale reconciliation of human activities and habitat needs of elephants.

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CHAPTER-10

SYNTHESIS AND CONCLUSIONS

The combined impacts of habitat loss, poaching and human–elephant conflict have rendered Asian elephants (*Elephas maximus*) endangered throughout their range. Outside of India and Sri Lanka, the elephant habitats and populations are under even more serious threat, which is further exacerbated by severe paucity of information (Leimgruber et al., 2008, 2003). India holds the largest wild Asian elephant population among the 13 range countries. Enablers of elephant conservation in India include the cultural significance of the species that elicits strong public opinion in favour of elephant conservation, relatively high tolerance of local communities towards wildlife in general, strong legislations, and the Institutional framework and capacity to implement conservation priorities. In India, the elephant populations have been holding steady and even growing in some landscapes. The official population estimates indicate that about 30,000 elephants occur in India across the four regions of Northern, North-East, East-central and Southern (Project Elephant Division, 2020). Although the population trends seem encouraging, the same cannot be said of elephant habitats, which continue to be under myriad threats resulting in fragmentation of populations and perpetuation of human–elephant conflict.

Although human–elephant conflict is widespread across the four regional elephant populations in India, in the East-central region comprising of Odisha, Jharkhand, Chhattisgarh and South West Bengal (and lately north Andhra Pradesh and Madhya Pradesh) the conflict is particularly acute. East-central region supports less than 10% (around 2500 elephants) of the wild elephant population in India, but accounts for over 50% (> 200 lives) of reported conflict-related human fatalities.

Addressing human–elephant conflict in the East-central region is complex and challenging, particularly in light of elephant dispersals (this is not post-natal dispersal of male elephants, but involve 'environmental dispersal'[6]) into new areas spreading the zone of conflict. The human–elephant conflict that intensified in the East-central region after 1980s clearly correspond with large-scale habitat disturbance wrought in by mineral mining activities and associated development (Singh et al., 2002; Singh, 2002; Singh and Chowdhury, 1999).

Elephant management in Chhattisgarh represents issues facing environmental dispersal of elephants in human–dominated areas. In relative terms, human–elephant conflict in Chhattisgarh is recent (about two decades old). But, the extent and severity of human–elephant conflict in Chhattisgarh are high necessitating basic research on elephants. Managing human–elephant conflict without conducting basic ecological research focusing on demography, ranging behaviour, habitat utilization and social aspects is akin to proverbial wild-goose chase resulting in fruitless pursuit despite investing painstaking efforts. This lacunae is partly addressed by the multi-dimensional research carried out by Wildlife Institute of India under which, this thesis is also a part.

In this chapter, the findings of different technical chapters presented in the thesis are coherently condensed. Overall, the thesis can be broadly classified into two related sections. While chapters-4, 5 and 6 elucidate on basic elephant ecology, chapters 7,8 and 9 deals with aspects of human–elephant conflict elucidating patterns, processes and management options to address the problem.

In the introductory chapter (**Chapter-1**), I elaborated the context and provided compelling reasons for investigating applied research objectives that were

[6] Environmental dispersal refers to dispersal of animals triggered by resource saturation in their home ranges caused either by habitat loss or increased population (Sinclair et al, 2006)

dealt in the thesis. I have also argued why it was essential to pursue applied research that is immediately relevant for management rather than pursuing theoretically stimulating hypothesis driven research. Following the introductory chapter, I described the landscape, its flora and fauna, human communities, land-use, and forest management in **Chapter-2**.

Chapter-3 provided a historic overview of elephants in East-central region in general and Chhattisgarh in particular based on review of relevant literature. The review discusses how vulnerable small elephant populations would be to demographic stochastic events that can cause local extinctions. Further to this, the review confronts the presupposition of wildlife ranges being 'static'. Clearly, elephant distribution range in the East-central region was not static and there was evidence for population-level redistributions marked by pulses of local extinctions and range re-colonization. The review also indicated that range expansion of elephants was not limited to Chhattisgarh as similar range expansions occurred in numerous other landscapes as well. Lastly, the Chapter-3 highlighted the importance of political economy of the states and how forestry policies seemingly unrelated to elephants can eventually have a bearing on elephant distribution and human–elephant conflict. I have argued that change in elephant occupancy would be a more sensitive metric to monitor than aspiring for estimating elephant abundances. Elephant occupancy can be easily assessed through beat-level interview surveys (gauging periodic presence/absence) and augmented with information on human–elephant conflict. The change in elephant occupancy over time can be correlated with variables like habitat loss, change in land-use and others.

Chapter-4 provided details on elephant distribution, abundance and other demographic variables. During the period 2000 to 2020, the elephant numbers in the Chhattisgarh had increased due to immigration and in-situ births. The current population estimate (2021) was around 250, which occurred in 16 forest divisions and four protected areas in the northern and central Chhattisgarh. It is noteworthy that since 2021, elephants have started ranging in southern districts of Chhattisgarh. The adult sex ratio recorded during the study was 1:4.5. Eleven adult bulls were identified during the study. About 44.2% of the female segment of population comprised of adult cows. In the sub-adult segment of population, the males were numerically higher and this was likely due to high turnover of sub-adult males as a consequence of dispersals. Body condition scores of elephants were optimal. Inter-calf interval was estimated to be about 3.4 years, which is relatively low. Conservation biologists that studied Asian lions (*Panthera leo*) rue that the lion population in Gir National Park, Gujarat represent the scenario of "all the eggs in one basket", whereby; the entire can be driven to extinction if anything adverse to the population as all the lions are in one place (Saberwal et al., 1994). The reverse of this appears true for elephants in Chhattisgarh. Although the number of elephants in Chhattisgarh oscillates around 200 to 250, the groups are spatially scattered and continue to move apart farther. If these spatially scattered groups get isolated overtime (which is a likely scenario given the pace of infrastructure development), they will become vulnerable to local extinction. Unlike species with relatively shorter longevity, extinction of elephants may not appear sensitive as the living members of the population can live longer creating an illusion that elephants are doing well.

Chapter-5 provided an assessment of elephant home ranges in Chhattisgarh. Elephant home ranges in Chhattisgarh were studied using two different field techniques namely (i) individual recognition and re-sighting (ii) satellite cum radio telemetry. Home ranges were estimated using minimum convex polygon (MCP) approach that provides a geometric representation of elephant home ranges and the kernel density estimates (KDE) that produces utility distribution based on location fixes. Seven elephants were collared and five were monitored for longer duration. Further, two groups of elephants were monitored using “re-sighting” approach. The average home range of elephants recorded during the study using 95% MCP approach was 2571.4 km^2 (SD ± 2300.2 km^2, Range: 256.2 – 6969.7 km^2). The average home range of elephants recorded during the study using 95% KDE approach was 605.3 km^2 (SD ± 509.2 km^2, Range: 246.3 – 662.9 km^2). This suggests that home ranges estimated using MCP approach comprises of a large fraction on unused areas. Conversely, it is also indicated that elephant home ranges include considerable extent of non-forest areas. The time-area curve of monthly home ranges indicated that elephant home ranges were not well defined. Significant shifts in home ranges across years were observed. In general, dry season ranges of elephants were significantly smaller than monsoon and winter seasons. Elephant idiosyncrasies best explained the observed monthly variations in home ranges. Elephant dispersals recorded during the study were elaborated.

In **Chapter-6**, the patterns of habitat selection by elephants were elaborated. Across the year, during all three classified seasons of dry (March to June), monsoon (July to September) and winter (October to February), elephants have spent over 75% of time in forests and 14 – 19% of time in the crop fields. During dry season, the collared cow elephant GI and herd remained almost entirely within the forests in an area measuring 25.5 km^2. For this herd, monsoon and winter months triggered movement of elephants into human–dominated areas. Among the three broad categories of forests namely open, moderately dense and very dense forests classified by Forest Survey of India based on crown densities, elephants selected open forests over the other two types at the landscape-scale. Open forests predominantly occur in human–dominated areas. From results it appears that elephant select forest patches not only based on inherent patch characteristics, but also by the potential foraging opportunities in the human–use areas surrounding the forest patches.

An omnipresent consequence of elephant occurrence in a convoluted mosaic of patchy forests interspersed with human–use areas is the problem of crop foraging by elephants. From human perspective, crop losses can be investigated based on economic considerations, livelihood consequences, and food security. In **Chapter-7**, the spatial patterns and possible determinants of crop losses by elephants were investigated at two different spatial scales. At the landscape-scale covering elephants' distributional range in northern Chhattisgarh, variations in crop loss intensity were assessed. In the intensive study area centered around 1200 km^2 of forest-agriculture crop losses were quantified and also broad correlates were identified. About 1426 villages from 10 forest divisions and 4 protected areas in northern Chhattisgarh reported crop losses during the period 2015-2020 indicating the enormous spatial scale of the problem. At landscape-scale, the explanatory variables of elephant habitat-use intensity, extent of forest cover, number of forest patches, and extent of agriculture explained variations in crop loss intensity. At finer spatial scales, probability of crop loss occurrence was high in areas far from main roads, but closer to forest patches. Practical options to minimize spatial spread of crop losses were discussed.

Chapter-8 focused on one of the most embarrassing issues facing elephant conservation: That of human deaths due to human–elephant conflict. Although over 500 human lives are lost annually due to human–elephant conflict, the issue had somehow evaded empiricism and existing details are often dramatic providing fewer insights to management. An understanding of patterns, drivers and circumstances surrounding human fatalities would be essential for conflict resolution. In Chhattisgarh an average of 60 human lives are lost every year due to human–elephant conflict. A total of 130 incidences of human fatalities due to elephants were assessed to understand spatial patterns. Among 130 incidences, for 61 cases first hand information on circumstances surrounding human fatalities was recorded. Results indicated that about 70% of human fatalities due to elephants occurred in areas of high-intensity habitat use by elephants. The remaining 30% of incidences occurred in areas of intermediate and sporadic elephant habitat use. The latter poses even greater challenge as monitoring elephants in areas where they sporadically occur is difficult. The results further demonstrated that probability of human fatalities was high near the roads. The shape complexity of forest patches added to the effects in explaining the observed variation in probability of human deaths by elephants. Furthermore, the probability of human deaths was high in areas that suffer frequent elephant house break-ins. The practical options to minimize fatal human–elephant interactions were discussed.

Chapter-9 provided insights on attitudes of local communities towards elephant conservation and identified activity patterns of stakeholders that increase their probability of interactions with elephants. This objective was assessed through structured interview surveys targeting 180 households from 51 forest-based settlements in Surguja and Surajpur districts of Surguja region. Among the measured variables, satisfactory compensation paid by forest department for elephant-related losses elicited favorable stakeholder attitudes towards conservation. Household activities that significantly increase the likelihood of encounters with elephants include use of narrow forest trails and roads for regular commutation; collecting NTFP (non-timber forest produce), and firewood from forest.

Plate-10.1: WE herd in the buffer areas of Tamor Pingla Wildlife Sanctuary, Surajpur

Plate-10.2: A perennial stream in the elephant habitat of Lakhanpur range of Surguja Forest Division during peak of summer month

10.1 Management recommendations

Management recommendations appropriate for the topic have been provided in the technical chapters itself so that there is relevance, continuity and flow. The overall general recommendations include:

(i) Restricting spread of human–elephant conflict by adopting a zonation policy that clearly identifies areas where elephants can be conserved in the state and where elephant dispersal need to be strongly discouraged

(ii) In the identified elephant conservation zones, habitat protection and improvement should be prioritized. Mining and associated development, which razed prime elephant habitats in East-central region, should be disallowed across the entire region. If this cannot be achieved, elephant conservation and management may not be possible. Most mitigation strategies touted as measures to reconcile development and conservation is not well-founded to address long-term habitat threats

(iii) Habitat consolidation and restoration should be attempted in Tamor Pingla and Guru Ghasidas NP (in Surajpur and Koriya districts respectively) and the connected territorial division forests complex along with the connected forests in the neighboring states of Madhya Pradesh (Sanjay TR) and Jharkhand (Palamu TR). Developing this large habitat complex comprising of many existing Protected Areas, territorial divisions and community forests could augur well for elephant conservation in the region

(iv) Capacity enhancement of frontline staff and village volunteers to deal with exigency situations.

10.2 General conclusions

Elephant habitats in India occupy less than 4% of country's land-area. Thus, even the largest elephant landscapes in India are insular and embedded in densely populated production landscapes with long interface areas where interactions with people are inevitable. Therefore, human–elephant co-existence is the only possible model for elephant conservation in India and perhaps whole of Asia. Nevertheless, harmonious coexistence between people and elephants is often assumed and glorified than it is actually demonstrated. Ignoring the pervasive impacts of human–elephant conflict, besides affecting people can potentially result in competitive exclusion of elephants from many range areas. Moving towards realism of elephant conservation, it is certain that conflict will continue to occur in the interface areas, which cannot be resolved wholly, but certainly needs to be addressed smartly with an objective of maintaining it in socially tolerable levels without unduly compromising on conservation priorities. This may at times require hard-nosed decisions involving exclusion of elephants and people from certain critical areas where co-occurrence may not be possible at all. Life history traits and corresponding ecological requirements of elephants undoubtedly indicate that relatively large and contiguous tracts of natural tropical forests and associated ecosystems are indispensable for elephant conservation. As elephants occur only in a tiny fraction of country's land-area, elephant conservation calls for keeping those landscapes sacrosanct without getting misled that habitat destruction and elephant conservation can go hand in hand. Situation in the East Central region that had already crossed thresholds of habitat threats may not augur well for elephant populations if development-related priorities continue to override conservation necessities.

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Annexure-1

Plant species observed to be fed by wild elephants in Chhattisgarh during 2017 to 2020

S.No	Family	Species	Local name	Group	Part eaten
1	Anacardiaceae	*Buchanania lanzen*	chaar	Tree	root (of saplings)
2	Anacardiaceae	*Lannea coromandelica*	gurjan	Tree	bark
3	Anacardiaceae	*Mangifera indica*	aam	Tree	Bark & fruits
4	Anacardiaceae	*Semecarpus anacardium*	bhilwa	Tree	bark
5	Apocynaceae	*Carissa spinarum*	jangli karunda	Shrub	bark
6	Apocynaceae	*Holarrhena pubescens*		Tree	root (of saplings)
7	Arecaceae	*Phoenix sp*		Shrub	young leaves
8	Combretaceae	*Terminalia bellerica*	baheda	Tree	bark
9	Combretaceae	*Terminalia elliptica*	saja	Tree	bark
10	Dipterocarpaceae	*Shorea robusta*	saal	Tree	bark
11	Ebenaceae	*Diospyros melanoxylon*	tendu	Tree	root (of saplings)
12	Euphorbiaceae	*Mallatous philippensis*	rori	Tree	bark
13	Fabaceae	*Bauhinia vahilii*		Climber	bark
14	Fabaceae	*Dalbergia sisoo*	sisham	Tree	Bark
15	Lamiaceae	*Tectona grandis*	sagon	Tree	bark
16	Lythraceae	*Largerstromia parviflora*	sejha	Tree	leaves
17	Malvaceae	*Bombax ceiba*	simal	Tree	bark
18	Malvaceae	*Grewia tiliaefolia*	dhaman	Tree	bark
19	Malvaceae	*Helicteres isora*		Shrub	bark
20	Malvaceae	*Sterculia urens*		Tree	bark
21	Mimosoideae	*Acacia catechu*	khair	Tree	bark
22	Moraceae	*Ficus benghalensis*	bargad	Tree	leaves and bark
23	Moraceae	*Ficus racemosa*		Tree	bark
24	Moraceae	*Ficus religiosa*	pipal	Tree	leaves and bark
25	Myrtaceae	*Syzygium cumini*	jamun	Tree	bark
26	Phyllanthaceae	*Phyllanthus emblica*	amla	Tree	fruits
27	Poaceae	*Dendrocalamus strictus*		Grass	leaves and stem
28	Rhamnaceae	*Ziziphus mauritiana*	ber	Shrub	leaves and bark
29	Rhamnaceae	*Ziziphus rugosa*		Shrub	bark
30	Rhamnaceae	*Ziziphus xylopyrus*		Shrub	bark
31	Rutaceae	*Aegle mermelos*	bael	Tree	Bark
32	Sapindaceae	*Schleichera oleosa*	kusum	Tree	bark
33	Sapotaceae	*Madhuca longifolia*	mahua	Tree	Bark

Annexure-2

Manuscript acceptance letter by the journal

Gmail   N. Lakshminarayanan <westernghats.nln@gmail.com>

[JBNHS]Accept for 3rd revised ms 167989
1 message

JBNHS Editor <publications@bnhs.org>   26 April 2022 at 15:24
To: Lakshminarayanan Natarajan <westernghats.nln@gmail.com>

Sir,

The 3rd revised draft of manuscript 167989 titled 'AN OVERVIEW OF ELEPHANT DEMOGRAPHIC PARAMETERS IN CHHATTISGARH: IMPLICATIONS FOR MANAGEMENT' has been accepted for JBNHS publication.

We will communicate with you once we schedule the ms for publication.

Thanking you,

Yours sincerely,

Editors, JBNHS

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