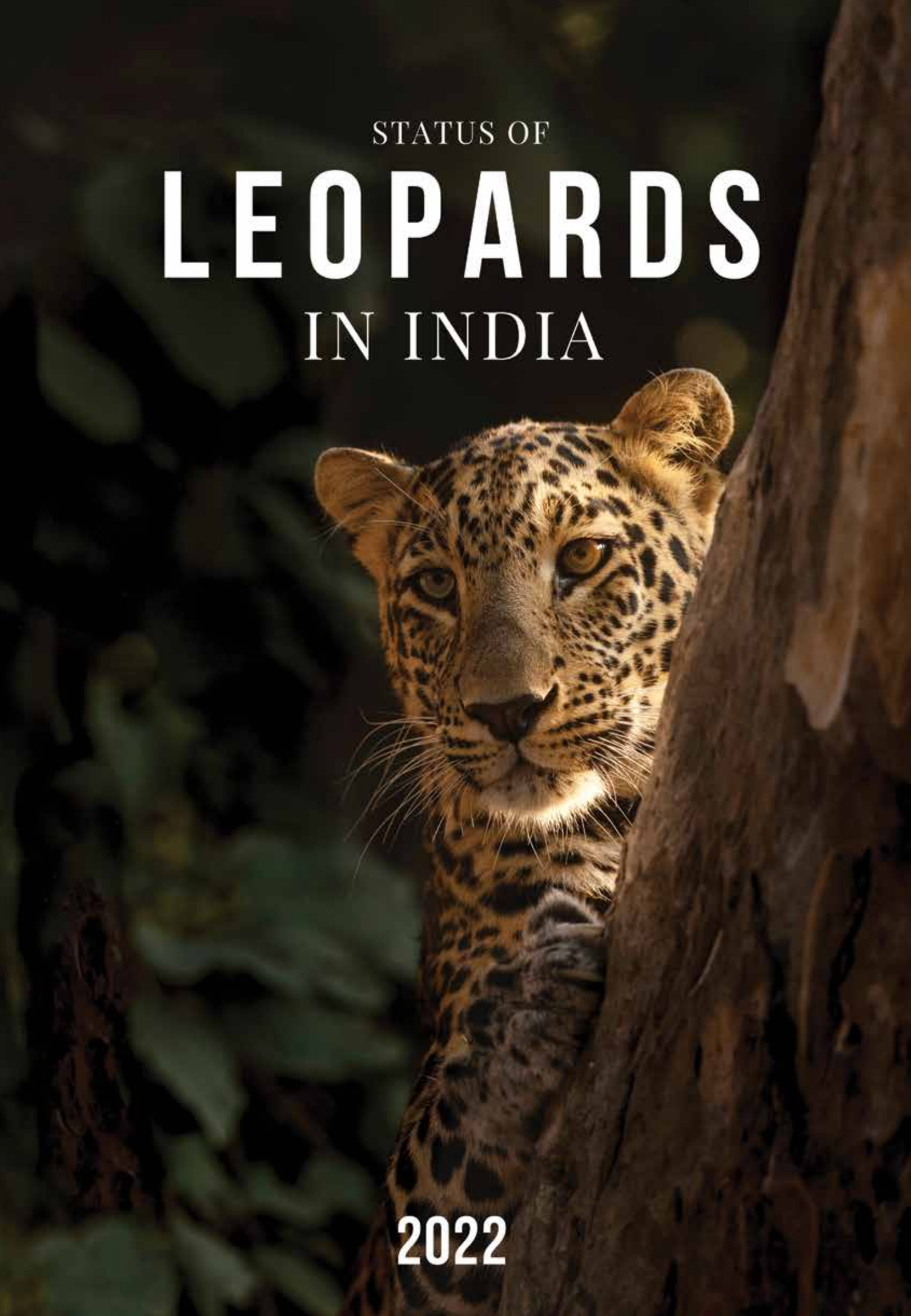

STATUS OF

LEOPARDS

IN INDIA

2022

Status of Leopards in India

2022

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मंत्री
पर्यावरण, वन एवं जलवायु परिवर्तन
और
श्रम एवं रोजगार
भारत सरकार

MINISTER
ENVIRONMENT, FOREST AND CLIMATE CHANGE
AND
LABOUR & EMPLOYMENT
GOVERNMENT OF INDIA

सत्यमेव जयते

एक कदम स्वच्छता की ओर

भूपेन्द्र यादव
BHUPENDER YADAV

आज़ादी का अमृत महोत्सव

संदेश

वन्यजीव संरक्षण के क्षेत्र में, प्रोजेक्ट टाइगर लंबे समय से वन पारिस्थितिकी तंत्र की सुरक्षा का पर्याय बन गया है। यह इस बात का उदाहरण है कि कैसे बाघों के अलावा अन्य प्रजातियों के संरक्षण पर भी ध्यान दिया जाता है। तेंदुओं की स्थिति पर यह रिपोर्ट इस पहल में शामिल व्यापक संरक्षण प्रयासों के प्रमाण के रूप में खड़ी है।

मानव-प्रधान परिदृश्यों में तेंदुए, पर्यावरणीय चुनौतियों के सामने वन्यजीवों के अनुकूलनशीलता का प्रतीक हैं। तेंदुओं के संरक्षण के प्रयास संरक्षित क्षेत्रों की सीमा से परे प्रजातियों की सुरक्षा की प्रतिबद्धता को स्पष्ट रूप से उजागर करते हैं। विशेष सराहना हमारे समर्पित वन विभाग की है जिनके अटूट प्रयास इस उद्देश्य में महत्वपूर्ण योगदान देते हैं।

प्रोजेक्ट टाइगर, बाघों से परे अपना ध्यान केंद्रित करके, पारिस्थितिक तंत्र के अंतर्संबंध और विविध प्रजातियों के संरक्षण को रेखांकित करता है। यह रिपोर्ट भारत सरकार के सहयोगात्मक प्रयासों, वैज्ञानिक कठोरता और संरक्षण की दिशा में गंभीर प्रयासों का प्रदर्शन है। मैं मंत्रालय, राष्ट्रीय बाघ संरक्षण प्राधिकरण के नेतृत्व , राज्य वन विभाग के कर्मचारियों और भारतीय वन्यजीव संस्थान के वैज्ञानिकों सहित इस प्रयास में शामिल सभी लोगों को बधाई देता हूं।

भारत के यशस्वी प्रधान मंत्री, श्री नरेन्द्र मोदी जी के नेतृत्व एवं मार्गदर्शन में, हम न केवल वन्यजीव का संरक्षण कर रहे हैं; बल्कि हम उस लोकाचार का उदाहरण दे रहे हैं जो हम सभी को एक साथ बांधता है; एक पृथ्वी, एक परिवार और एक भविष्य।

तारीख : 19 .02.2024

(भूपेन्द्र यादव)

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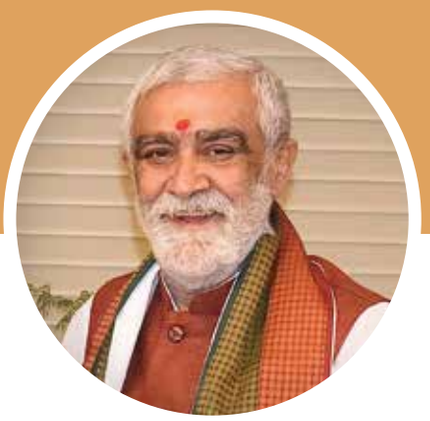

अश्विनी कुमार चौबे
Ashwini Kumar Choubey

राज्य मंत्री
पर्यावरण, वन एवं जलवायु परिवर्तन
उपभोक्ता मामले, खाद्य और सार्वजनिक वितरण
भारत सरकार
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आहारशुद्धौ सत्त्वशुद्धिः
एक कदम स्वच्छता की ओर

जब हम **"वसुधैव कुटुंबकम"** की बात करते हैं, **सर्वे भवन्तु सुखिनः सर्वे संतु निरामयाः** कहते हैं तो उस परिधि में मात्र मनुष्य हीं नहीं, इस वसुधा के सभी प्राणी आते हैं । हमारे यशस्वी प्रधानमंत्री श्री नरेंद्र मोदी जी के दूरदर्शी नेतृत्व में सभी प्राणियों के महत्व को रेखांकित किया है। तेंदुओं पर आधारित यह स्थिति रिपोर्ट (आबादी का आकलन) इस दर्शन का एक ज्वलंत उदाहरण है। भारत के वन्यजीवों के बीच, कोई अन्य वन्यप्राणी तेंदुए से बेहतर मानव-वन्यजीव सह-अस्तित्व का उदाहरण नहीं देता है।

भारत में तेंदुआ की आबादी निरन्तर बढ़ रही है, जिसमें इसकी बड़ी सफलता का श्रेय बाघ संरक्षण परियोजना के अन्तर्गत किए गए सुरक्षा एवं संरक्षण उपायों को जाता है।

भारतीय समुदायों के अतिरिक्त पृथ्वी पर कहीं और कोई भी अन्य समुदाय, वन्य जीवों के प्रति इतनी सहनशीलता नहीं दिखाते हैं। जैव विविधता में गिरावट से जूझ रही दुनिया में, भारत आशा की किरण के रूप में खड़ा है, जो यह दर्शाता है कि एकजुट प्रयासों से वन्यजीवों का संरक्षण हो सकता है।

मैं दुनिया को पर्यावरण संरक्षण एव वन्यजीव सुरक्षा का सच्चा सार दिखाने के लिए भारत की जनता और हमारे समर्पित वन कर्मिकों को हार्दिक बधाई देता हूं। इस संरक्षण के प्रयास को वास्तविकता बनाने में उनकी महत्वपूर्ण भूमिका के लिए राष्ट्रीय बाघ संरक्षण प्राधिकरण के अधिकारियों, राज्य वन विभाग के कर्मचारियों और भारतीय वन्यजीव संस्थान के वैज्ञानिकों को हार्दिक साधुवाद देता हूं।

मैं आशा करता हूं कि हम सब साथ मिलकर आने वाली पीढ़ियों के लिए अपने साझा पर्यावरण एवं वन्यजीवों को संरक्षित एवं संवर्धित करने में सामूहिक उतरदायित्व का पालन करेंगे ।

(अश्विनी कुमार चौबे)

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Contents

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Executive Summary


©Gurinderjit Singh

Leopards have held cultural significance in ancient civilizations, symbolizing power, agility, and nobility. Today, contemporary portrayals across various mediums continue to highlight their strength, courage, and sensuality. The Indian leopard (*Panthera pardus fusca*) is distributed across a variety of forested habitats in India, Nepal, Bhutan, and parts of Pakistan, excluding mangrove forests and desert habitats (Prater 1980, Daniel 1996). Despite being listed in Schedule I of the Wildlife (Protection) Act, 1972 and classified as "Vulnerable" by the IUCN Red List, leopard populations face significant threats including habitat loss, fragmentation, human-wildlife conflict, poaching, and illegal trade. Leopards occupy a prominent position in the trophic pyramid alongside tigers, lions and dholes exhibiting adaptability in habitat and dietary preferences, and playing a vital role as top predators in a wide array of landscapes across India. However, their adaptability often leads to conflicts with humans, posing a significant conservation challenge within their range.

Global distribution and population trends indicate significant declines due to various anthropogenic pressures, including habitat loss, prey depletion, and poaching. The NTCA, in collaboration with state forest departments and coordinated by Wildlife Institute of India (WII) conducts comprehensive assessments of tiger habitats, which also include data on leopard density and abundance. Genetic diversity varies across landscapes, with central India exhibiting the highest diversity. Unlike tiger populations, leopard populations show weak structuring across landscapes, with shared genetic affinity between different regions.


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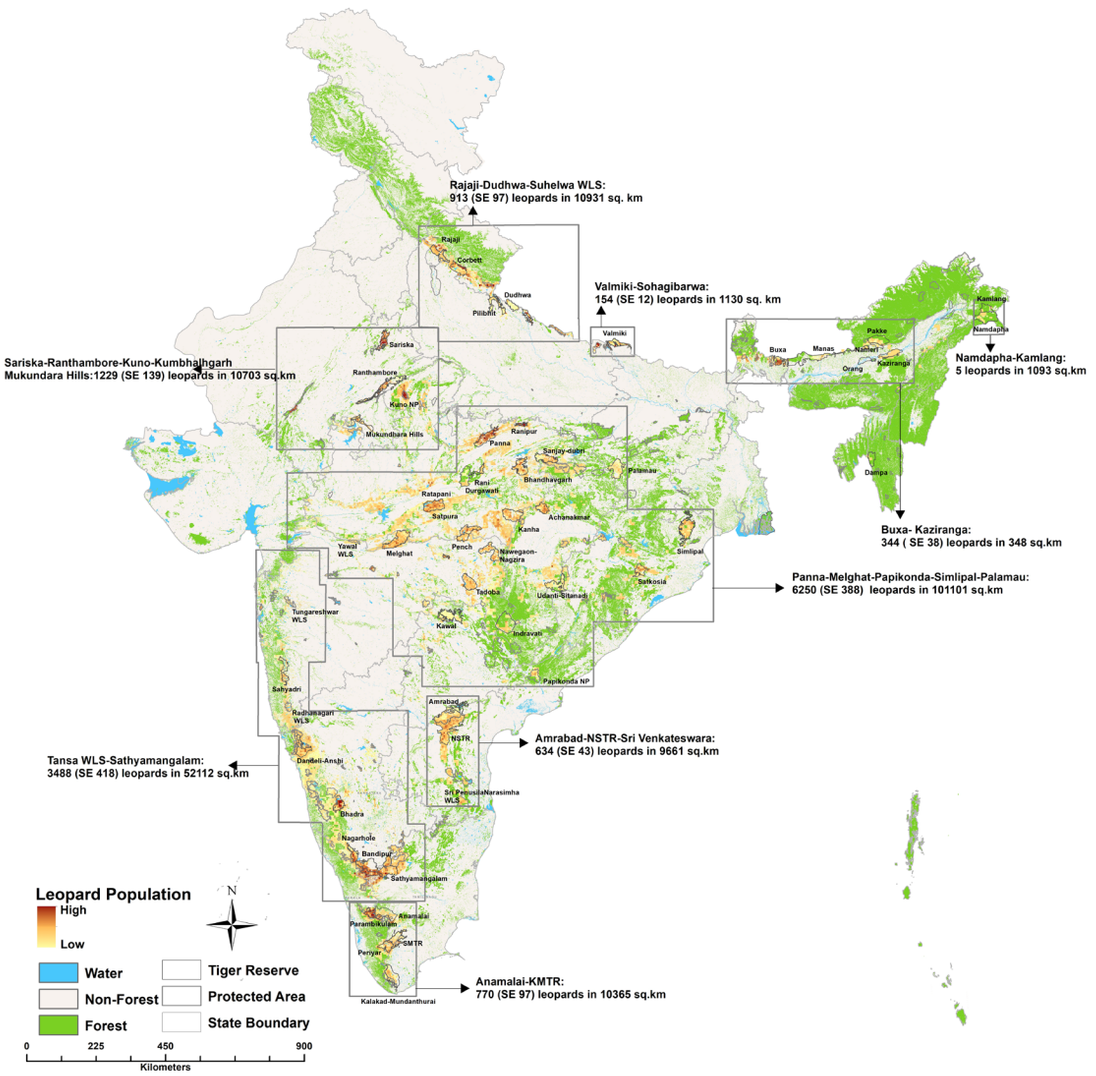
Figure E.1:

Leopard abundance, extent and population blocks in India, 2022.



Methodology

The fifth cycle of leopard population estimation (2022) in India focused on forested habitats within 18 tiger states, covering four major tiger conservation landscapes. Non-forested habitats, arid, and high Himalayas above 2000 msl (~ 30% area) were not sampled for leopard. To estimate leopard abundance, photo-captures were combined with spatial data on prey, habitat, and anthropogenic factors using a likelihood-based spatially explicit capture mark-recapture (SECR) covariate framework. This method involved three phases:

Phase I: Systematic sampling across forested areas within each landscape using M-STrIPES Android application and desktop software.

Phase II: Utilization of remotely sensed and secondary data to model leopard occupancy and abundance based on habitat characteristics and human impacts.

Phase III: Application of SECR models to estimate leopard density, facilitated by camera trap data and individual identification through image and pattern processing software CaTRAT and ExtractCompare respectively. The SECR approach accounted for spatial context and movement patterns, allowing robust population parameter estimates. Covariate-based abundance models were developed for each landscape, with optimal models selected based on statistical criteria. Overall, this comprehensive methodology provided leopard populations across India.

Countrywide Estimate

The fifth cycle of leopard population assessment (2022) covered 20 states in India, conducting a foot survey spanning 6,41,449 km to estimate carnivore signs and prey abundance.

Table E.1: *Estimated leopard numbers in each landscape from 2018 and 2022 (Number in parenthesis are one standard error limit of the mean).*

State	2018 Population (SE)	2022 Population (SE)
Bihar	98 (8)	86 (3)
Uttarakhand	839 (48)	652 (77)
Uttar Pradesh	316 (39)	371 (54)
Shivalik Hills & Gangetic Plains	**1,253 (95)**	**1,109 (134)**
Andhra Pradesh	492 (31)	569 (41)
Telangana	334 (16)	297 (20)
Chhattisgarh	852 (39)	722 (45)
Jharkhand	46 (10)	51 (10)
Madhya Pradesh	3,421 (150)	3,907 (215)
Maharashtra	1,690 (99)	1,985 (122)
Odisha	760 (33)	568 (35)
Rajasthan	476 (39)	721 (112)
Central India & Eastern Ghats	**8071 (417)**	**8,820 (600)**
Goa	86 (3)	77 (13)
Karanataka	1,783 (71)	1,879 (261)
Kerala	650 (28)	570 (76)
Tamil Nadu	868 (40)	1,070 (132)
Western Ghats	**3387 (142)**	**3,596 (482)**
Arunachal Pradesh	11 (3)	42 (10)
Assam	47 (9)	74 (11)
North Bengal	83 (17)	233 (21)
North Eastern Hills, and Brahmaputra Floodplains	**141 (26)**	**349 (42)**
India	**12,852 (680)**	**13,874 (1,258)**

Additionally, 3,24,003 habitat plots were sampled for vegetation, human impacts, and ungulate dung. Camera traps were strategically placed at 32,803 locations, resulting in a total of 4,70,81,881 photographs, resulting in 85,488 photo-captures of leopard. The survey comprised of a total effort of 6,41,102 man-days, representing the largest wildlife survey effort worldwide. Leopard presence was recorded in approximately 40% of total 10,846 sampled cells. The estimated leopard population for India was 13,874 (SE 1,258) (Table E.1, Fig E.1). This population adequately covered forested habitat of 13 states barring entire landscape of North East Hills and Brahmaputra Flood Plains where sampling is largely done in Tiger Reserves and partial sampling is done in Uttarakhand (below 2000 msl) and Rajasthan. This estimate of leopard represents ~70% of leopard occupied area. Central India has highest population with Madhya Pradesh having 3,907 individuals followed by Maharashtra, and Karnataka and Tamil Nadu in Western Ghats landscape (Table E.1).

Shivalik Hills and Gangetic Plains Landscape

Leopard occupy 76% of 351 cells (100 km^2) which are below 2,000 msl and while numbers have increased in Uttar Pradesh, Uttarakhand has shown a decline in leopard numbers. The leopard population in this landscape is 1,109 (SE 134) (Table E.1, Fig. E.1). There has been a 3.4% decline in overall leopard population in the landscape. Dehradun-Kalsi areas of Uttarakhand were camera trapped for the first time and harbours a sizeable population of leopards (107 minimum leopard number). Leopard number has declined in Ramnagar Forest Division, where tiger numbers have shown a very steep growth in the past four years (Qureshi *et al.,* 2023). Rajaji, Dudhwa and Corbett Tiger Reserves have the largest site wise leopard population (Table E.2) in this landscape. Shivalik landscape has seen an increase in large carnivores and mega-herbivore related conflict in recent years. 65% of the leopard population is present outside Protected Areas in the landscape, which will lead to increase in such conflicts . In the state of Uttarakhand 30% of all the human death and injury cases by wildlife were caused by leopard (Uttarakhand Forest Department, 2024) in the past 5 years. With an increase in tiger number in the landscape (Qureshi *et al.,* 2023), the large carnivore-conflict is what the states need to actively manage. In Uttar Pradesh both leopard and tiger numbers have increased which requires an active engagement for resolution of human-animal conflict by the forest department and civil administration.

Table E.2:

The leopard population in Tiger Reserves of India in 2022.

State	Tiger Reserve	Leopards within Tiger Reserve (SE)	Leopards utilising Tiger Reserve (SE)
Shivalik Hills and Gangetic Plains			
Uttrakhand	Corbett	115 (2)	150 (7)
	Rajaji	171 (6)	215 (10)
Uttar Pradesh	Pilibhit	29 (1)	36 (3)
	Dudhwa	125 (5)	158 (10)
	Ranipur	67(3)	86 (7)
Bihar	Valmiki	78 (1)	86 (3)
Central India and Eastern Ghats			
Andhra Pradesh	Nagarjunasagar Srisailam	270 (5)	360 (14)
Chhattisgarh	Achanakmar	76 (3)	108 (9)
	Indravati[#]	3	3
	Udanti Sitanadi	28 (2)	52 (9)
Jharkhand	Palamau	35 (6)	51 (10)
Madhya Pradesh	Bandhavgarh	146 (4)	176 (8)
	Kanha	157 (2)	209 (9)
	Panna	256 (5)	317 (11)
	Pench	132 (3)	175 (9)
	Sanjay Dubri	110 (3)	154 (9)
	Satpura	215 (2)	256 (8)
Maharashtra	Bor	37 (2)	45 (4)
	Melghat	181 (4)	233 (10)
	Navegaon Nagzira	116 (3)	140 (7)
	Pench	70 (3)	102 (9)
	Sahyadri	87 (2)	135 (10)
	Tadoba Andhari	129 (1)	148 (7)
Odisha	Satkosia	80 (2)	111 (7)
	Similipal	91 (2)	131 (10)
Rajasthan	Mukundara	49 (4)	99 (15)
	Ramgarh Visdhari	19 (1)	25 (3)
	Ranthambore	87 (6)	167 (18)
	Sariska	167 (7)	269 (18)
Telangana	Amrabad	121(2)	173 (10)
	Kawal	19 (1)	25 (3)

State	Tiger Reserve	Leopards within Tiger Reserve (SE)	Leopards utilising Tiger Reserve (SE)
Western Ghats			
Karnataka	Bandipur	138 (3)	185 (9)
	Bhadra	116 (2)	178 (11)
	Biligiri Rangaswamy Temple	66 (3)	98 (9)
	Kali	124 (6)	246 (21)
	Nagarhole	105 (3)	140 (8)
Kerala	Parambikulam	137 (3)	209 (12)
	Periyar	89 (9)	147 (19)
Tamil Nadu	Anamalai**	121 (5)	NA
	Kalakad-Mundanthurai	54 (3)	87 (10)
	Mudumalai	135 (4)	220 (14)
	Sathyamangalam	131 (8)	190 (15)
	Srivilliputhur-Meghamalai	97 (7)	147 (17)
North East Hills and Brahmaputra Flood Plains			
Arunachal Pradesh	Pakke	36 (1)	44 (3)
	Kamlang*	NA	NA
	Namdapha	5	5
Assam	Orang	1	1
	Manas	37 (2)	44 (4)
	Kaziranga	14 (1)	15 (1)
	Nameri	12 (1)	15 (2)
Mizoram	Dampa*	NA	NA
West Bengal	Buxa	61 (1)	74 (4)

** No evidence of Leopard found during sampling.*
 # Minimum identified Leopard from photographs.
*** Estimate derived from covariate model.*

Central India and Eastern Ghats Landscape

The Central India and Eastern Ghats landscape has the largest number of leopards and diverse habitats, from semi-arid regions to mixed deciduous forest. Leopard presence has been identified across all Protected Areas and major forest corridors within the central Indian landscape. While the leopard population in this landscape is growing, largely due to protective measures under the umbrella of tiger conservation, declines are also occurring in states like Chattisgarh, Telangana and Odisha. The surveyed forest in this area has an estimated total leopard population of 8,820 (SE 600) (Table E.1, Fig E.1). Approximately 68% of the leopard population exists outside the Protected Area. The leopard population estimates for Rajasthan was restricted to current and proposed Tiger Reserves only. Madhya Pradesh holds the largest leopard population in India followed by Maharashtra which signifies that tiger conservation measures also helping the co-predator's recovery (Table E.1). The site wise leopard population is higher in Nagarjunasagar Srisailam, Panna, Sariska, Satpura, Melghat and Kanha Tiger Reserves (Table E.2). The leopard densities are higher in the Tiger Reserves compared to outside Protected Areas, despite the fact that tigers exert regulatory pressure on leopards. Efforts regarding prey recovery and protection need to be strategized and at the same time conflict resolution mechanism need to be evaluated to timely mitigate issues of human-leopard interface.

Western Ghats Landscape

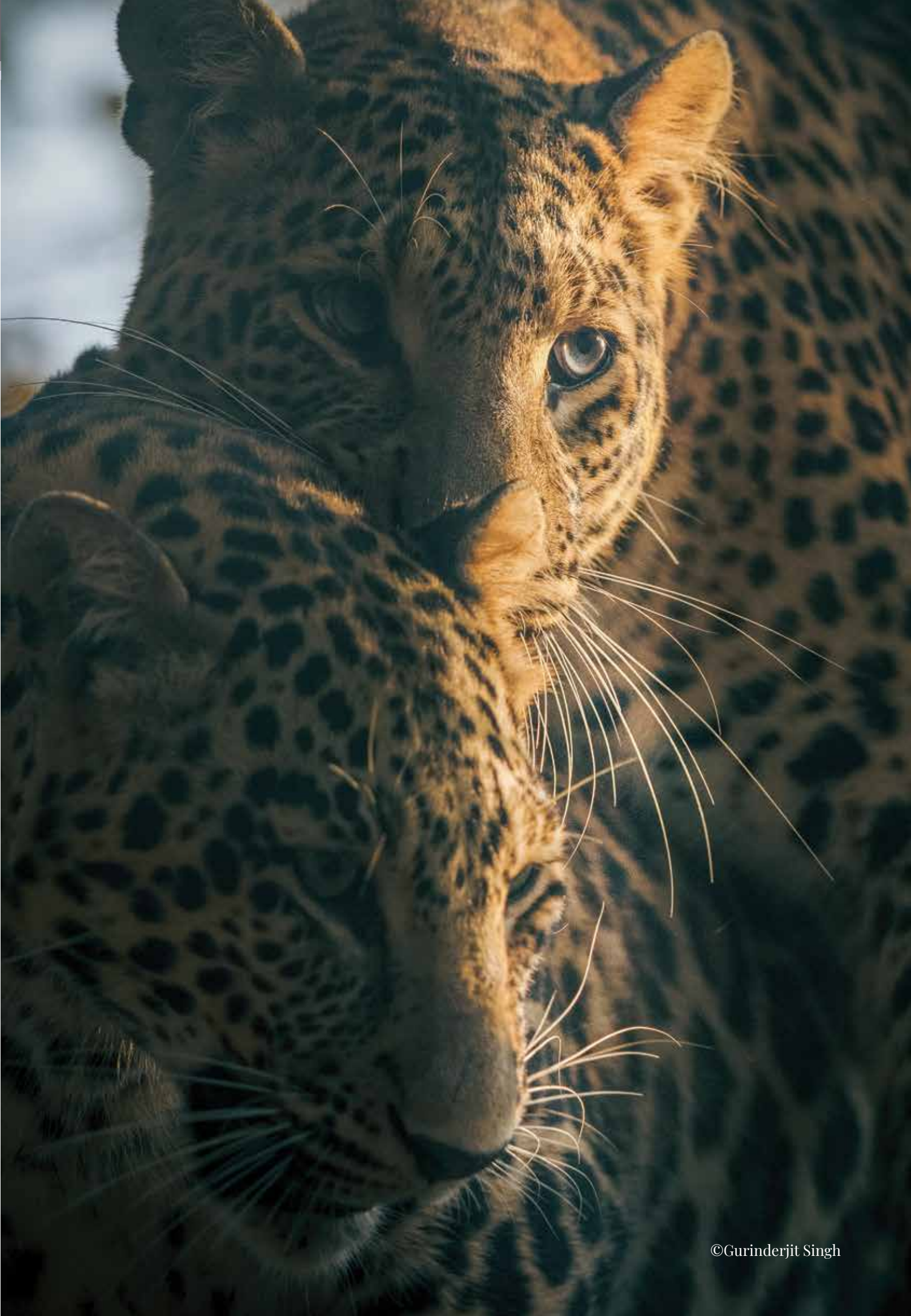
Although the leopard population in the Western Ghats is widely distributed, it faces the repercussions of habitat loss and fragmentation and poaching (Athreya *et al.,* 2011). The leopard population estimated in the sampled forests of Western Ghats was 3,596 (SE 482) (Tale E.1, Fig. E.1). Leopards in the Western Ghats often inhabited the human-dominated matrices, leopard-human conflict is prevalent in the entire landscape and increased in recent times. While the Nilgiri forests harbour high-density leopard populations (13 leopards/100 km^2), leopards occur in much lower densities in the scrubland-open forest mosaics of central Karnataka or the evergreen patches of southern Western Ghats (<1 leopard/100 km^2). In the central and northern Western Ghats, leopard populations are distributed in higher densities inside the Tiger Reserves (Bhadra, Kali, Mudumalai and Sathyamanglam) (Table E.2) while moderate to low densities outside the Protected Areas. The cluster of Anamalai-Parambikulam, located south of the Palghat gap, hosts a population of leopards with good density. The Parambikulam Tiger Reserve, within this cluster, is a hotspot for leopards, where they occur at high densities (Table E.2). In the landscapes of Periyar- Srivilliputhur- Meghamalai and KMTR- Kanyakumari, leopards are found at lower densities, particularly in the evergreen and semi-evergreen forests. More than 65% of the leopard population is present outside the Protected Areas in the Western Ghats landscape. Although the leopard population in the landscape showed a stable trend in the consistent sampling area, in certain areas, the leopard population declined significantly, e.g., the Wayanad landscape, which needs to be appropriately examined. At present, leopards often use the mosaics of forests, plantations, and human land uses outside the Protected Areas. However, the situation is changing as people start fencing their lands in order to reduce crop damage, and mushrooming developmental projects have come up, which are causing fragmentation in the population.

North East Hills and Brahmaputra Floodplains Landscape

North East Hills and Brahmaputra Flood Plains is a mosaic of forested habitat interspersed with human habitation and land cover patterns which provides ample cover for adaptable species like leopard. Although leopard presence is evident across the landscape, population estimates of leopards are available only from the Tiger Reserves, and some areas outside Reserves in North Bengal. Despite efforts put in since the last five cycles of All India Tiger Estimation, large forested areas of Assam and Arunachal Pradesh outside Tiger Reserves were not sampled. The sampling remains inadequate in this landscape and needs attention to expand the scope of adequate monitoring. A total of 15 sites were sampled in this landscape in camera trap based mark-recapture framework and leopards were photo-captured in 11 sites. Estimated leopard population of this landscape is 349 (SE 42). Although there is an increase in the leopard population as compared to earlier cycle, this is mostly because of the increase in sampling effort in North Bengal *Dooars.* Growing human leopard conflict in this landscape owing to habitat mosaic and developmental projects is a major concern towards leopard conservation.

Conservation Implications

The population growth in common area from 2018 to 2022 across India was 1.08 %/annum, Shivalik Hills and Gangetic Plains recorded -3.4%/annum decline, while Central India and Eastern Ghats, Western Ghats and North East Hills and Brahmaputra Flood Plains recorded growth of 1.5%, 1.0% and 1.3% per annum respectively. The population in last four years is stable, which also indicates the growth is minimal and in comparison to tiger its population is likely getting impacted by people in multiple use area. Current trend of poaching is unknown but seems to be likely cause of stable population, which includes commercial poaching and people's retaliation to conflict with leopards.



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I. Status of leopards in India

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Leopards commanded great reverence in ancient cultures (Egyptian, African and Indian cultures), symbolizing traits of power, agility, and nobility. Among Native cultures, the leopard's hunting prowess and camouflage were deeply respected, with tales highlighting their significance in transformational narratives and superstitions. Myths and folklore surrounding leopards often depict them as bold, cunning spirits intertwined with the spirit realm. Today, contemporary portrayals of leopards across fashion, literature, cinema, and art persist in symbolizing qualities of strength, courage, and sensuality (https://roaringrealms.com/leopard-myths-cultural-significance/). The Indian leopard, with its spotted coat and powerful presence, has long held a significant place in Indian art and culture. More than just a magnificent predator, it has been woven into the fabric of myths, folklore, and artistic expressions, representing a captivating blend of fear, power, and beauty.

The Indian leopard (*Panthera pardus fusca*) is found in a variety of forested habitats, including tropical rainforests, dry deciduous forests, temperate forests, and coniferous forests. The subspecies is found in India, Nepal, Bhutan, and parts of Pakistan, and it is not found in mangrove forests or desert habitats (Prater 1980, Daniel 1996). According to the Wildlife (Protection) Act, 1972 leopard is listed in Schedule I, which accorded highest protection and as per International Union for Conservation of Nature (IUCN) Red List of Threatened Species, it is classified as "Vulnerable". Its population is decreasing across its range, primarily due to habitat loss, fragmentation, human-wildlife conflict, poaching, and illegal trade (Athreya *et al.,* 2011 and Raza *et al.*, 2012).

Following tigers (*Panthera tigris*), dholes (*Cuon alpinus*) and lions (*Panthera leo*), leopards hold a prominent position in the trophic pyramid. While tigers migrated to India from the East, specifically the Malayan realm, leopards share an origin similar with lions, originating in the Ethiopian realm. Interestingly, leopards entered India through the Western corridor, preceding the arrival of lions and tigers (Mani 1974). In the Himalayas, leopards are occasionally sympatric with snow leopards (*Panthera uncia*) and have been sighted at altitudes as high as 5,200 meters (Uphyrkina *et al.,* 2001). Leopards exhibit remarkable adaptability in terms of habitat and dietary preferences, thriving in agro-pastoral areas, plantations, and even near human settlements, both rural and urban (Nowell and Jackson, 1996). Known for their prolific breeding rates and faster life history traits compared to tigers, leopards have demonstrated an annual growth rate of 15% in parts of Kanha Tiger Reserve in Central India (Kumar *et al.,* 2019).

Being one of the most widely distributed felids, leopards owe their extensive range to their dietary flexibility and ability to inhabit various environments, including human-dominated landscapes (Sunquist and Sunquist, 2002; Hayward *et al.,* 2006; Athreya *et al.,* 2013; Gubbi *et al.,* 2020). However, this adaptability often leads to conflicts with humans, presenting a significant conservation challenge within their range (Rahalkar, 2008; Athreya *et al.,*2011; Navya *et al.,* 2014; Sidhu *et al.,* 2017; Naha *et al.,* 2018).

The global distribution and population of leopards have witnessed significant declines due to habitat loss, depletion of prey species, human-wildlife conflicts, and poaching over the past century. Recent studies suggest a range loss of 48–67% for leopards in Africa and 83–87% in Asia (Jacobson *et al.,* 2016), corroborating genetic evidence indicating a 75-90% human-induced population decline within the last ~120-200 years in India (Bhatt *et al.,* 2020).

The National Tiger Conservation Authority (NTCA), in collaboration with state forest departments, conservation NGOs, and coordinated by the Wildlife Institute of India, conducts a comprehensive national assessment of "Tigers, Co-predators, Prey, and their Habitat" every four years since 2006. While past assessments primarily focused on occupancy for species other than tigers and leopards, the 2014 cycle marked the first reporting of leopard density and abundance across tiger habitats in India, estimating the leopard population at 7,910 (SE 1,344) and 12,852 (SE 680) individuals in 2014 and 2018 (Jhala *et al.,* 2015 & Jhala *et al.,* 2021) respectively. This report presents the status of leopards based on camera trap data and occupancy surveys conducted in 2022 across 20 states of India where tigers are present, utilizing a spatially explicit capture-recapture framework. Given the substantial coverage of forested landscapes in these 18 states using camera traps, photo-capture

data are also employed to reliably estimate occupancy and abundance.The genetic diversity of leopard populations in India varies across landscapes, with Central India exhibiting the highest diversity. Unlike tiger populations, leopard populations show weak structuring across landscapes, as indicated by genetic analysis (Jhala *et al.,* 2019). The data reveals three clusters, with largely overlapping signatures. While there are no genetically distinct populations observed at lower levels of division, Terai and parts of Central Indian leopards appear distinct from Western Ghats and North Eastern populations. There is a shared affinity of genes between Eastern Ghats, Western Ghats and North Bengal populations. Notably, leopard populations exhibit genetic continuity throughout the Western Ghats, contrasting with the structured nature of tiger populations in the same regions (Kolipakam *et al.,* 2019).

Conservation efforts for the Indian leopard require habitat restoration initiatives, protection outside Protected Area system and the implementation of measures to mitigate human-leopard conflict. There is a need to collaborate with local communities to raise awareness, and promote coexistence between humans and leopards. Research on leopard ecology, behavior, and population dynamics is needed for informed conservation strategies and management decisions.

Methodology

The leopard population estimation was carried out within forested habitats in tiger occupied states of the country. Four major tiger conservation landscapes, 1) Shivalik Hills and Gangetic Plains, 2) Central India and Eastern Ghats, 3) Western Ghats and, 4) North East Hills and Brahmaputra Flood Plains, were sampled for estimating leopard abundance. Details of these landscapes are available in Qureshi *et al.,* 2023. Non-forested habitats like commercial plantations, and other land use forms, higher elevations in Himalayas (>2000 msl), arid landscapes and majority of North East landscapes, where leopards are known to occur, were not sampled. Therefore, the current estimate of leopards presented here should be considered as ~70% of leopard's landscape sampled.

To arrive at the abundance of leopards, photo-captures of individual leopards were used in combination with spatial data on prey, habitat, and anthropogenic factors as covariates in a likelihood based spatially explicit capture mark-recapture (SECR) covariate framework (Efford 2015). This method entails estimating spatial covariates of relative abundance of leopard and other co-predators, ungulates, human impact indices, and habitat characteristics across all potential tiger habitats in India, at a fine spatial resolution of a forest beat which is on average about 15 km^2 (Phase I and II). Within each landscape, sampling was carried out at a high density, and one double sided camera station placed in a 2 km^2 area (Phase III) (Fig. I.1). The raw counts of abundance obtained from the sample space are calibrated against absolute density obtained from the areas where camera trapping is carried out. In this SECR approach, spatial information on capture-mark-recapture (that accounts for detection correction) is used with spatial covariates of leopard sign intensity, prey abundance, human disturbance and habitat characteristics to estimate leopard population directly in the camera trapped area, and extrapolates to forested areas with leopards but not camera trapped, based on covariates.

Phase I

Sampling is systematically carried out across all forested areas within each landscape. The average size of a forest beat in India is 15-16 Km^2. These spatial administrative units are the basis of ensuring fine scale sampling across the forested habitats in each tiger bearing landscape. To ensure appropriate data collection, the State Forest Departments were trained by NTCA-WII Tiger Cell in the Phase I sampling protocols to be carried out across current and potential tiger habitats (in Tiger Reserves, Protected Areas, Reserve Forests and in all Wildlife and Territorial divisions) across 20 states (Figure I.2). Data was recorded digitally using M-STrIPES (Monitoring System for Tigers: Intensive Protection and Ecological Status) ecological android mobile application. The protocol for Phase I and the details of the forms are explained in Qureshi *et al.,* 2023. Broadly, the data is collected on carnivore sign encounters (Form 1), Ungulate abundance (Form 2), Habitat status (Form 3A, 3B, 3C) and index of herbivore presence (Form 4) (Fig I.1) (Table I.1).

Since data is collected in a digital format on the M-STrIPES mobile Android app, it was directly imported and analysed on the complementing desktop software. Phase I data was received from 628 Forest Divisions of India and these were processed using M-STrIPES desktop software. Data for each spatial and temporal replicate was recorded at the beat scale (occupancy surveys, line transects, and plots) were transferred to the standard 25 and 100 km^2 cells for analysis and subsequent inference. Tiger and leopard sign encounter rates, ungulate encounter (direct sighting) rates, ungulate dung density, human disturbance indices (signs of livestock, human trails, wood cutting, lopping, grass removal) were computed as average encounter rates for 5x5 and 10x10 km cells based on effort (km of survey) invested in each cell.

Phase II

Remotely sensed data is used to obtain covariates like habitat characteristics and anthropogenic impacts that are likely to determine the distribution and abundance of leopards. This data is used then to model leopard occupancy and abundance. Habitat characteristics were surrogated by forest area, vegetation cover [Normalized Difference Vegetation Index, (NDVI)], forest patch size, forest core areas, elevation, distance from Protected Areas and drainage density. Human impacts were surrogated by human footprint, distance to night lights, night light intensity, distance to roads and density of road network (Fig. I.1, Table I.2).

Table I.1:

Country wide sampling effort for ground surveys and camera traps during Phase I and III of each state and landscape, 2022.

State	Number of Trails	Total Length of Trails (Kms)	Number of Transects	Total Length of Transects (Kms)	Number of Habitat Plots	Camera Trap Numbers
Bihar	232	1775	499	981	1372	429
Uttar Pradesh	1270	6412	1237	2408	4396	1343
Uttarakhand	2735	12389	2522	4299	8256	2165
Shivalik Hills and Gangetic Plains	**4237**	**20576**	**4258**	**7688**	**14024**	**3937**
Andhra Pradesh	3456	16597	3430	6637	11090	989
Chhattisgarh	9855	46176	8422	16185	31664	459
Jharkhand	976	4600	732	1457	4570	323
Madhya Pradesh	26757	139651	26341	54256	96924	6894
Maharashtra	16331	78016	16124	31210	56512	4872
Odisha	9623	52633	9531	19522	33544	733
Rajasthan	988	4449	981	1911	3422	685
Telangana	6633	29188	5599	10502	18264	1578
Central India and Eastern Ghats	**74619**	**371310**	**71160**	**141680**	**255990**	**16533**
Karnataka	8874	45323	10002	18297	31742	5163
Kerala	1522	7463	1201	2361	4156	1314
Tamil Nadu	1892	11019	1845	3681	5376	3650
Goa	174	765	165	324	526	95
Western Ghats	**12462**	**64570**	**13213**	**24663**	**41800**	**10222**
Assam	389	1816	483	856	1356	619
North Bengal	786	4011	586	1203	2174	329
Mizoram	87	330	NA	NA	8064	43
Arunachal Pradesh	309	840	NA	NA		407
Nagaland	178	568	NA	NA		NA
North East Hills and Brahmaputra Flood Plains	**1749**	**7565**	**1069**	**2059**	**11594**	**1398**
Sundarbans	**315**	**1339**	**NA**	**NA**	**595**	**713**
India	**93,382**	**4,65,360**	**89,700**	**1,76,090**	**3,24,003**	**32,803**

Table I.2:

Remotely sensed spatial data based on field sampling and secondary data used for modelling occupancy and abundance of leopards.

S. No	Dataset	Source	Spatial Resolution
1	Leopard sign encounter rate	Phase I survey, AITE 2022	25 km^2
2	Tiger sign encounter rate	Phase I survey, AITE 2022	25 km^2
3	Prey encounter rate (Chital, Sambar, Wild Pig, Barking Deer, Langur)	Phase I survey, AITE 2022	25 km^{2*}
4	Prey faecal pellet (Chital, Sambar, Wild Pig, Barking Deer, Langur)	Phase I survey, AITE 2022	25 km^{2*}
5	Extractive human use (Wood cutting, lopping, human & livestock trails, people seen)	Phase I survey, AITE 2022	25 km^{2*}
Remotely sensed data			
3	Night time lights Intensity (2021)	C. D. Elvidge, K. Baugh, M. Zhizhin, F. C. Hsu, and T. Ghosh, "VIIRS night-time lights," International Journal of Remote Sensing, vol. 38, pp. 5860–5879, 2017.	500 m
4	Normalised Difference Vegetation Index-Pre and post monsoon	Vermote, E., Justice, C., Claverie, M., & Franch, B. (2016). Preliminary analysis of the performance of the Landsat 8/OLI land surface reflectance product. Remote Sensing of Environment, 185, 46-56.	30 m
5	Digital Elevation Model	NASA Shuttle Radar Topography Mission (SRTM) (2013). Shuttle Radar Topography Mission (SRTM) Global. Distributed by OpenTopography. https://doi.org/10.5069/G9445JDF.	30m
6	Global human modification Index (2016)	Kennedy, C. M., J. R. Oakleaf, D. M. Theobald, S. Baruch-Mordo, and J. Kiesecker. 2020. Global Human Modification of Terrestrial Systems. Palisades, NY: NASA Socioeconomic Data and Applications Center (SEDAC). https://doi.org/10.7927/edbc-3z60.	1000 m
7	Forest Cover (2017)	India State of Forest Report (2017).Forest Survey of India, Ministry of Environment, Forest and Climate Change , Government of India	23.5 m
8	Ruggedness	Derived from Digital Elevation Model	30 m
9	Distance to Nightlights	Euclidean distance from Nightlights data	1000 m
10	Distance to water sources	Euclidean distance derived from global surface water dataset (Pekel *et al.,* 2016)	1000 m
11	Distance to Protected Areas	Data archived from Wildlife Database Cell, WII and Project Tiger database	1000 m

**Data collected on 2-3 km line transects & plots laid at every 400 m were extracted at 25 km^2 cell*

Phase III

Spatially Explicit Capture Recapture (SECR) models integrate the spatial context of capturing and recapturing individuals with their temporal capture history to estimate density. By linking the detection process to the actual space utilization of an animal, SECR provides robust population parameter estimates (Borchers and Efford, 2008). Individual identification and abundance estimation of tigers and leopards are facilitated by their distinctive stripes and rosettes, within the framework of capture-mark-recapture. Camera traps were placed at 32,803 locations, spread across 175 sites for mark recapture analysis (Figure I.2, I.3).

Camera traps were systematically positioned in the sampling area through a 2 km² cell overlay, deploying at least one pair of cameras in each cell. The cameras were strategically located to maximize photo-captures of tigers and leopards, identified through thorough sign surveys. Each cell received a unique code and was positioned within the nationwide 100 km² cell established since the initial National Tiger Status Estimation cycle in 2006, ensuring consistent spatial comparison for subsequent inferences. Sampling occurred concurrently in a minimum block of 200 km², expanding to larger blocks if more camera traps were available to cover areas exceeding 200 km². A minimum spacing of approximately 1 km between camera trap locations was maintained. Typically, cameras operated for 25 to 35 days at each site, with an average effort exceeding 1,200 trap-nights per ~100 km².

Phase III analysis: As explained in Qureshi *et al.,* 2023, in collaboration with the Indraprastha Institute of Information Technology, New Delhi, an AI-based image processing tool was developed to automatically geotag and categorize camera trap images by species (Fig. I.1, I.3 & I.4). This image processing software, known as CaTRAT (Camera Trap Data Repository and Analysis Tool) (Cheema *et al.,* 2018), was employed for geotagging, coding, and organizing images into individual species folders. The geo-tagged images underwent careful examination to identify potential software misclassifications, and the separated photos of tigers and leopards were further processed for individual identification of these species.

Leopard images were grouped utilizing Hotspotter (Crall *et al.,* 2013), and final leopard identification was conducted using ExtractCompare (Hiby *et al.,* 2009). A total of 85,488 Leopard photographs were collected from camera traps. In ExtractCompare, a three-dimensional surface model of a leopard is overlaid on a leopard photo to accommodate pitch and roll associated with body posture before extracting the spot pattern (Figure I.5). Employing an automated process, pattern recognition software searches the image database to calculate similarity scores between digitized leopard coat patterns, facilitating the recognition of common and unique individuals. Initially, leopard(s) photographed at each camera trap site were identified using this method. Subsequently, comparisons were made between leopard photographs from adjacent sites and within each landscape using the National database to eliminate any duplicate leopards and comprehend leopard dispersal events. Once individual leopards were identified, a spatial capture history matrix for each leopard was developed for each site, including camera trap IDs, their coordinates, and the deployment and operation history of each camera.

We utilized likelihood-based SECR methods (Borchers *et al.,* 2008; Efford, 2011) to estimate leopard abundance from camera trap data. The two fundamental detection parameters in SECR include the detection probability (g0) at the home range center of the animal and a parameter for spatial movement (σ). A habitat mask, incorporating a realistic buffer around the camera trap array to exclude non-habitat, was provided in our analysis. Density was modeled as a function of covariates, including tiger and leopard sign encounter rates, prey encounter or dung densities, and human footprint variables from ground surveys and remotely sensed data. These covariates were employed within SECR to model leopard density through the secr package (Efford, 2015) in the R programming environment (R Core Team, 2023). Covariate-based abundance models were developed for each landscape to estimate leopard abundance within tiger-occupied forests. The optimal covariate model was selected based on Akaike Information Criteria (Akaike, 2011) for each landscape. In areas where leopards were detected but not camera-trapped, their numbers were estimated by predicting leopard density from covariates (prey, habitat, and human disturbances) using the best model or model-averaged parameters.

We used a combination of several covariates (including tiger and leopard sign encounters, extractive use indices, NDVI, elevation, human-modified indices, and distance to Protected Areas) in a spatially explicit capture-recapture model to predict leopard density outside the camera-trapped area (except North East Hills and Brahmaputra Flood Plains where sufficient Phase I information was not available for areas outside camera trapped sites). The selection of the most parsimonious covariate model for each landscape was based on the lowest AICc value.

For the Shivalik Hills and Gangetic Plains landscapes, the best model included leopard sign encounters ($\beta = 0.11 \pm 0.03$, positively correlated) and tiger sign encounters ($\beta = -0.25 \pm 0.06$, negatively correlated).In the Central India and Eastern Ghats landscape, the optimal model comprised leopard sign encounters ($\beta = 0.16 \pm 0.01$, positively correlated) and prey encounters (chital, sambar, barking deer, langur, and wild pig) ($\beta = 0.26 \pm 0.03$, positively correlated). For the Western Ghats landscape, the preferred model incorporated leopard sign encounters ($\beta = 0.25 \pm 0.02$, positively correlated), prey encounters (chital, sambar, barking deer, langur, and wild pig) ($\beta = 0.09 \pm 0.01$, positively correlated), and extractive use from the forest ($\beta = -0.07 \pm 0.02$, negatively correlated). The selection of these models was based on the lowest AICc values.

Figure I.1:

Outline of Sampling framework for leopard estimation

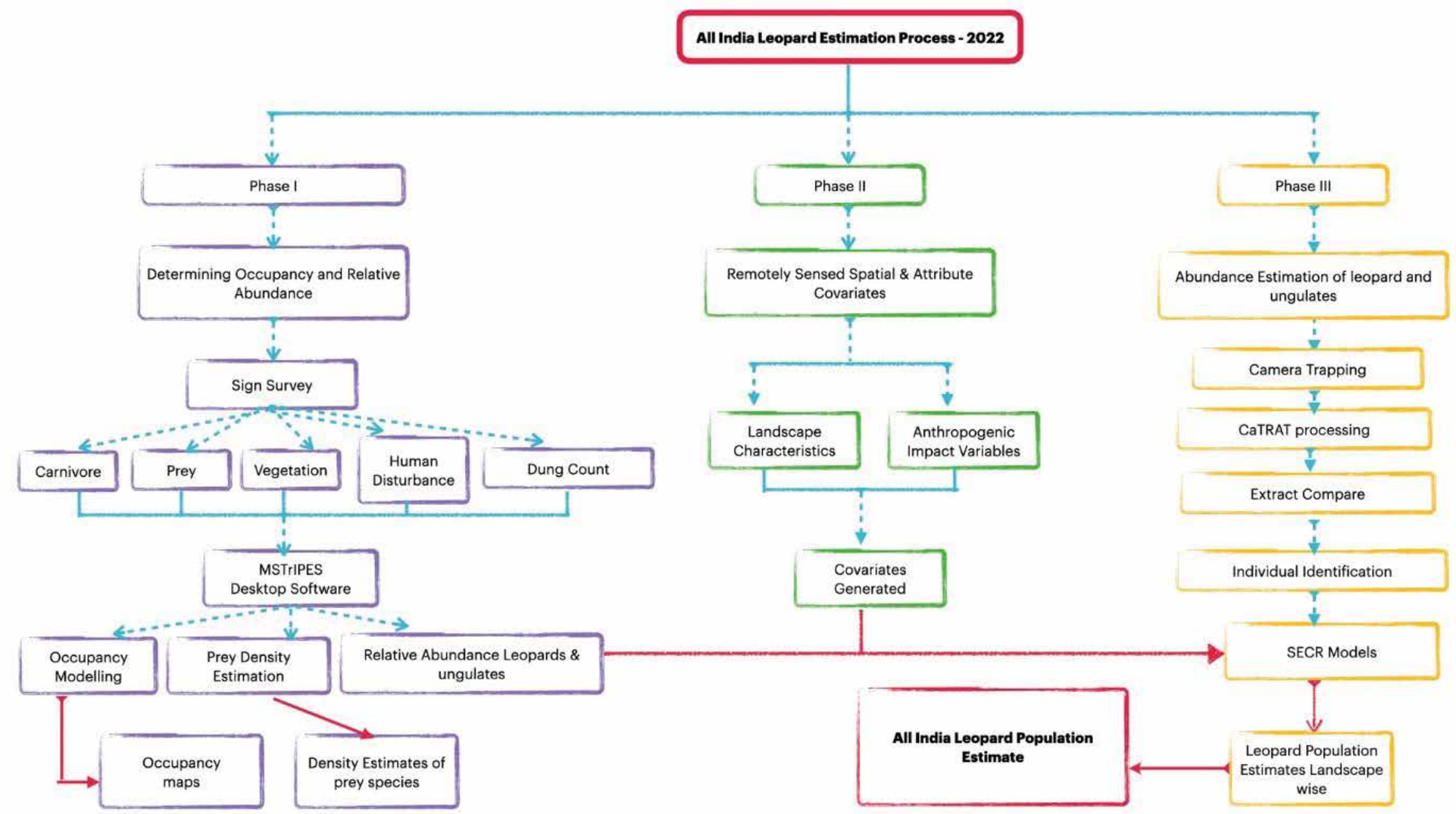


Figure I.2.

Spatial coverage of sampled forests for carnivore signs where leopard evidence was recorded is shown in orange and black denotes camera trap locations with leopard photo-captures in India, 2022.

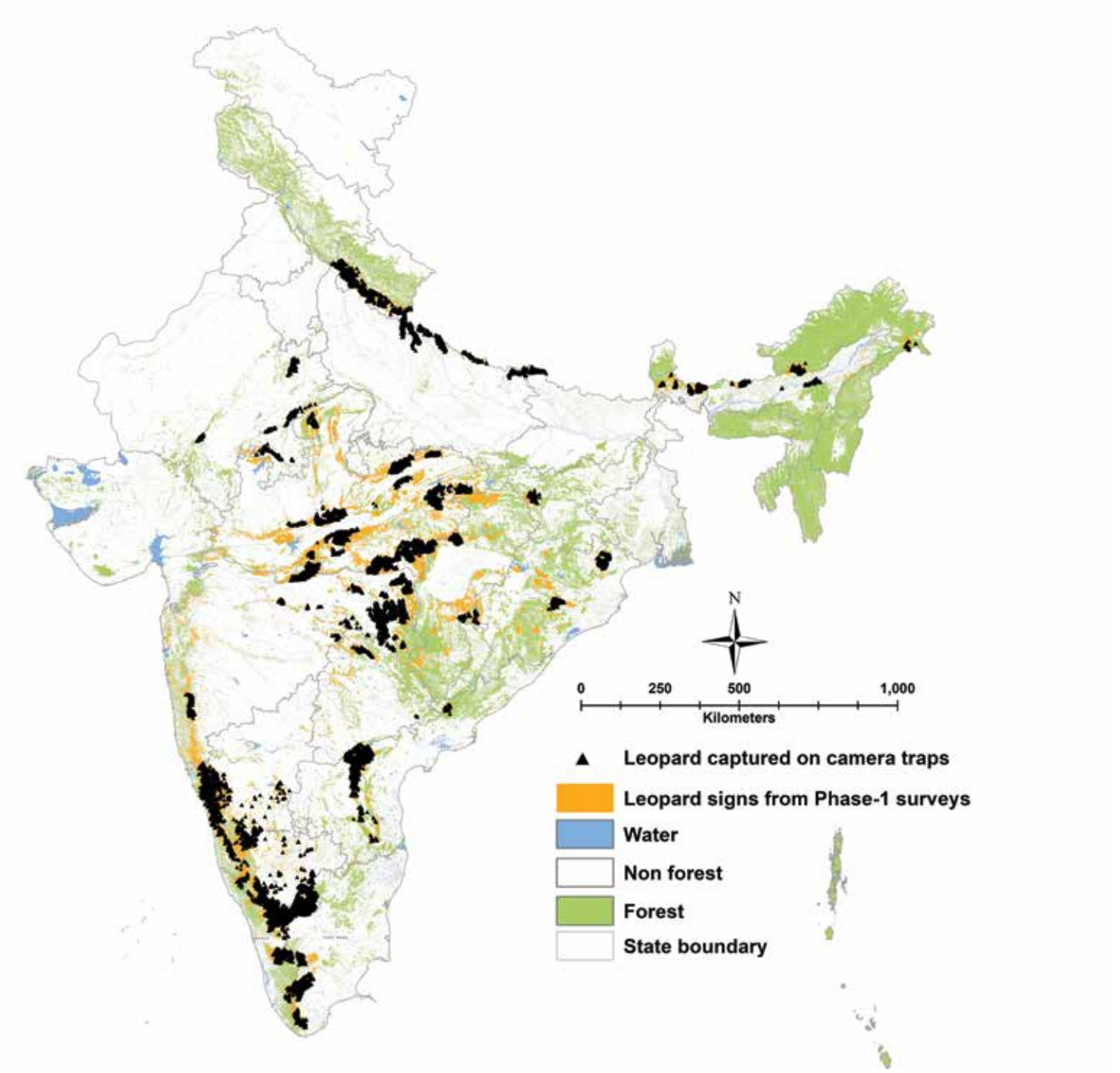


Figure I.3.

Workflow of species identification from camera trap images using artificial intelligence based tool, CaTRAT

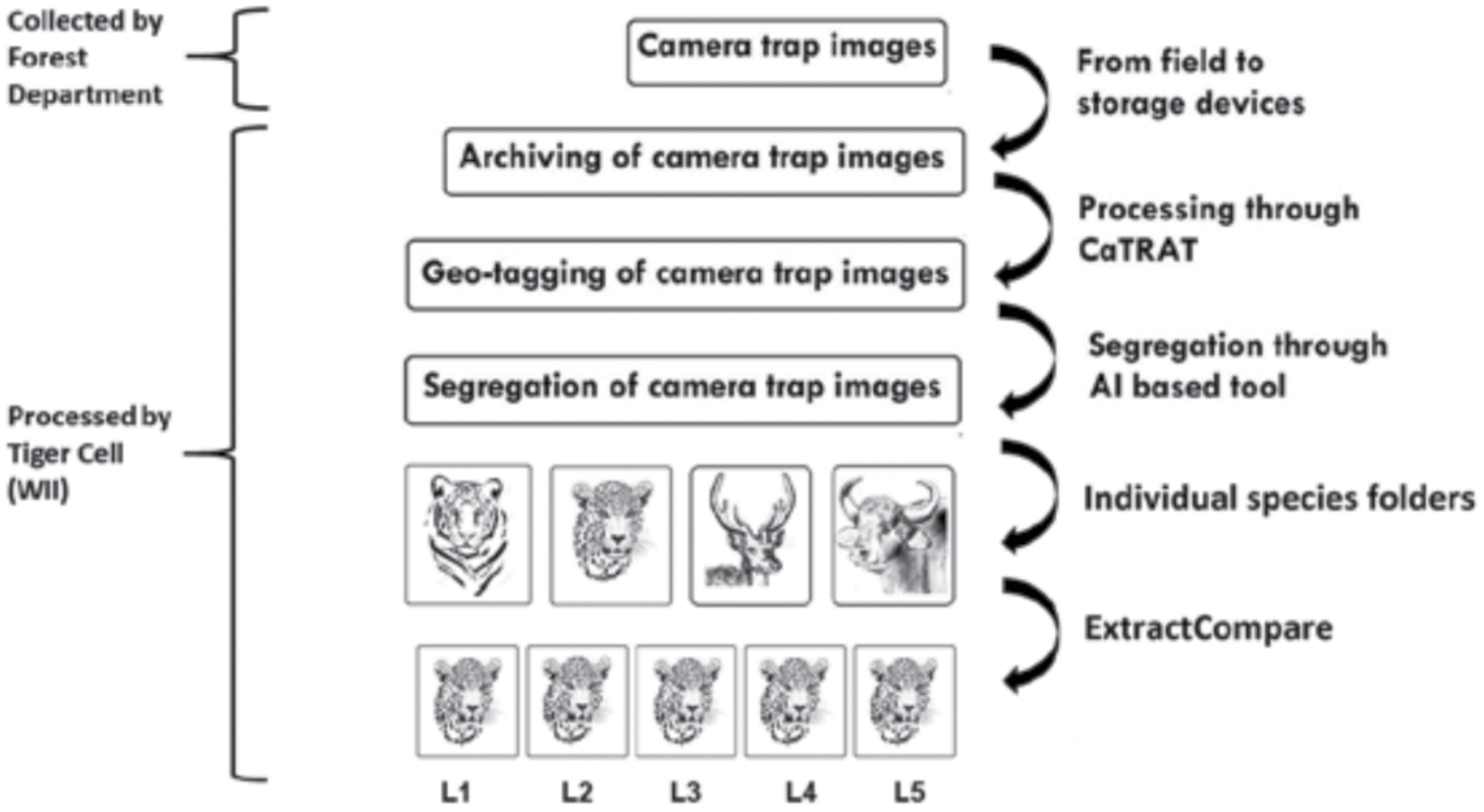


Figure I.4.

Process of individual identification of leopards using Program ExtractCompare

a) Placing seeds on prominent body parts (mid shoulder, tail, hip)

b) 3-D model fitting which takes into account the angle at which the photo is taken

c) Pattern extracted

d) Visual compare to match leopard images after the computer program has provided a few options from several thousand images

Abundance Assessment of Leopards in India

The fifth cycle of leopard population (2022) was conducted in 20 states of India, encompassing a foot survey of 6,41,449 km for carnivore signs and prey abundance estimation. Additionally, 3,24,003 habitat plots were sampled for vegetation, human impacts, and ungulate dung. Camera traps were deployed at 32,803 locations, resulting in 4,70,81,881 photographs, of which 85,488 were of leopards. The total effort invested in the survey was 6,41,102 man-days, making it the world's largest effort invested in any wildlife survey to date. Leopard presence was recorded in 40 % (4321) of sampled cells (n=10846). The leopard estimate for India was 13,874 (SE 1,258) and 67% of this leopard population is outside Protected Areas. This estimate of leopard represents ~70% of leopard occupied area in 18 states.

Table I.3: *Estimated leopard numbers in each landscape from 2018 and 2022 (Number in parenthesis are one standard error limits of the mean).*

State	2018 Population (SE)	2022 Population (SE)
Bihar	98 (8)	86 (3)
Uttarakhand	839 (48)	652 (77)
Uttar Pradesh	316 (39)	371 (54)
Shivalik Hills and Gangetic Plains	**1,253 (95)**	**1,109 (134)**
Andhra Pradesh	492 (31)	569 (41)
Telangana	334 (16)	297 (20)
Chhattisgarh	852 (39)	722 (45)
Jharkhand	46 (10)	51 (10)
Madhya Pradesh	3,421 (150)	3,907 (215)
Maharashtra	1,690 (99)	1,985 (122)
Odisha	760 (33)	568 (35)
Rajasthan	476 (39)	721 (112)
Central India and Eastern Ghats	**8071 (417)**	**8,820 (600)**
Goa	86 (3)	77 (13)
Karanataka	1,783 (71)	1,879 (261)
Kerala	650 (28)	570 (76)
Tamil Nadu	868 (40)	1,070 (132)
Western Ghats	**3,387 (142)**	**3,596 (482)**
Arunachal Pradesh	11 (3)	42 (10)
Assam	47 (9)	74 (11)
North Bengal	83 (17)	233 (21)
North East Hills and Brahmaputra Flood Plains	**141 (26)**	**349 (42)**
India	**12,852 (680)**	**13,874 (1,258)**

This population adequately covered forested habitat of 13 states baring states of North-Eastern Hills and Brahmaputra Flood Plains where sampling is largely done in Tiger Reserves and partial sampling is done in Uttarakhand (below 2000 msl) and Rajasthan (Protected Areas).

Central India has highest population with 8,820 (SE 600) leopards followed by Western Ghats 3,596 (SE 482) and Shivalik Hills and Gangetic Plains having 1,109 (SE 134) individuals. The partial sampling of North East Hills and Brahmaputra Flood Plains have population of 349 (42) leopards. The states which have largest population of leopards were Madhya Pradesh (3,907), Maharashtra (1,985), Karnataka (1,879) and Tamil Nadu (1,070) (Table I.3) and Tiger Reserves or sites with highest leopard population are, Nagarajunasagar Srisailam, Panna, Satpura, Sariska, Melghat, Kali, Mudumalai, Kanha and Parambikulam (Table I.4).

The population growth in common area from 2018 to 2022 across India was 1.08 %/annum, Shivalik Hills and Gangetic Plains recorded -3.4%/annum decline, while Central India and Eastern Ghats, Western Ghats and North East Hills and Brahmaputra Flood Plains recorded growth of 1.5%, 1.0% and 1.3% per annum respectively.

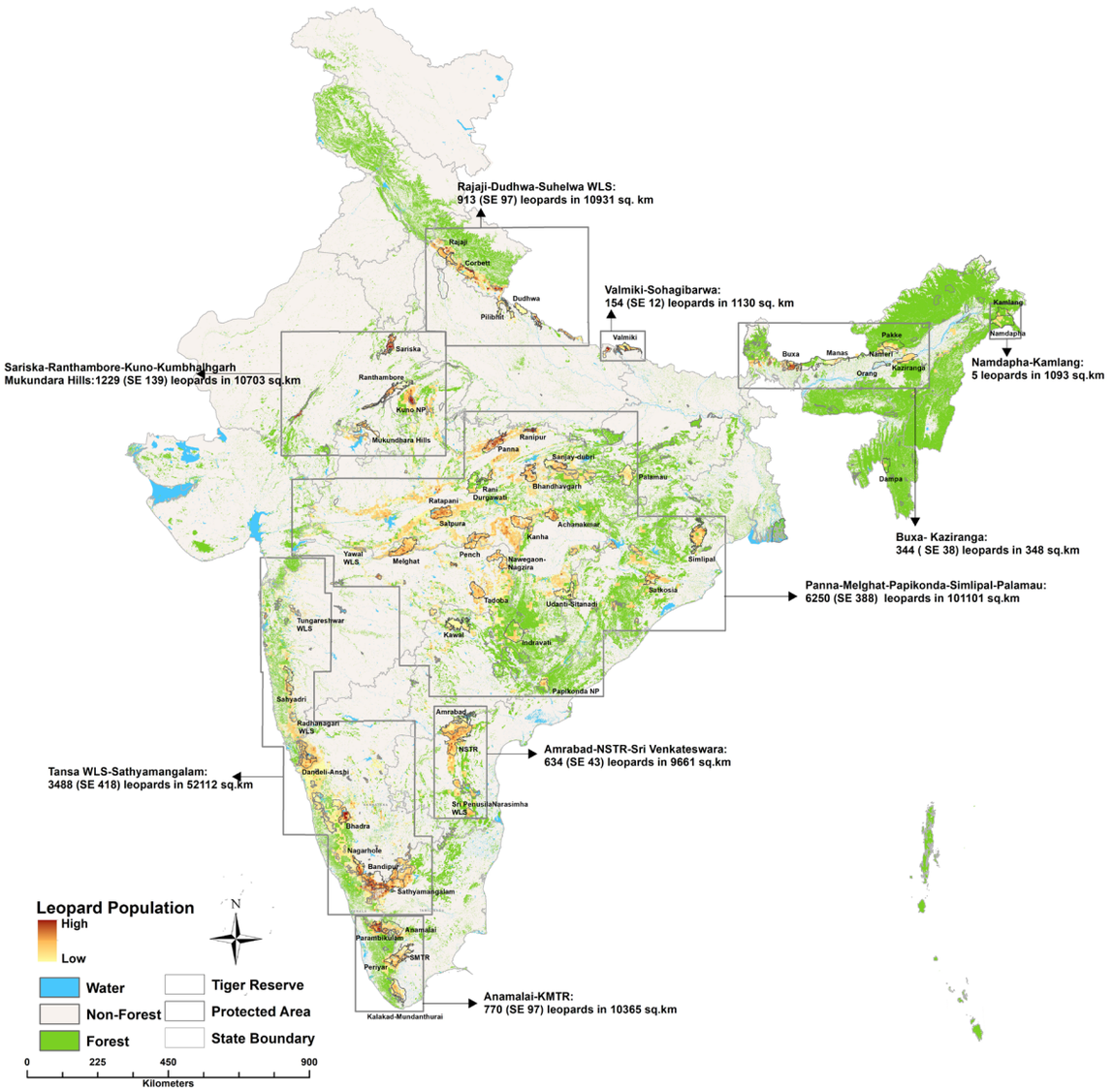
In the Shivalik Hills Landscape, it is crucial to monitor tiger and leopard dynamics annually, not only within Tiger Reserves but also in territorial and forest divisions, especially in Uttarakhand where a significant portion of the leopard population (79%) resides outside Protected Areas while for entire landscape it is 65%. The Rajaji, Dudhwa and Corbett Tiger Reserves have substantial leopard population (Table I.4). Annual camera trapping similar to Phase IV monitoring is recommended to track leopard populations effectively. Additionally, consideration should be given to declaring areas like Terai East and Nandhaur Wildlife Sanctuary as Tiger Reserves to facilitate staff training and annual monitoring efforts.

Nagarajunasagar Srisailam, Panna, Sariska and Satpura Tiger Reserves have very good leopard population (Table I.4). In Central India, a substantial portion (68%) of the leopard population inhabits human-use forests outside Protected Areas, increasing vulnerability to poaching and human-leopard conflicts. This region is a hotspot for leopard poaching (Raza *et al.,* 2012), necessitating strategic planning to address challenges such as prey recovery, mitigating road-hit mortalities, and capacity building for managing human-leopard conflicts. Effective patrolling and law enforcement are particularly critical in states like Jharkhand, Chhattisgarh, Odisha, and Telangana.

In the Western Ghats, leopard populations exhibit stability, but 65% of leopards reside outside Protected Areas, raising concerns for conservation efforts. Substantial population of leopards occur in Kali, Parambikulum and Mudumalai (Table I.4). This scenario increases the likelihood of leopard-human conflicts, leading to retaliatory killings of

Figure I.5

Leopard density, extent and population blocks in India, 2022.



leopards, especially in states like Karnataka, Kerala, Tamil Nadu, and Goa. Landscape-level plans are imperative to study conflict dynamics, and long-term studies focusing on leopard population dynamics and behavior are essential for comprehensive understanding. These measures can contribute to the development of a landscape-level leopard conservation plan for the Western Ghats.

North East Hills and Brahmaputra Flood Plains comprise a mosaic of forested habitats interspersed with human habitation and various land cover patterns, providing ample cover for adaptable species like leopards. While leopard presence is evident across the landscape, population estimates are only available from Tiger Reserves and some areas outside Reserves in North Bengal. Despite efforts made in the past five cycles of the All India Tiger Estimation, large forested areas of Assam and Arunachal Pradesh outside tiger reserves have remained unsampled, indicating inadequate sampling in this landscape and necessitating attention to expand monitoring scope. A total of 15 sites were sampled in this landscape using a camera trap-based mark-recapture framework, with leopards being photo-captured in 11 sites. The estimated leopard population in this landscape is 349 (SE 42). Although there has been an increase in the leopard population compared to earlier north Bengal *Dooars*. The growing human-leopard conflict in this landscape, stemming from habitat mosaic and developmental projects, poses a significant concern for leopard conservation

Table I.4:

Leopard population in Tiger Reserves of India in 2022.

State	Tiger Reserve	Leopards within Tiger Reserve (SE)	Leopards utilising Tiger Reserve (SE)
Shivalik Hills and Gangetic Plains			
Uttrakhand	Corbett	115 (2)	150 (7)
	Rajaji	171 (6)	215 (10)
Uttar Pradesh	Pilibhit	29 (1)	36 (3)
	Dudhwa	125 (5)	158 (10)
	Ranipur	67(3)	86 (7)
Bihar	Valmiki	78 (1)	86 (3)
Central India and Eastern Ghats			
Andhra Pradesh	Nagarjunasagar Srisailam	270 (5)	360 (14)
Chhattisgarh	Achanakmar	76 (3)	108 (9)
	Indravati#	3	3
	Udanti Sitanadi	28 (2)	52 (9)
Jharkhand	Palamau	35 (6)	51 (10)
Madhya Pradesh	Bandhavgarh	146 (4)	176 (8)
	Kanha	157 (2)	209 (9)
	Panna	256 (5)	317 (11)
	Pench	132 (3)	175 (9)
	Sanjay Dubri	110 (3)	154 (9)
	Satpura	215 (2)	256 (8)
Maharashtra	Bor	37 (2)	45 (4)
	Melghat	181 (4)	233 (10)
	Navegaon Nagzira	116 (3)	140 (7)
	Pench	70 (3)	102 (9)
	Sahyadri	87 (2)	135 (10)
	Tadoba Andhari	129 (1)	148 (7)
Odisha	Satkosia	80 (2)	111 (7)
	Similipal	91 (2)	131 (10)
Rajasthan	Mukundara	49 (4)	99 (15)
	Ramgarh Visdhari	19 (1)	25 (3)
	Ranthambore	87 (6)	167 (18)
	Sariska	167 (7)	269 (18)
Telangana	Amrabad	121 (2)	173 (10)
	Kawal	19 (1)	25 (3)
Western Ghats			
Karnataka	Bandipur	138 (3)	185 (9)
	Bhadra	116 (2)	178 (11)
	Biligiri Rangaswamy Temple	66 (3)	98 (9)
	Kali	124 (6)	246 (21)
	Nagarhole	105 (3)	140 (8)

State	Tiger Reserve	Leopards within Tiger Reserve (SE)	Leopards utilising Tiger Reserve (SE)
Kerala	Parambikulam	137 (3)	209 (12)
	Periyar	89 (9)	147 (19)
Tamil Nadu	Anamalai**	121 (5)	NA
	Kalakad-Mundanthurai	54 (3)	87 (10)
	Mudumalai	135 (4)	220 (14)
	Sathyamangalam	131 (8)	190 (15)
	Srivilliputhur-Meghamalai	97 (7)	147 (17)
North East Hills and Brahmaputra Flood Plains			
Arunachal Pradesh	Pakke	36 (1)	44 (3)
	Kamlang*	NA	NA
	Namdapha	5	5
Assam	Orang	1	1
	Manas	37 (2)	44 (4)
	Kaziranga	14 (1)	15 (1)
	Nameri	12 (1)	15 (2)
Mizoram	Dampa*	NA	NA
West Bengal	Buxa	61 (1)	74 (4)

** No evidence of Leopard found during sampling.*
 # Minimum identified Leopard from photographs.
*** Estimate derived from covariate model.*

A study conducted in 2012 suggests an alarming rate of poaching, 4 leopards are being poached every week in the past decades (Raza *et al.,* 2012). These figures may represent only a fraction of the actual poaching and trade in leopard parts occurring in India. Poaching of large carnivores may alter demography, behaviour of the target species also leaves cascading impact on the native biodiversity. Beyond poaching, habitat fragmentation due to developmental activities such as the development of linear infrastructure and mining poses significant threats to leopards. Mineral mining, linear development without appropriate mitigation that intersect its biodiverse forest habitats. Over the last century, leopards in India have experienced a substantial human-induced population decline (Bhatt *et al.,* 2020).

With increase in human populations and encroachments further into leopard habitats, incidents of human-leopard conflict are on the rise. In some instances, these conflicts escalate into violence, with communities retaliating against leopards that have preyed on their livestock or injures human. While recent studies have accumulated substantial knowledge about leopard populations, habitat use, food habits, and human-leopard conflict, there remains a notable gap in understanding their behaviour in varying natural conditions. With the leopard population expected to increase in the future, a concerted effort toward long-term monitoring, coupled with a deeper understanding of their natural history and behaviour, is imperative to devise effective management strategies.

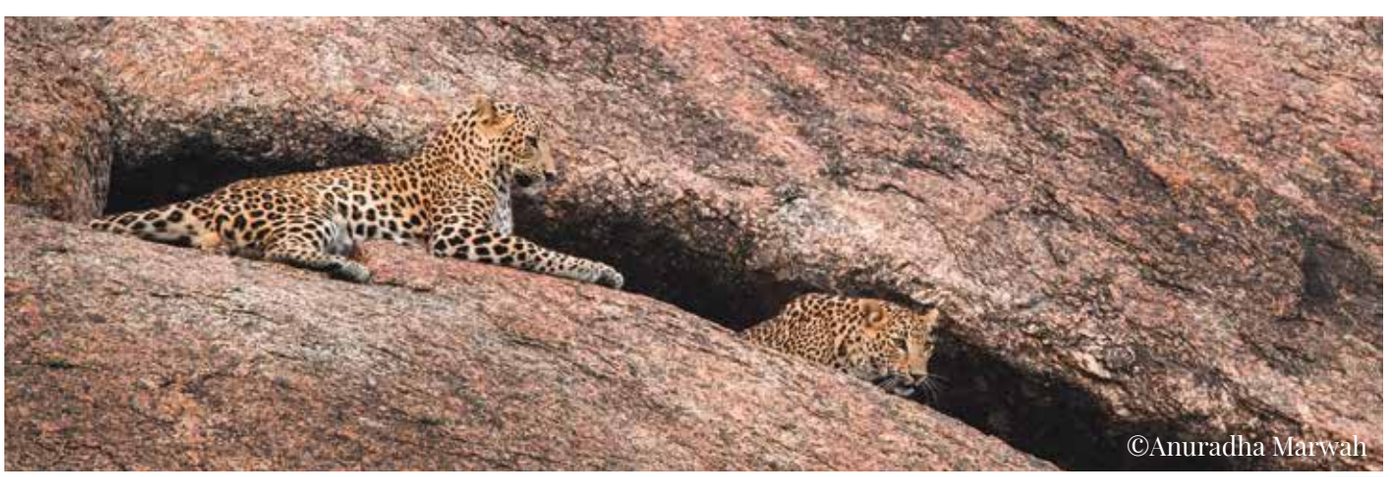
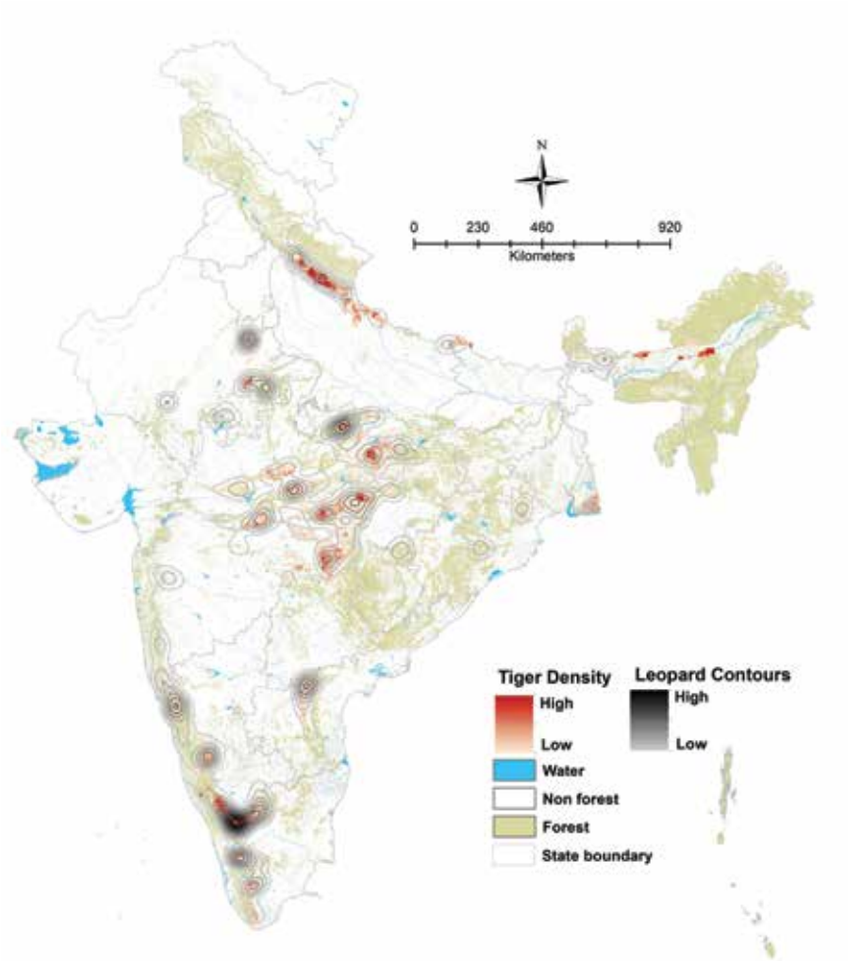


Figure I.6:

Leopard and Tiger abundance and distribution across India, 2022



The three major carnivores in the tropical forests of India are tigers, leopards, and dholes. The dominance hierarchy is Tiger > Dholes > Leopard (Srivathsa *et al.,* 2023). It is important to understand the distribution, abundance, and interaction amongst them, as they play an important role in shaping the community structure in tropical forests. Tiger and dhole have almost similar distribution except in Shiwalik Hills, Gangetic Plains, and Sunderbans. In their former habitat, dholes were persecuted and are almost wiped out of this area, and Sunderbans is not a dhole habitat. The leopard is more widespread across India in almost all habitats except deserts and sunderbans. The tigers are distributed in forest ecosystems that are less disturbed and have good deer density. The principal prey of all three carnivores are chital, sambar, hog deer, barking deer, wild pigs, and primates (Johnsingh 1992; Karanth 1995; Majumdar 2013; Steinmetz *et al.,* 2023). The three species exhibit spatio-temporal interaction, behavioral mechanisms, and prey diversity that allow for a form of co-occurrence, despite some level of avoidance and occasional aggression. There are complex interactions and dynamics within large carnivore guilds, as well as the influence of human activities on these interactions (Athreya, 2012; Gubbi *et al.,* 2017; Jhala *et al.,* 2020 & 2021; Srivathsa *et al.,* 2023).

The countrywide data indicates a positive or no relationship between the tiger and leopard populations in most of the areas except parts of the Gangetic and Brahmaputra floodplains (Fig I.6). Terrain complexity provides space for leopards and other large carnivores to persist with spatio-temporal segregation (Kumar *et al.,* 2019). The extractive use by humans has a negative relationship, indicating the interaction of protected areas providing prey and protection, as most of the high-density multi-carnivore areas are tiger reserves or other protected areas. The grassland management in protected areas at village-relocated sites has provided an opportunity for the sustenance of large prey biomass. It is important to maintain the grasslands and habitat free from invasive plant species, and the removal of ungulates on a large scale should be avoided as large-medium carnivore guilds coexist in a productive ecosystem.

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II. Shivalik Hills and Gangetic Plains Landscape

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Shivalik Hills and Gangetic Plains Landscape

The Shivalik Hills and Gangetic Plains landscape in India spans across the states of Himachal Pradesh, Uttarakhand, Uttar Pradesh and Bihar is comprised of three parallel geological zones, viz. the Shivaliks, the Bhabar tract and the Terai plains. We assessed leopard population only in the potential areas where tiger could occur in this landscape. Leopards are distributed in the Shivalik Forest Division adjoining Rajaji Tiger Reserve, towards Himachal Pradesh, and in the higher hilly regions of the state of Uttarakhand. But these areas were outside the purview of the current project's study area and hence, we provide the estimate of leopard population in potential tiger bearing forests below 2000 msl.

Leopards are distributed across the Shivalik Hills and Gangetic Plains, and are reported to use non-forested areas that include vicinity of human habitations, plantations and agricultural fields (Fig. II.1). Major wild prey for leopard in the Rajaji Tiger Reserve was chital, sambar, hog deer, barking deer and wild pig. Patel *et al.,* 2023 reported that in Shivalik and Terai region, diet of leopards was primarily composed of large and medium-sized prey species (85%), whereas small prey species made up just 15%. Sambar (23%) and Chital (45 %) had the majority of contribution to the diet. In all, nine different species of prey were found in the diet of leopard, large-bodied Sambar, Nilgai, and Livestock; medium-bodied Chital, Wild pig, and Hog deer; and small-bodied Langur, Hare, and Peafowl. Most of the studies in the landscape focus on human-leopard conflict (Naha *et al.,* 2018 and 2020).


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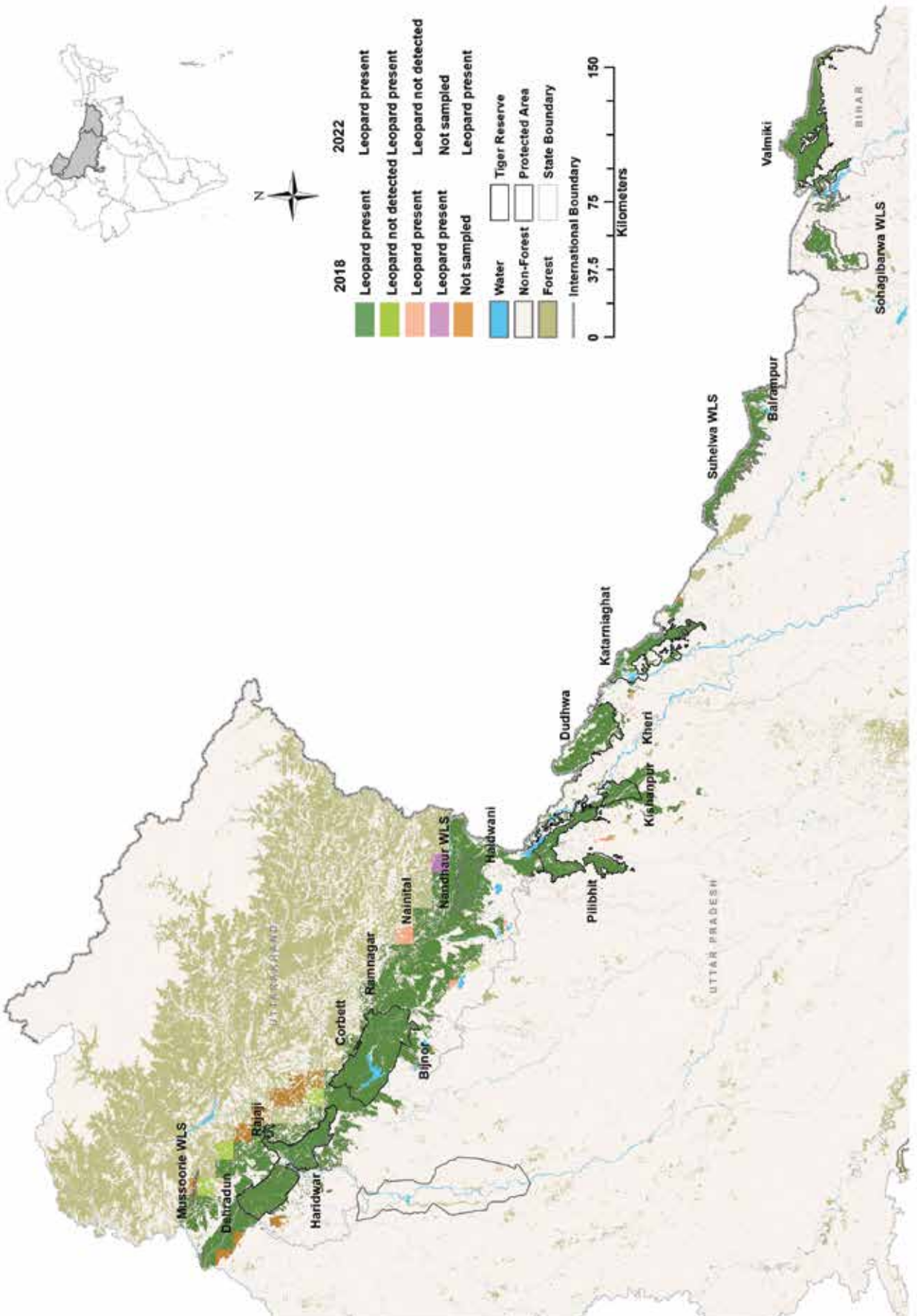

Figure II.1: *Change in leopard distribution in Shivalik Hills and Gangetic Plains from 2018 to 2022.*

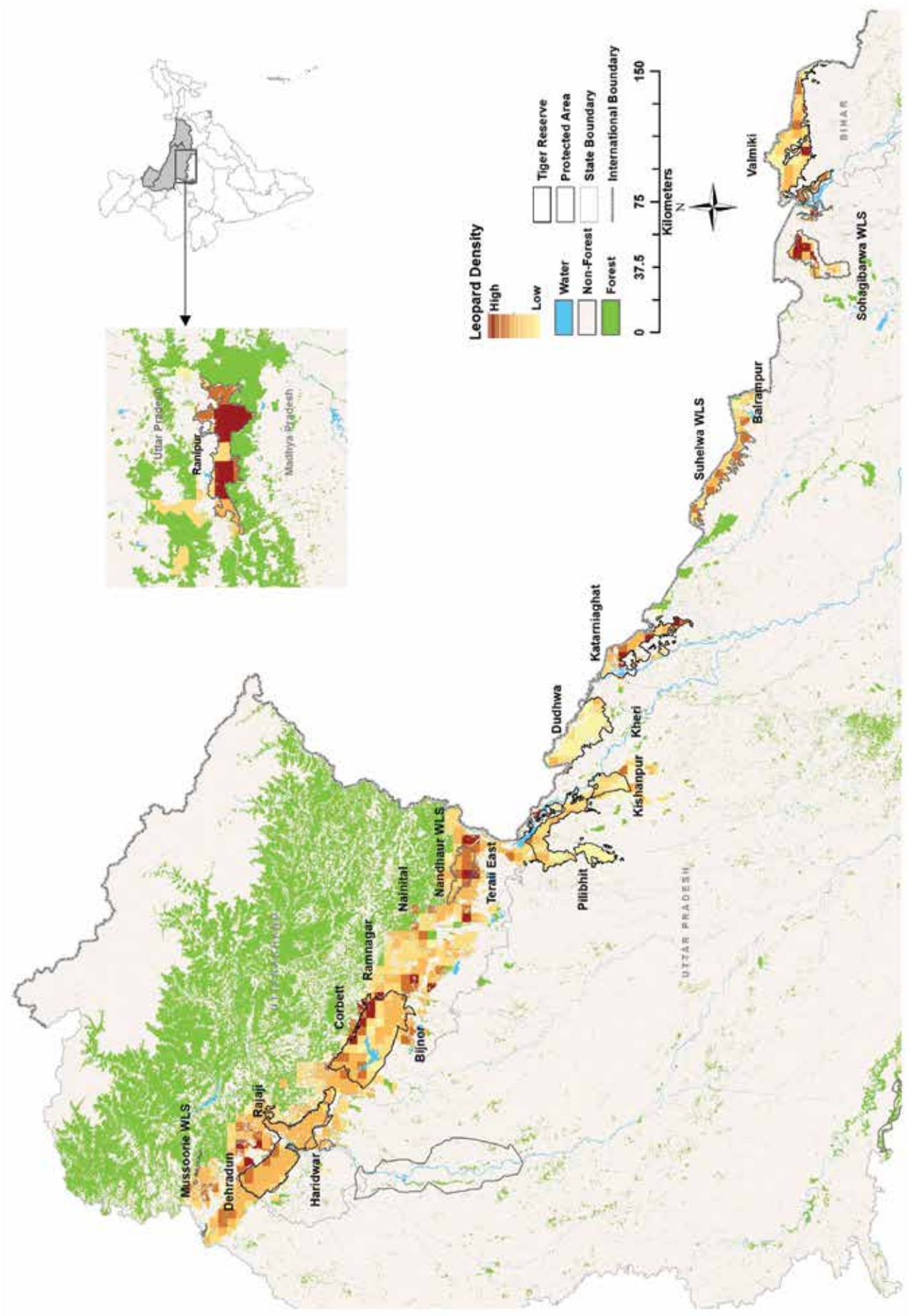

Figure II.2: *Spatially explicit leopard density modelled from camera traps-based capture-mark-recapture and covariates of leopard sign for Shivalik Hills and Gangetic Plains Landscape 2022.*

Leopard distribution, population extent and abundance

Phase I data collected by the forest department and camera trap based photo-captures show leopard to be distributed across the forested areas of Uttarakhand, Uttar Pradesh and parts of Bihar. The population in much of Uttar Pradesh is contiguous with habitats in Nepal. Leopards were also reported from the higher reaches of Himalayas (Narendranagar, Almora, Nainital and Champawat forest division) wherever the habitat was sampled.

Of the 351 cells of 100 km^2 that were sampled, 268 cells (76 %) were occupied by leopards in the landscape. The landscape sampling has saturated with respect to the available forest and hence occupancy has remained constant in the area. Some areas between Katarniaghat and Suhelwa Wildlife Sanctuary have seen presence of leopard in 2022 where leopards were not reported in 2018 (Fig. II.1). Leopard occupied area in the landscape has remained consistent over the two monitoring cycles and only some parts of Nainital in Uttarakhand show loss in leopard occupancy in 2022 (Fig. II.1). Dehradun, Kalsi and Narendranagar Forest Division were sampled for the first time in 2022.

Leopard density was computed from 26 camera trapped sites within this landscape (Table II.1). A total of 10,564 leopard photo-captures were obtained from which 943 individuals were identified. Leopard sign encounter rate, prey density and human disturbance were used as covariates to model leopard density in a likelihood SECR framework. Model with leopard sign encounter and tiger sign best explained leopard density across the landscape. Total population of leopard within the sampled forested landscape of Shivalik-Gangetic plains was estimated at 1,109 (SE 134) as compared to 1,253 (SE 95) in 2018 and 929 (SE 75) in 2014.


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Uttarakhand

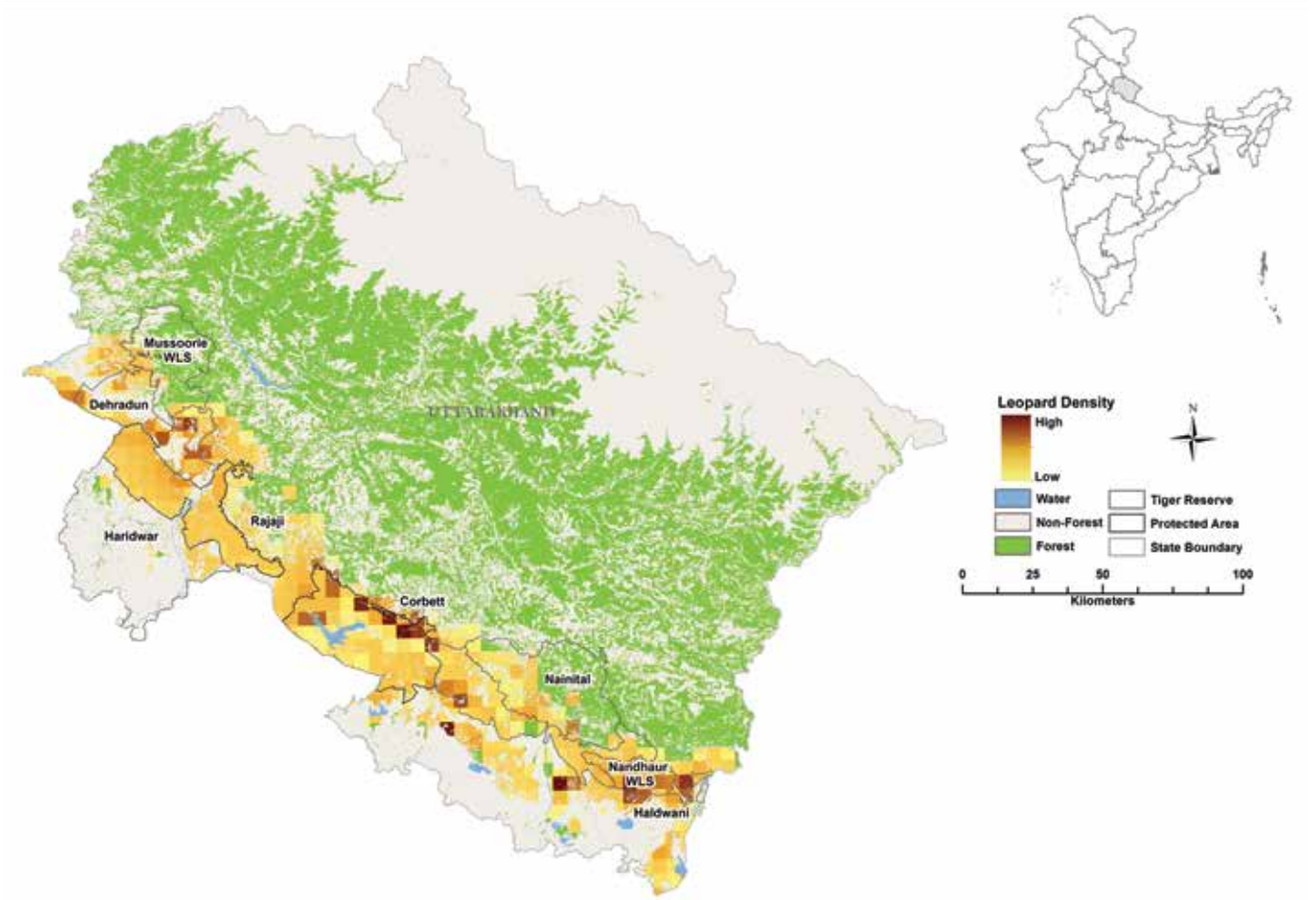

Figure II.3:

Spatially explicit leopard density (individuals /100 km^2) modelled from camera traps-based capture-mark-recapture and covariates; Uttarakhand, 2022.

A total of 15 sites were camera trapped in Uttarakhand (Table II.1) that yielded 5,358 photo-captures of 588 leopard individuals. Like mentioned earlier, we only report leopard numbers from potential tiger habitat of the state. Leopard population of the state was 652 (SE 77) as compared to 839 (SE 48) in 2018. Leopard numbers remains stable in Rajaji and Corbett Tiger Reserve but density has not changed significantly since 2018 (Jhala *et al.,* 2021). Ramnagar Forest Division has recorded significant decline in leopard population possibly owing to increased tiger density (Qureshi *et al.* 2023). Three new sites, Kalsi, Dehradun and Narendranagar Forest Divisions were sampled for the first time. Dehradun Forest Division which was camera trapped for the first time had high leopard density and this is also the place where frequent movement of leopard is reported in the habitations. Terai West has seen significant increase in both tiger and leopard population. With frequent tiger attacks on people reported in the Terai (area south and east of Corbett Tiger Reserve) and a high density of leopard in the area as well, there is an urgent need to sensitise people about movement in forest. Both Terai West and Terai East are connected to Corbett and Pilibhit Tiger Reserve respectively and have the potential to be declared as Tiger Reserves, this will assist in bringing much needed resources for better management.

Human leopard conflict remains cause of major concern in the state. With tiger and leopard occupying most of the forested areas, the state has to deal with conflicts on a regular basis. Leopard conflict is not limited to rural areas anymore and has spread to urban areas (like the recent leopard attacks in the outskirts of Dehradun city). Most of the studies on leopard conflict in the state have been carried out above 2000 msl which is beyond the study area for this report. But the conflict is no more limited to higher reaches of the state as evident from the recent leopard attack in township of Raipur in Dehradun in January 2024. In the past 5 years there have been nearly 2000 human-animal conflict (that includes injuries caused to humans and death), of this around 570 were attributed to leopard (Uttarakhand Forest Department 2024). In the state of Uttarakhand 30% of all the human death and injury cases by wildlife were caused by leopard (Uttarakhand Forest Department, 2024)

Uttar Pradesh

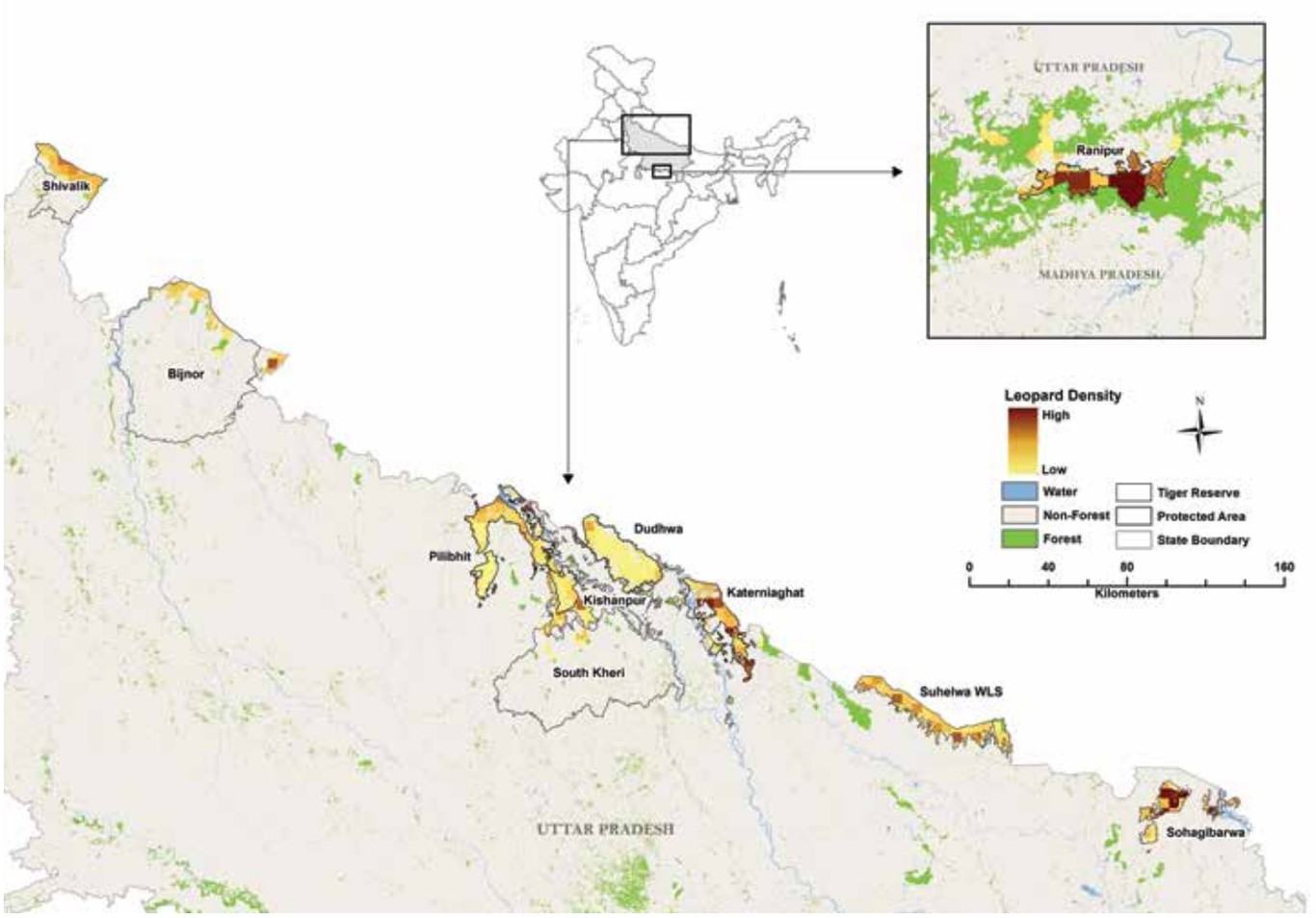

Figure II.4:

Spatially explicit leopard density (individuals /100 km^2) modelled from camera traps-based capture-mark-recapture and covariates; Uttar Pradesh, 2022.

A total of 9 sites were camera trapped in Uttar Pradesh (Table II.1) that yielded 4,282 photo-captures of 317 leopard individuals. Leopard population in the state was estimated at 371 (SE 54). Even though overall leopard population for the state has increased as compared to 2018 which was 316 (SE 39), (Jhala *et al.,* 2021), leopard population has shown significant decline in Dudhwa National Park and remained constant in Pilibhit and Suhelwa (Table II.1). There has been a significant increase in leopard population in Katarniaghat and Kishenpur WLS since 2018. Leopard density in Ranipur has also gone up but that is due to better sampling effort in 2022 as compared to 2018. This increase in leopard population in Katarniaghat and Kishenpur are a worrying trend with respect to human-animal conflict in the state. Uttar Pradesh is already battling increasing number of tigers using multiple use matrix around its Protected Areas and with 47% of the leopard population present outside Protected Areas, the conflict intensifies.

Uttar Pradesh's human-leopard conflict problem is an outcome of its protected area's unique geography where most of the Protected Areas are less than 10 km wide for much of their extent, with Katarniaghat just 4-6 km wide. The matrix surrounding these areas in all directions comprises of extensive agricultural land (sugarcane, wheat and paddy cultivation) and numerous villages with high human densities. Farmlands are essentially an extension of wildlife habitats for many mammals, especially when the crops are tall. In case of Katarniaghat, the farmlands to the north of the sanctuary in Nepal are fallow for several months of the year and there is little sugarcane cultivation. Many villages are at the forest edge. Thus, human reach within the forest is high, both because of these settlements and because the forests are accessed by residents of matrix villages. Local dependence on forest resources (primarily firewood and fodder) is also high, and large number of cattle are grazed in some grasslands within Katarniaghat. Wild prey is relatively low in the division (Chanchani *et al.,* 2014). For these reasons, the likelihood of humans encountering leopards both within the division and around is high. Given Protected Areas narrow width and high human pressure, it is remarkable that the areas still harbour populations of large

carnivores and herbivores – which can be attributed both to conservation measures and protection, and equally to the willingness of communities to coexist with wildlife in their neighbourhoods. However, the long-term persistence of these species rests at least in part on more effective conflict management, principally to significantly reduce encounters between humans and leopards. Bista *et al.*, (2019) study in Katarniaghat notes that unlike attacks by tigers which typically occur in areas with dense cover, 38% of the conflict with leopards occurred when the victim was either inside or adjacent to a home. Another 40% of the conflict was recorded in agricultural fields, and 11% of attacks were on people who were defecating in farmlands (a common practice in rural areas as homes generally do not have toilets or their use is minimal). The remaining cases were reported from forests, along village roads and other places. Most of these rescue operations of leopards are carried-out during the monsoon and winter seasons as the cover availability increases in sugarcane farmlands and as harvesting period approaches. It is further evident that female leopards give birth to their litters in sugarcane fields during the winter season and use these farmlands to raise their cubs (Bista *et al.*, 2019).

Local forest department has been sensitising the local community with awareness programs. These program are aimed at spreading awareness amongst locals by sending messages on the phone to alert the user and by providing solar street lights to increase visibility in the conflict prone villages. Awareness building program is an effective tool to reduce conflict by bringing in a behavioural change in people.

Bihar

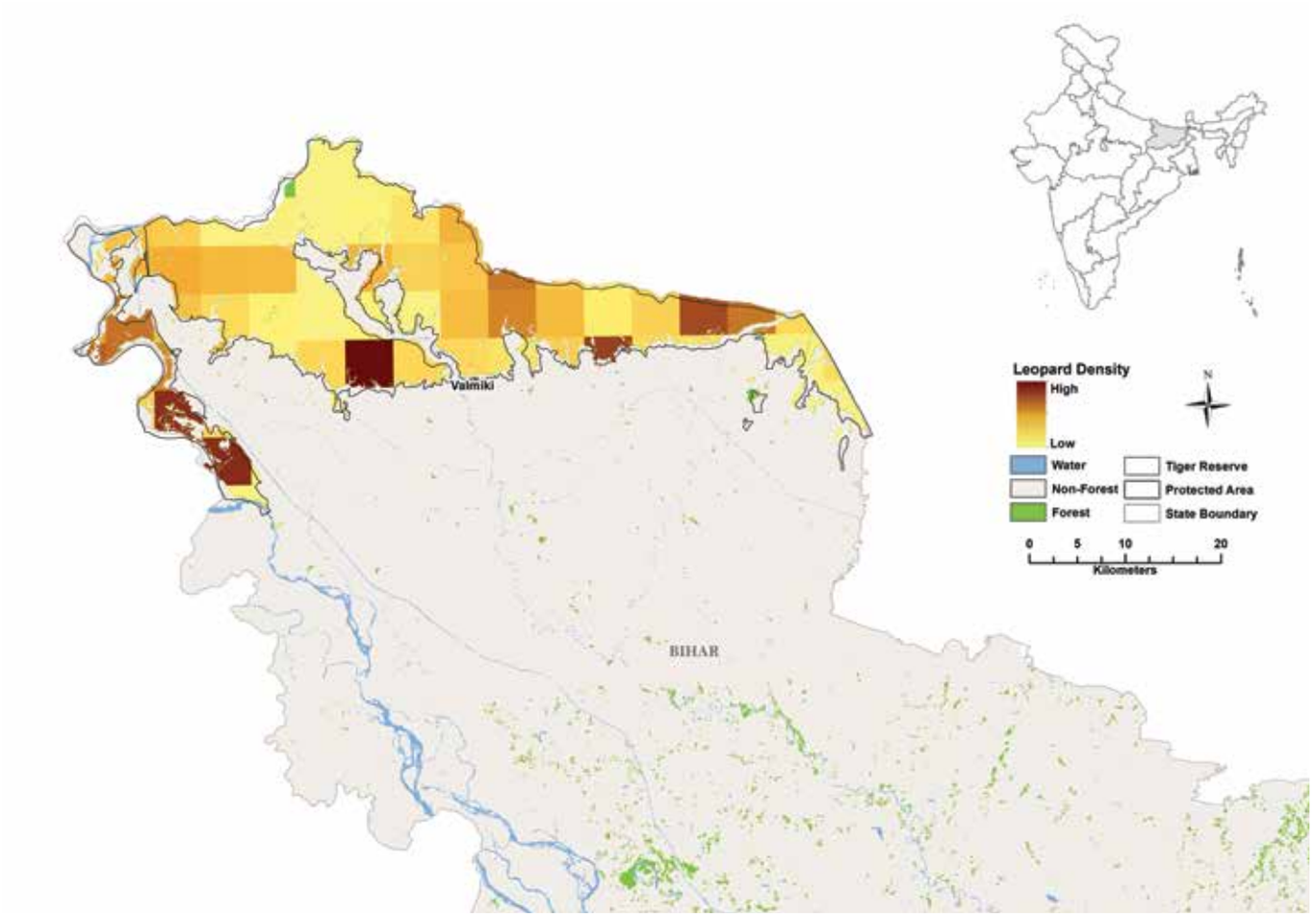

Figure II.5:

Spatially explicit leopard density (individuals /100 km^2) modelled from camera traps-based capture-mark-recapture and covariates; Bihar, 2022.

Valmiki Tiger Reserve was the only camera trapped site in Bihar, where 924 leopard photo-captures yielded 78 leopard individuals. Leopard population in the state is 86 (3) which was 98 (SE 8) in 2018 (Jhala *et al.*, 2021). The leopard population needs to be monitored, as Valmiki have limited space and large tiger and leopard population will contribute to conflict with humans.

Conservation Implications

Shivalik Hills and Gangetic Plains landscape recorded decline in leopard population and the five Tiger Reserves in this landscape had leopard density varying from 2.12 (SE 0.55) leopards per 100 km^2 in Dudhwa National Park to 14.07 (SE 1.57) leopards per 100 km^2 in Katarniaghat Wildlife Sanctuary. Detection corrected sex ratio was female biased in all the Tiger Reserves except Pilibhit. Uttarakhand harbours major portion of the leopard population in the landscape, and the numbers will be more given that the hills of the state were not sampled for leopards. All states in this landscape are facing human-animal conflict with respect to tiger and leopard, this conflict will intensify in future and the state needs to take pro-active measures to avoid loss of life and property in such cases. With 65% of leopard population in the state present outside Protected Areas, training of forest staff in the forest divisions and territorial forests is first step towards managing the conflict. Timely compensations and awareness amongst local communities will also help alleviate the problem.

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Table II.1: *Sampling details and leopard density parameter estimates using spatially explicit capture mark recapture analysis in a likelihood framework for sites in Shivalik Hills and Gangetic Plains Landscape, 2022.*

State	Site	Model Space (km^2)	Camera traps	Mt+1	Best Fit Model	$\hat{D}$ secr/ 100 km^2 (SE)	g0 Female (SE)	g0 Male(SE)	σ Female (SE) (km)	σ Male (SE)(km)	Pmix(SE)
Uttarakhand	Dehradun	1643	266	82	~(sex), Pmix~(sex), g0~(sex)	9.58 (1.08)	0.05(0.005)	0.06(0.01)	1.39(0.06)	2.10(0.10)	0.71:0.29(0.06)
Uttarakhand	Kalsi	756	151	25	~(sex), Pmix~(sex), g0~(.)	5.80(1.24)	0.03(0.005)		1.31(0.11)	2.82(0.26)	0.70:0.30(0.10)
Uttarakhand	Narendranagar	NA	11	5	NA	NA	NA	NA	NA	NA	NA
Uttarakhand	Rajaji	1487	426	151	~(.), Pmix~(sex), g0~(.)	12.32(1.01)	0.04(0.003)		1.31(0.03)		0.35:0.65(0.05)
Uttarakhand	Lansdowne	1389	181	54	~(sex), Pmix~(sex), g0~(sex)	8.78(1.33)	0.09(0.01)	0.09(0.01)	0.70(0.04)	2.54(0.15)	0.85:0.15(0.04)
Uttarakhand	Corbett	2017	514	113	~(sex), Pmix~(sex), g0~(sex)	7.46(0.70)	0.01(0.001)	0.03(0.002)	1.83(0.07)	1.62(0.04)	0.61:0.39(0.05)
Uttarakhand	Terai West	624	88	32	~(sex), Pmix~(sex), g0~(sex)	9.54(1.71)	0.12(0.03)	0.10(0.01)	0.82(0.08)	1.58(0.09)	0.47:0.53(0.10)
Uttarakhand	Almora	NA	13	1	NA	NA	NA	NA	NA	NA	NA
Uttarakhand	Ramnagar	NA	100	14	NA	NA	NA	NA	NA	NA	NA
Uttarakhand	Haldwani	1114	149	43	~(sex), Pmix~(sex), g0~(sex)	8.20(1.26)	0.09(0.01)	0.05(0.01)	0.91(0.04)	1.99(0.10)	0.69:0.31(0.07)
Uttarakhand	Terai Central	NA	15	1	NA	NA	NA	NA	NA	NA	NA
Uttarakhand	Champawat	NA	32	12	NA	NA	NA	NA	NA	NA	NA
Uttarakhand	Nainital	642	40	16	~(.), Pmix~(sex), g0~(sex)	7.83(2.12)	0.28(0.04)		0.72(0.06)		0.36:0.64(0.15)
Uttarakhand	Terai East	1225	178	55	~(.), Pmix~(sex), g0~(.)	6.82(0.93)	0.02(0.002)		2.36(0.10)		0.45:0.55(0.08)
Uttar Pradesh	Amangarh	NA	45	8	NA	NA	NA	NA	NA	NA	NA
Uttar Pradesh	Dudhwa	1196	296	17	~(sex), Pmix~(sex), g0~(sex)	2.12(0.55)	0.01(0.01)	0.02(0.003)	1.29(0.33)	5.09(0.24)	0.56:0.44(0.14)
Uttar Pradesh	Katarniaghat	669	251	81	~(sex), Pmix~(sex), g0~(sex)	14.07(1.57)	0.004(0.0005)	0.01(0.001)	3.41(0.17)	3.90(0.16)	0.62:0.38(0.05)
Uttar Pradesh	Kishenpur	1127	167	25	~(sex), Pmix~(sex), g0~(sex)	3.01(0.71)	0.08(0.02)	0.04(0.01)	0.92(0.07)	6.45(0.28)	0.88:0.12(0.06)
Uttar Pradesh	South Kheri	NA	22	3	NA	NA	NA	NA	NA	NA	NA
Uttar Pradesh	Pilibhit	1218	308	29	~(sex), Pmix~(sex), g0~(sex)	2.92(0.55)	0.02(0.003)	0.03(0.002)	3.86(0.26)	4.18(0.12)	0.31:0.69(0.09)
Uttar Pradesh	Sohagibarwa	500	80	53	~(.), Pmix~(sex), g0~(.)	13.12(1.81)	0.12(0.01)		1.32(0.04)		0.55:0.45(0.08)
Uttar Pradesh	Suhelwa	668	75	40	~(sex), Pmix~(sex), g0~(sex)	7.91(1.29)	0.17(0.03)	0.11(0.02)	0.90(0.07)	2.10(0.13)	0.67:0.33(0.08)
Uttar Pradesh	Ranipur	510	99	61	~(.), Pmix~(sex), g0~(.)	16.93(2.21)	0.03(0.003)		1.64 (0.07)		0.52:0.48(0.070
Bihar	Valmiki	1097	429	78	~(sex), Pmix~(sex), g0~(sex)	7.79(0.89	0.06(0.01)	0.04(0.003)	1.24(0.04)	2.80(0.08)	0.66:0.34(0.05)

SE: *Standard error, D^SECR: Density estimate from Maximum Likelihood based spatially explicit capture recapture, σ : Spatial scale of detection function, g0: Magnitude (intercept) of detection function, Pmix: Detection corrected estimate of proportion of female and male*

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III: Central India and Eastern Ghats Landscape

Ujjwal Kumar, Rutu J. Prajapati, Vishnupriya Kolipakam, Jayanta Kumar Bora, Omkar Nar, Ayan Sadhu, Juri Roy, Shravana Goswami, Ashish Prasad, Swati Saini, Dhruv Jain, Krishna Mishra, Kainat Latafat, Manish A. Singanjude, Anup Kumar Pradhan, Gaurav A. Shinde, Anshuman Gogoi, Hemant Kamdi, Satya.P. Yadav, Yadvendradev V. Jhala and Qamar Qureshi


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Central India and Eastern Ghats

The Central Indian and Eastern Ghats landscape encompasses the semi-arid zone of Rajasthan, deciduous and semi-evergreen forests forming a continuous expanse across the Deccan plateau, which includes the states of Maharashtra, Madhya Pradesh, Chhattisgarh, Jharkhand, and Odisha. It comprises sections of the Eastern Ghats, extending into Telangana, Andhra Pradesh, and Odisha. For administrative continuity and to avoid dividing the state of Maharashtra, the Sahyadri Hills of Maharashtra in the northern Western Ghats are included in this landscape. Conversely, certain portions of the Eastern Ghats in Tamil Nadu and Karnataka are excluded from this chapter, as they are addressed in the context of the Western Ghats landscape chapter. It is important to note that the leopard population in Rajasthan is specifically reported for tiger-occupied habitats within the Ranthambore, Sariska, Mukundara Hills, Ramgarh Visdhari Tiger Reserves and three Wildlife Sanctuaries (Kumbhalgarh, Shergarh and Bhainsrodgarh).

The Central Indian and Eastern Ghats landscape harbours the largest population of leopards fostered by diverse array of habitats ranging from semi-arid to dry and moist mixed deciduous forests and a rich prey base (Jhala *et al.,* 2021). The country wide genetic assessment of the leopard population suggests the Central Indian leopard population also has the highest genetic diversity (Jhala *et al.,* 2021).

The leopard population in this landscape is growing, owing much of its success to the protective measures under the umbrella of tiger conservation. The Tiger Reserves within this landscape also emerge as the major source sites for leopard populations. However, the expanding tiger population is not without consequences, as it exerts regulatory pressure on leopards. A recent study in Kanha revealed adverse effects of tigers on leopard populations (Kumar *et al.,* 2019). It is also evident in high leopard abundance estimates in the Tiger Reserves in the region such as Panna and Sariska where tiger abundance is low (Jhala *et al.,* 2019).

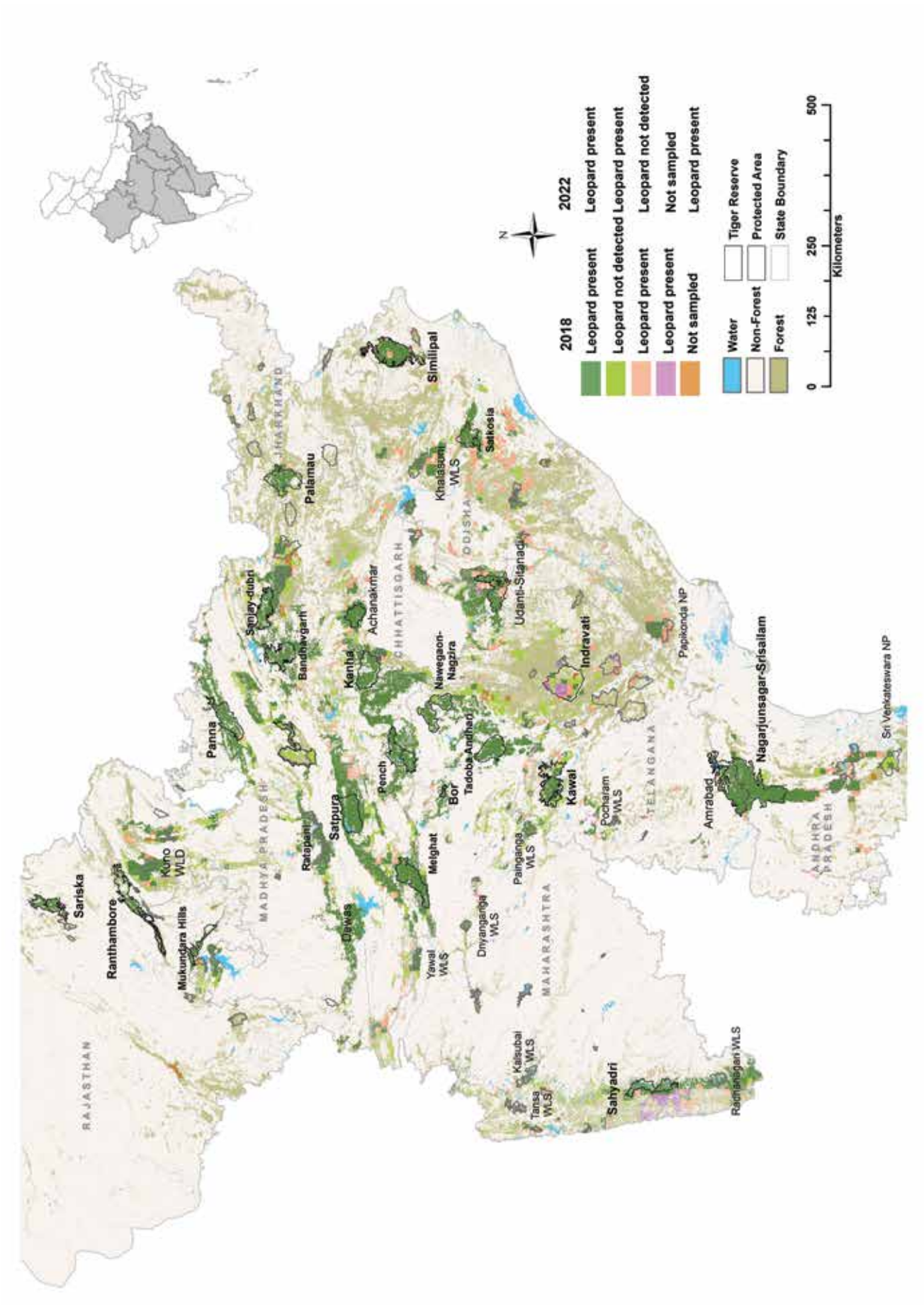

Figure III.1 *Change in leopard distribution from 2018 to 2022 in the Central India and Eastern Ghats landscape*

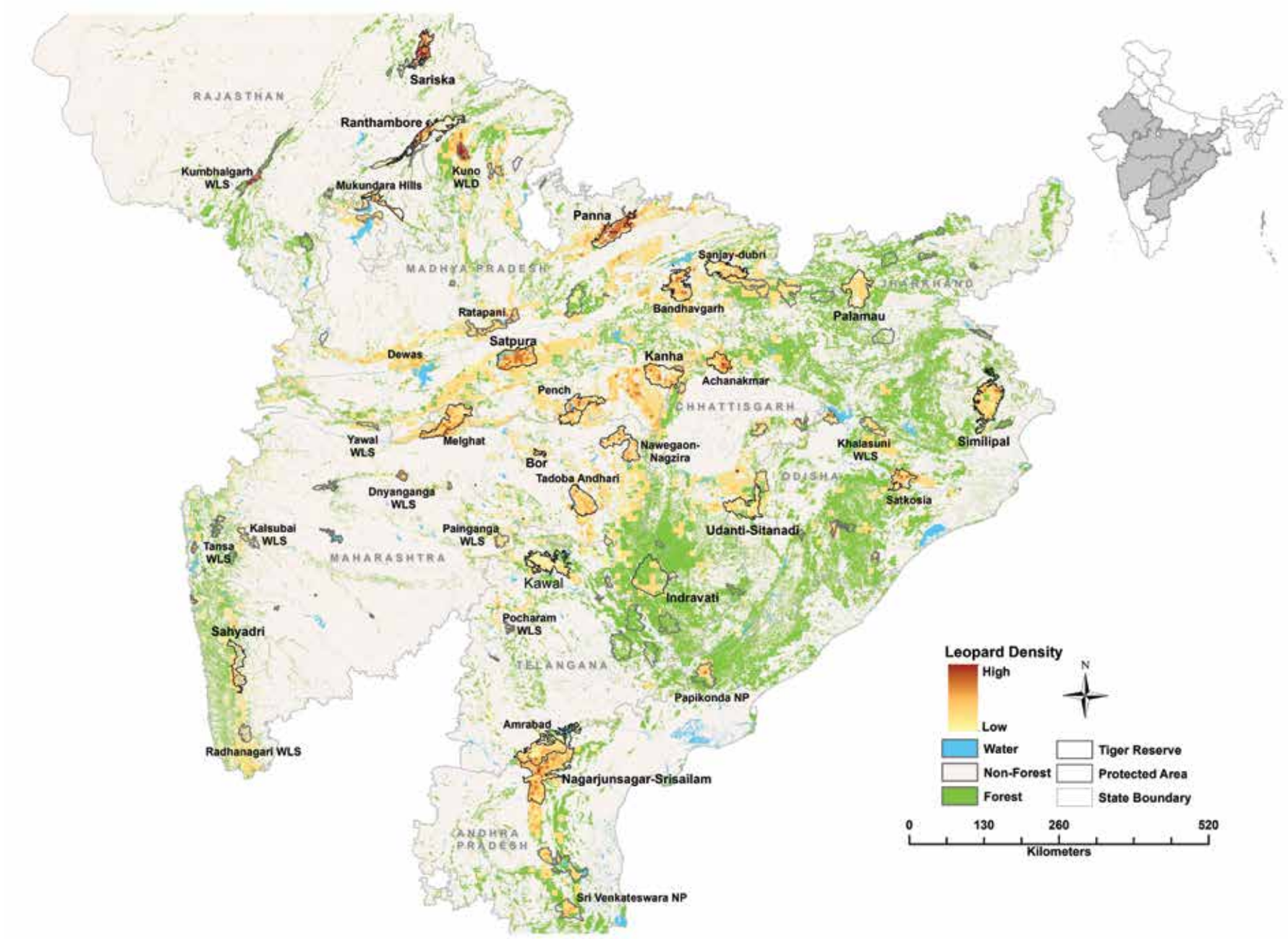

Figure III.2 *Spatially explicit leopard density modelled from camera trap based capture-mark-recapture and covariates of leopard sign, prey abundance and human disturbance within the Central India and Eastern Ghats landscape, 2022.*

Leopard Occupancy, Population Extent and Abundance

Leopards exhibited a notable increase in occupancy within surveyed cells (100 km^2) compared to the cells in the previous estimation cycle of 2018 (Figure III.1). Total 8652 cells (100 km^2) were sampled in 2022, out of which leopard presence was recorded in 30.87% (2,671) cells. Leopard presence was consistent in 1,751 cells in 2018 & 2022; leopards were not detected in 455 of previously occupied cells, whereas leopard presence was detected in 833 previously unoccupied cells in 2018 (Fig. III.1). Major gain in occupancy was reported from Madhya Pradesh & Rajasthan (Due to additional sampling areas).

The central Indian landscape, encompassing a total area of 1,10,653 km^2, exhibits significant leopard occupancy distributed across four distinct patches. These patches are identified as follows:

(a) The central block spans the entire states of Madhya Pradesh, Chhattisgarh, Jharkhand, Odisha, Maharashtra, and Northern Telangana.
(b) The southern block extends from the Amrabad Tiger Reserve and Nagarjunsagar Srisailam Tiger Reserve to the Sri Venkateshwara Wildlife Sanctuary.
(c) The western block includes the western ghats of Maharashtra (Sahyadri hills) and the surrounding areas of the Deccan Plateau.
(d) The northern block encompasses Sariska, Ranthambore, and Mukundara Tiger Reserves, as well as the northern part of Madhya Pradesh, consisting of the Kuno-Palpur National Park, Madhav National Park, and Sheopur forests.

Leopard presence has been identified across all Protected Areas (Protected Areas) and major forest corridors within the central Indian landscape. Madhya Pradesh exhibits the highest leopard occupancy in this region, followed by Maharashtra. The comprehensive understanding of leopard distribution in these patches contributes to the conservation efforts and ecological management of leopard in Central India.

Leopard densities were computed using data from 67 camera-trapped sites in this region. A total of 51,598 photographs were obtained that yielded 3,666 unique individuals. Over 200 individual leopards were captured on camera in Panna, Nagarjunasagar Srisailam, and Satpura Tiger Reserves (Table III.1). The total leopard population in the surveyed forest of this area was estimated at 8,820 (SE 600). About 68% leopard population are outside to the Protected Area (PAs). However, high leopard densities were mainly observed in Protected Areas (PAs) and the major forest corridors connecting Protected Areas in this region (Figure III.2). The leopard population has increased in Madhya Pradesh, Maharashtra, and Andhra Pradesh, while a decline has been noted in Odisha, Chhattisgarh, and Telangana. It's noteworthy that the trend is similar to the decline in the tiger population (Qureshi *et al.,* 2023). This suggests common threats, such as poaching of prey for bush meat, targeted poaching for tiger and leopard skins and body parts (Raza *et al.,* 2012), and habitat loss due to mining and other human activities. Additionally, road accidents are a significant cause of leopard fatalities.

To address these issues, states should consider supplementing prey in low-density areas, implementing effective protection strategies using M-STrIPES, and providing wildlife management training for forest staff. Ensuring wildlife passage measures on roads passing through leopard habitats is also crucial.


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Andhra Pradesh

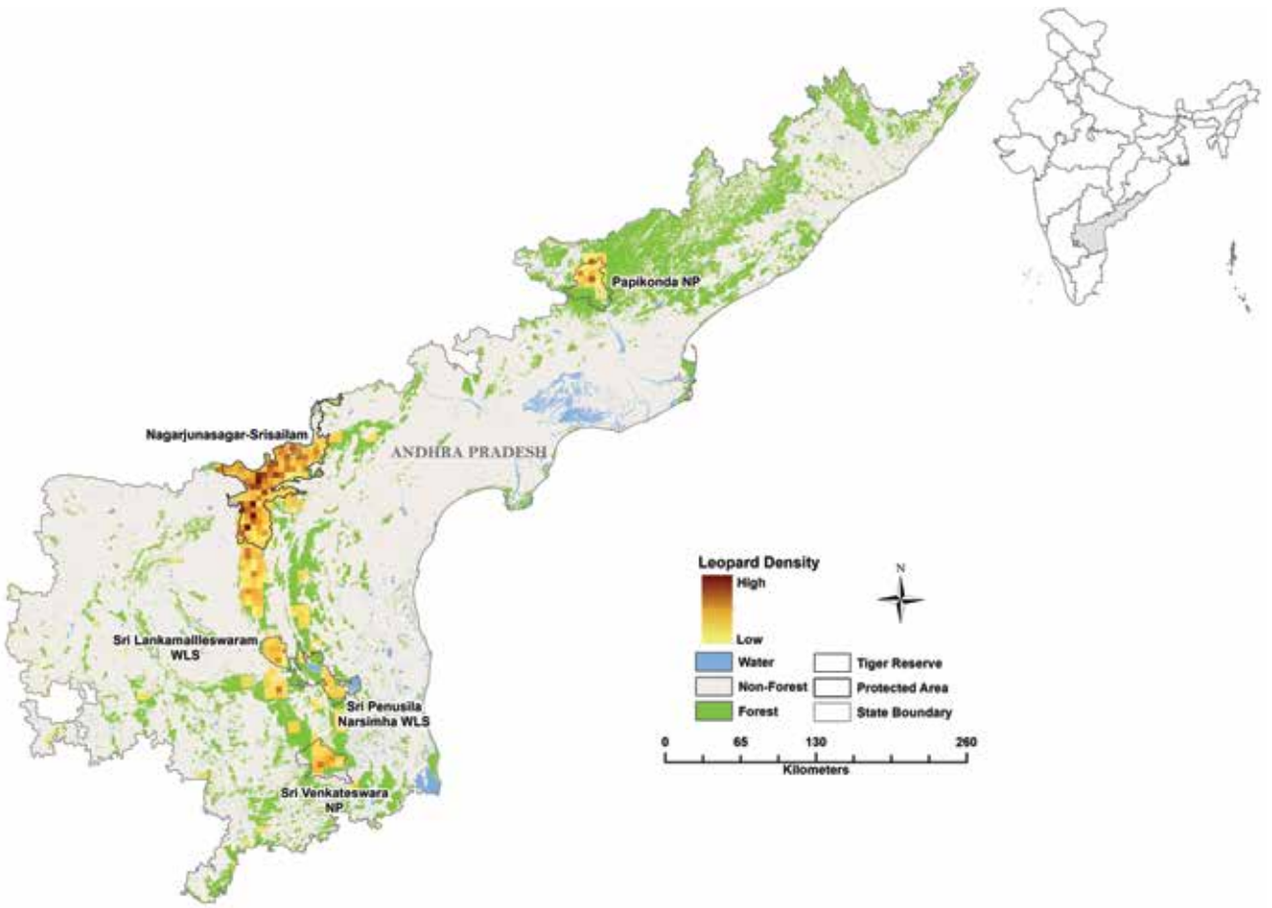

Figure III.3:

Spatially explicit leopard density (individuals/100 km^2) modelled from camera traps-based capture-mark-recapture and covariates; Andhra Pradesh, 2022

Andhra Pradesh has a forest cover of 29,784 km^2, making up 18.28 % of the state's total area (Indian State of the Forest Report 2021). Andhra Pradesh's diverse topography, ranging from the hills of Eastern Ghats and Nallamala to the shores of the Bay of Bengal, supports a rich variety of ecosystems. Eco-geographically the leopard population in Andhra Pradesh categorized into two regions (Figure III.3): (i) Rayalaseema: This region encompasses the forests of Nagarjunasagar Srisailam Tiger Reserve (NSTR), Sri Venkateshwara National Park, Sri Penusila Narasimha Wildlife Sanctuary and the territorial areas of Kadapa Forest Divisions. (ii) Godawari basin: Leopard signs were not reported in this region, except for Papikonda National Park, situated in the Papi hills with its forested habitat extending into Odisha.

Leopard occupancy has been reported to have declined in the southern region of Papikonda National Park. However, there were mixed occupancy changes in the Rayalaseema region (Figure III.1). Camera trapping was carried out at Papikonda National Park and Nagarjuna Srisailam Tiger Reserve, along with nearby sanctuaries including Sri Lankamalleshwara, Sri Penusila Narasimha Wildlife Sanctuaries, Sri Venkateshwara National Park, and the territorial areas of Kadapa Forest Divisions. A total of four sites were camera trapped in Andhra Pradesh that yielded of 310 unique leopard individuals. The total estimated population of Andhra Pradesh is 569 (SE 41) leopards in 2022 showed an increase compared to previous estimate (492 SE 31) of countrywide monitoring of 2018 (Jhala *et al.*, 2021). Majority of the leopard population (69%) is concentrated in the Protected Areas and 31% population is in the territorial forests (Figure III.3). The leopard density from NSTR is not significantly different from previous estimate of 2018 (Jhala *et al.*, 2021), however more than 250 Adult leopards were photo-captured from NSTR alone (Table III.1), the largest single population.

A significant threat to the leopard population in Andhra Pradesh is human-leopard conflict. There have been reports of leopard attacks on devotees near the Tirumala hills, where the renowned Tirupati temple is situated. Other threats such as road kills by speeding vehicle on the road passing through leopard habitat are major concern in Andhra Pradesh. Appropriate mitigation measures should be adopted on the roads for the passageways of leopards.

Chhattisgarh

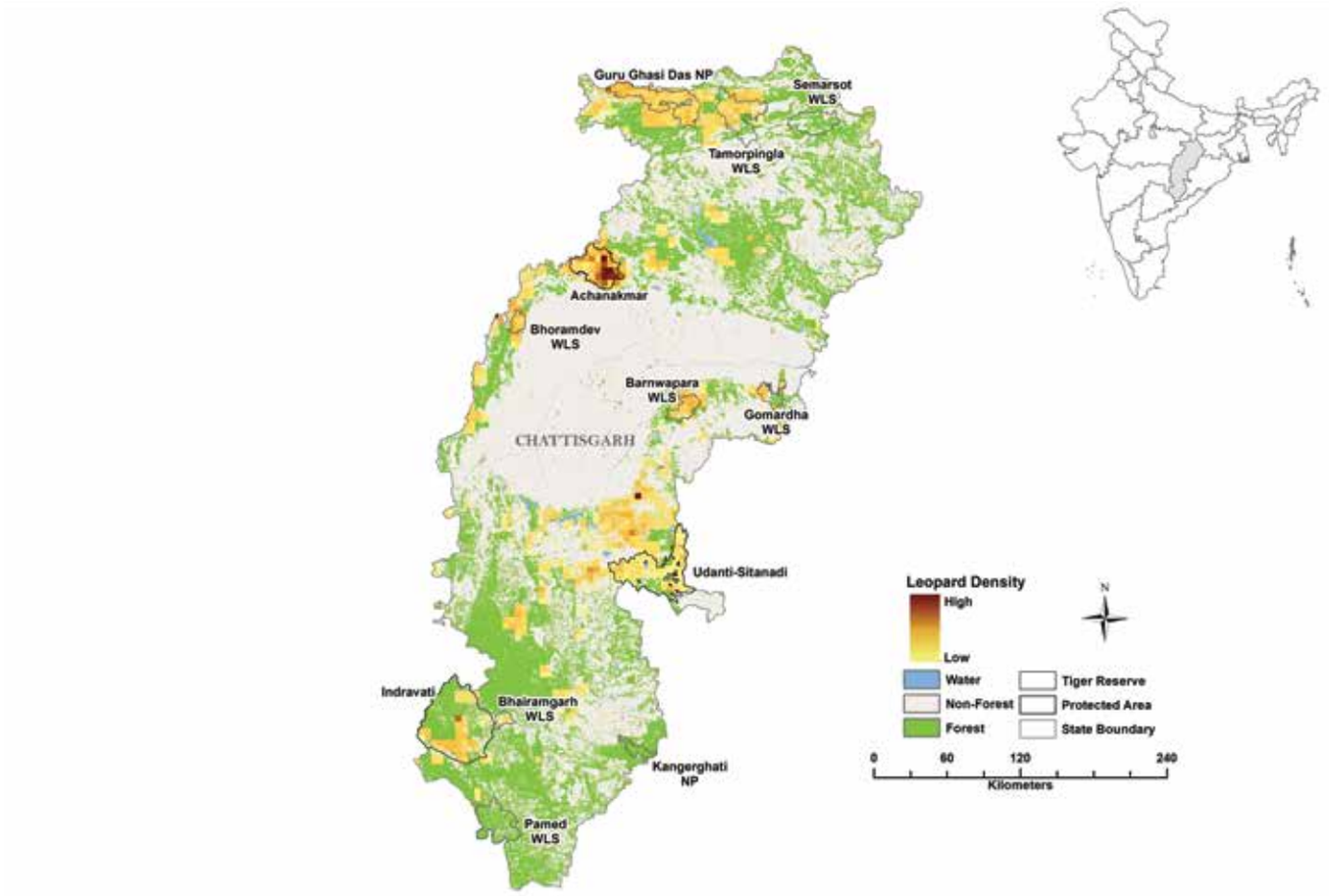

Figure III.4:
Spatially explicit leopard density (individuals/100 km^2) modelled from camera traps-based capture-mark-recapture and covariates; Chhattisgarh, 2022

Chhattisgarh has a forest cover of 55,717 km^2 constituting 41.21% of the state's total area (Indian State of the Forest Report 2021). Although leopard distribution is interconnected within Chhattisgarh, the population and occupancy can be categorized into three blocks based on the connectivity and eco-geographic zones. (i) Northern Chhattisgarh, comprising Guru Ghasidas National Park-Tamor Pingla Wildlife Sanctuary, connected to Achanakmar Tiger Reserve through the forests of Madhya Pradesh. The area mostly falls under Northern hills and part of Chhattisgarh plains. Achanakmar Tiger Reserve holds the highest leopard population within the state's protected area network. (ii) Central Chhattisgarh, including Udanti Sitanadi Tiger Reserve and adjacent forest divisions along with Gomardha Wildlife Sanctuaries.

The region is located primarily within the Chhattisgarh plains and includes a portion of the Bastar hills. Leopard occupancy in these areas has declined since the previous nationwide monitoring exercise in 2018 (Fig. III.1). (iii) Southern Chhattisgarh, encompassing Indravati Tiger Reserve and the territorial forests of the Bastar region, connected to Gadchiroli in Maharashtra and the Kawal region of Telangana. The area mostly falls into Bastar plateau region of Chhattisgarh. The total estimated population of Chhattisgarh is 722 (SE 45) leopards in 2022, showing a decline compared to the previous estimate of 852 (SE 39) in 2018 (Jhala *et. al.*, 2021). A total of two sites were camera trapped in Chhattisgarh that yielded 96 unique leopard individuals. Majority of the leopard population (75%) are outside PA network and concentrated in the territorial forests (Figure III.4).

The leopard density at Achanakmar Tiger Reserve was 7.19 (SE 0.89) per 100 km^2 which is not significantly different from previous estimate of 2018 (Jhala *et al.*, 2021) (Table III.1), however Udanti Sitanadi Tiger Reserve showed a decline (Table III.1). The leopard population and occupancy both are on declining trend in Chhattisgarh. The major threats are poaching (Rana & Kumar 2023), habitat loss, and prey depletion.

Jharkhand

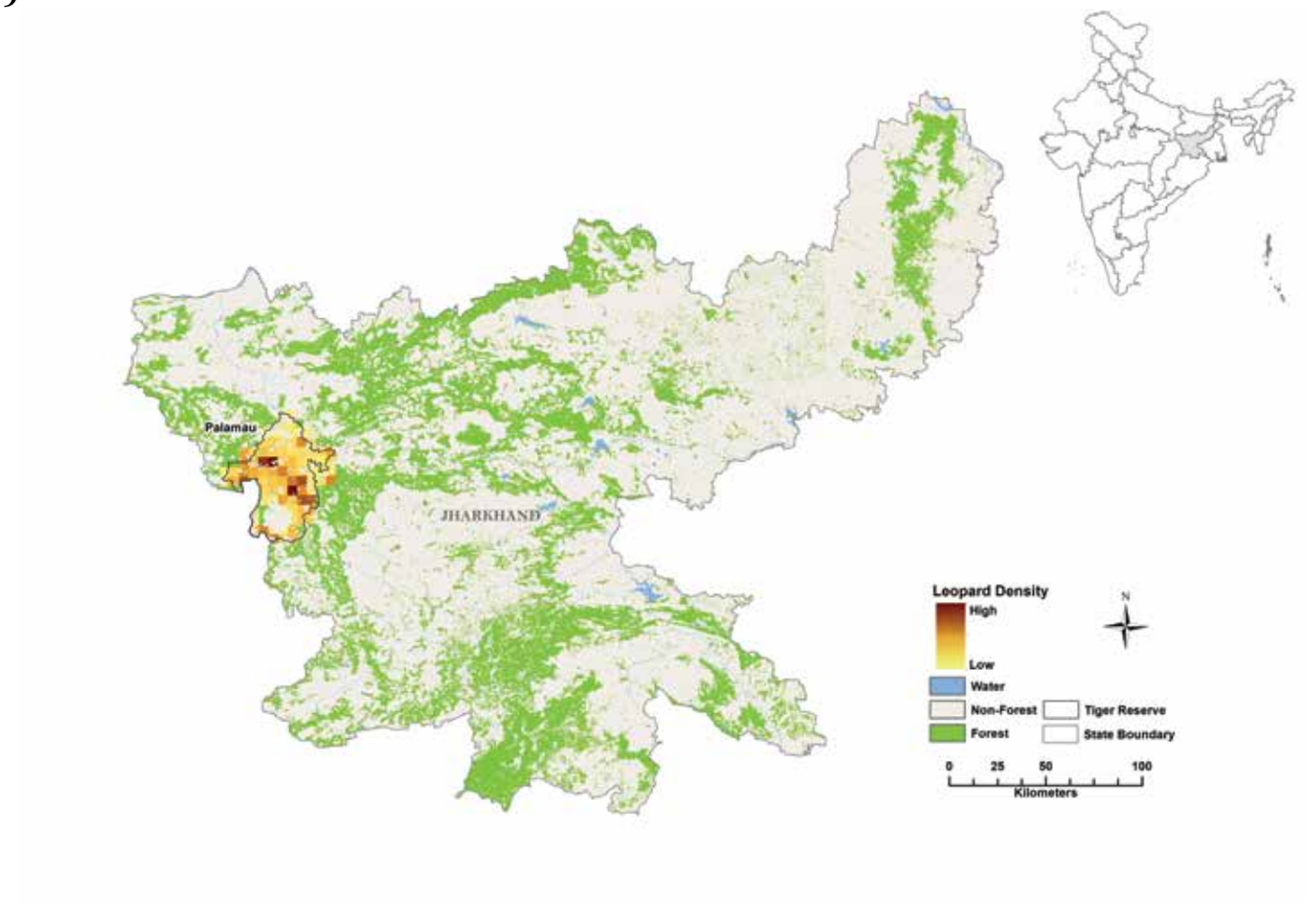

Figure III.5:

Spatially explicit leopard density (individuals/100 km^2) modelled from camera traps-based capture-mark-recapture and covariates; Jharkhand, 2022.

Jharkhand has a forest cover of 23,721 km^2 constituting 29.76 % of the state's total area (Indian State of the Forest Report 2021). The leopard population in Jharkhand is facing a worsening situation, with current occupancy only reported in Palamau Tiger Reserve and its adjacent forest division. Leopard distribution in Jharkhand was not uniform across the state, and their presence were commonly reported in Protected Areas such as Dalma and Hazaribagh Wildlife Sanctuaries besides Palamau Tiger Reserve. These regions provide suitable ecosystems for leopards, characterized by a mix of deciduous and tropical forests.

However, during the estimation of 2022, leopard occupancy from the other Protected Areas of Jharkhand were not reported (Figure III.1). The total estimated population of Jharkhand is 51 (SE 10) leopards in 2022 (Figure III.5) which is stable in comparison to countrywide monitoring of 2018 (Jhala *et al.*, 2021). Only one site, i.e. Palamau Tiger Reserve was camera trapped in Jharkhand that yielded 23 unique leopard individuals. The leopard density at Palamau Tiger Reserve was reported to be 3.06/100 km^2 (Table III.1).

The state need to control prey poaching for bush meat consumption. There is a need to prioritize efforts to enhance the skill set of its forest staff through comprehensive capacity-building programs and to strengthen protection measures in National Parks and Sanctuaries. Furthermore, innovative methods which involves providing safe passage should be implemented to mitigate the impact of mining operations near forested areas.

Madhya Pradesh

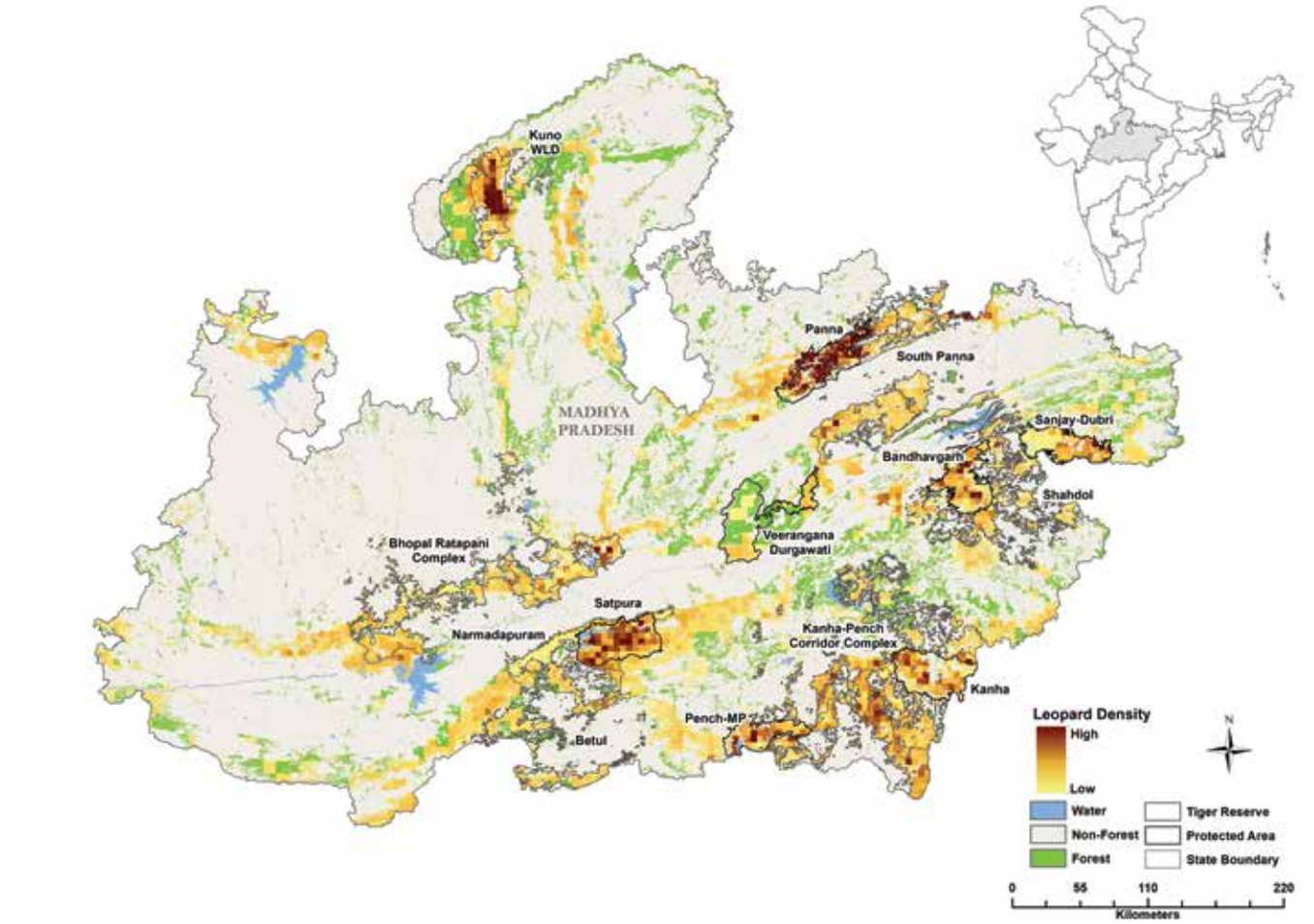

Figure III.6:

Spatially explicit leopard density (individuals/100 km^2) modelled from camera traps-based capture-mark-recapture and covariates; Madhya Pradesh, 2022.

Madhya Pradesh has a forest cover of 77,493 km^2 constituting 25.14 % of the state's total area (Indian State of the Forest Report 2021). Madhya Pradesh features diverse eco-geographic characteristics, encompassing parts of the semi-arid zone, central highlands, and plateau biotic provinces within the Deccan Peninsula biogeographic zones of India. Leopard has colonised in the Nauradehi Wildlife Sanctuary and northern part of Rani Duragawati Wildlife Sanctuary both are now part of the newly created Veerangana Durgavati Tiger Reserve.

Leopard occupancy has increased in the Chambal and Bundelkhand regions of Madhya Pradesh, with a marginal decline reported from the Chhindwara forests. Madhya Pradesh holds the largest leopard population in the country 3,907 (SE 215), (Table I.3) which is a significant increase from the previous estimation of 3,421 (SE 150) in 2018. Camera trapping at a total of 27 sites in Madhya Pradesh yielded images of 1692 unique leopard individuals (common individuals between sites counted only once). The majority of the leopard population (74%) exists outside the Protected Area network, residing in territorial forest divisions or the multiple-use (buffer zone) forests of Tiger Reserves (Figure III.6). Panna Tiger Reserve and Kuno National Park exhibit some of the highest leopard densities in India (Table III.1). Other Tiger Reserves, including Satpura, Bandhavgarh, Pench, and Kanha, also feature high leopard densities, showcasing their coexistence with tigers. Obadullaganj (Ratapani Wildlife Sanctuary) and Balaghat forest divisions have reported a significant increase in leopard densities compared to the nationwide estimates of 2018 (Table III.1) (Jhala *et al.,* 2021). We believe due to data loss of leopard photos in 2018, the density estimates of Obaduallganj & Kuno were lower and should not be used for population trend with the 2022 estimates. While leopard populations thrive in Madhya Pradesh, ongoing effective vigilance is essential to address both targeted and unintentional poaching. Additionally, there is a need for the effective implementation of mitigation measures concerning linear infrastructure development projects to ensure the continued well-being of leopard populations in the region.

Maharashtra

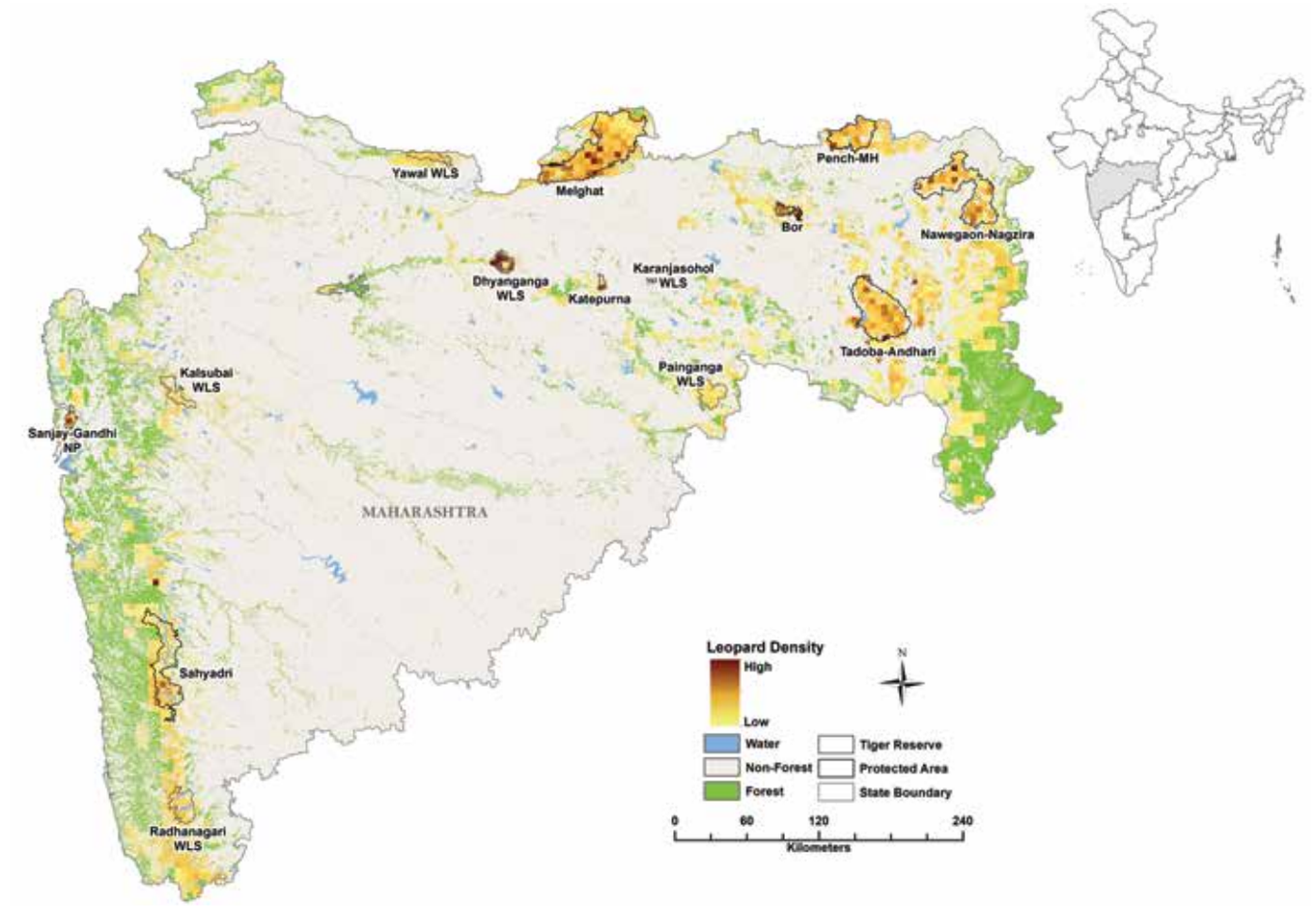

Figure III.7:

Spatially explicit leopard density (individuals/100 km^2) modelled from camera traps-based capture-mark-recapture and covariates; Maharashtra, 2022.

Maharashtra has a forest cover of 50,798 km^2 constituting 16.51 % of the state's total area (Indian State of the Forest Report 2021). Maharashtra spans three bio-geographic zones: The Deccan Peninsula, Western Ghats, and West Coast. In the central plateau region, dry deciduous mixed and dry teak forests are predominant, while the Western Ghats region is characterized by moist deciduous and evergreen forests. Leopards are distributed across Maharashtra's forested landscape, with limited presence was recorded in the large forest patches of Sahyadri region close to west coast (Figure III.1).

Maharashtra holds the second largest leopard population in the country 1,985 (SE 122), which is a significant increase from the previous estimation of 1,690 (SE 99) in 2018. Major population (75%) are outside the PA network (Figure III.7). Camera trapping at a total of 16 sites in Maharashtra yielded images of 904 unique leopard individuals (common individuals between sites counted only once). Based on the population connectivity, Leopard population in Maharashtra are classified into three sub population (i) Vidarbha : This region includes most of the Tiger Reserves, such as Bor, Tadoba-Andhari, Nawegaon-Nagzira, Pench, and Melghat. It also encompasses sanctuaries like Painganga, Tipeswar, Umred-Pauni-Karhandla and large forest patches in territorial forest divisions such as Chandrapur, Central Chanda, Wardha, Yavatmal, and Gadchiroli. The leopard densities within this region is moderate to high. Leopard density has increased in the Chandrapur & Bramhapuri territorial divisions, Melghat and Tadoba Tiger Reserves since previous countrywide estimates of 2018 (Table III.1) (Jhala *et al.,* 2021). Tiger and leopard densities both are occurring at same scale within this region (Qureshi *et al.,* 2023). (ii) Sahyadri – Nasik: This area encompasses the Sahyadri Tiger Reserve, Sanjay Gandhi National Park, Radhanagri Wildlife Sanctuary, and the territorial forests of Sindhudurg, Kolhapur, Sawantwadi up to Nashik divisions. The leopard density of Sahyadri Tiger Reserve has increased from the previous countrywide estimate of 2018 (Table III.1) (Jhala *et al.,* 2021). We believe due to data loss of leopard photos in 2018, the density estimates of Sahyadri & Chandrapur were lower and should not be used for population trend with the 2022 estimates. Major threat for leopard in Maharashtra are conflict with humans and targeted poaching for body parts.

Odisha

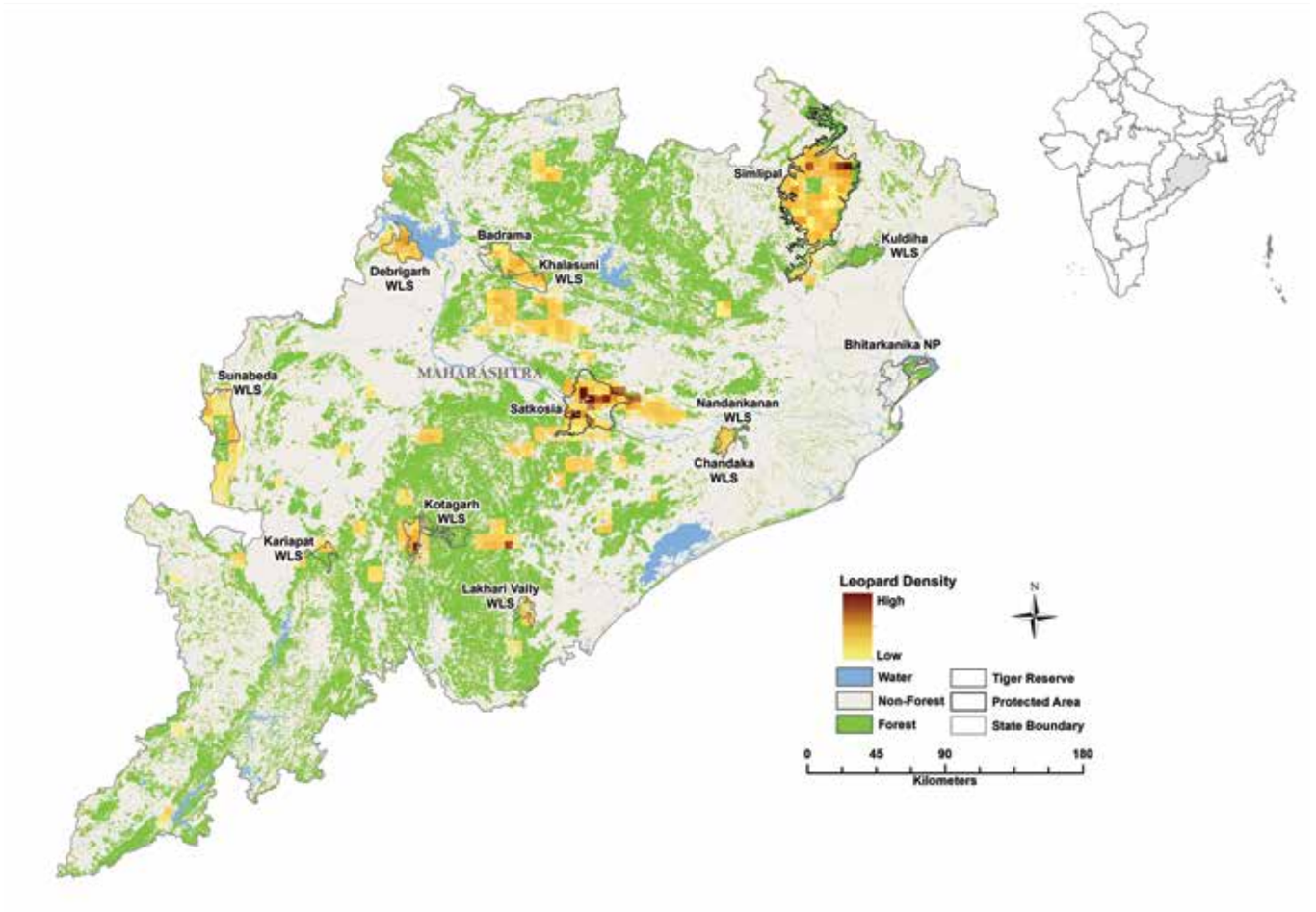

Figure III.8:

Spatially explicit leopard density (individuals/100 km^2) modelled from camera traps-based capture-mark-re-capture and covariates; Odisha, 2022

Odisha has a forest cover of 52,156 km^2 constituting 33.50 % of the state's total area (Indian State of the Forest Report 2021). Odisha's major forest types include peninsular Sal and dry deciduous mixed forests. Leopard occupancy has been reported exclusively within Protected Areas (PAs) and their adjoining forest divisions. The leopard occupancy has declined from the previous occupied regions.

Leopard presence was not recorded from Nayagarh and Gumsur forest divisions in this cycle of countrywide monitoring. Leopard distribution is now majorly concentrated in the Similipal & Satkosia Tiger Reserves, Hirakund, Kotagarh Khalasuni Wildlife Sanctuaries (Figure III.8). Camera trapping at total of three sites in Odisha yielded images of 162 unique leopard individuals (common individuals between sites counted only once).

The leopard population in Odisha is estimated at 568 (SE 35), the population has significantly declined since last countrywide estimate of 760 (SE 33). However, the leopard densities from both the Tiger Reserves have increased significantly (Table III.1). This indicates the major efforts of recovery is restricted to Tiger Reserve. The state should also put efforts of effective patrolling, prey recovery and habitat management outside Tiger Reserve since major population of leopard (55%) are outside the Protected Area network (Figure III.8).

Rajasthan

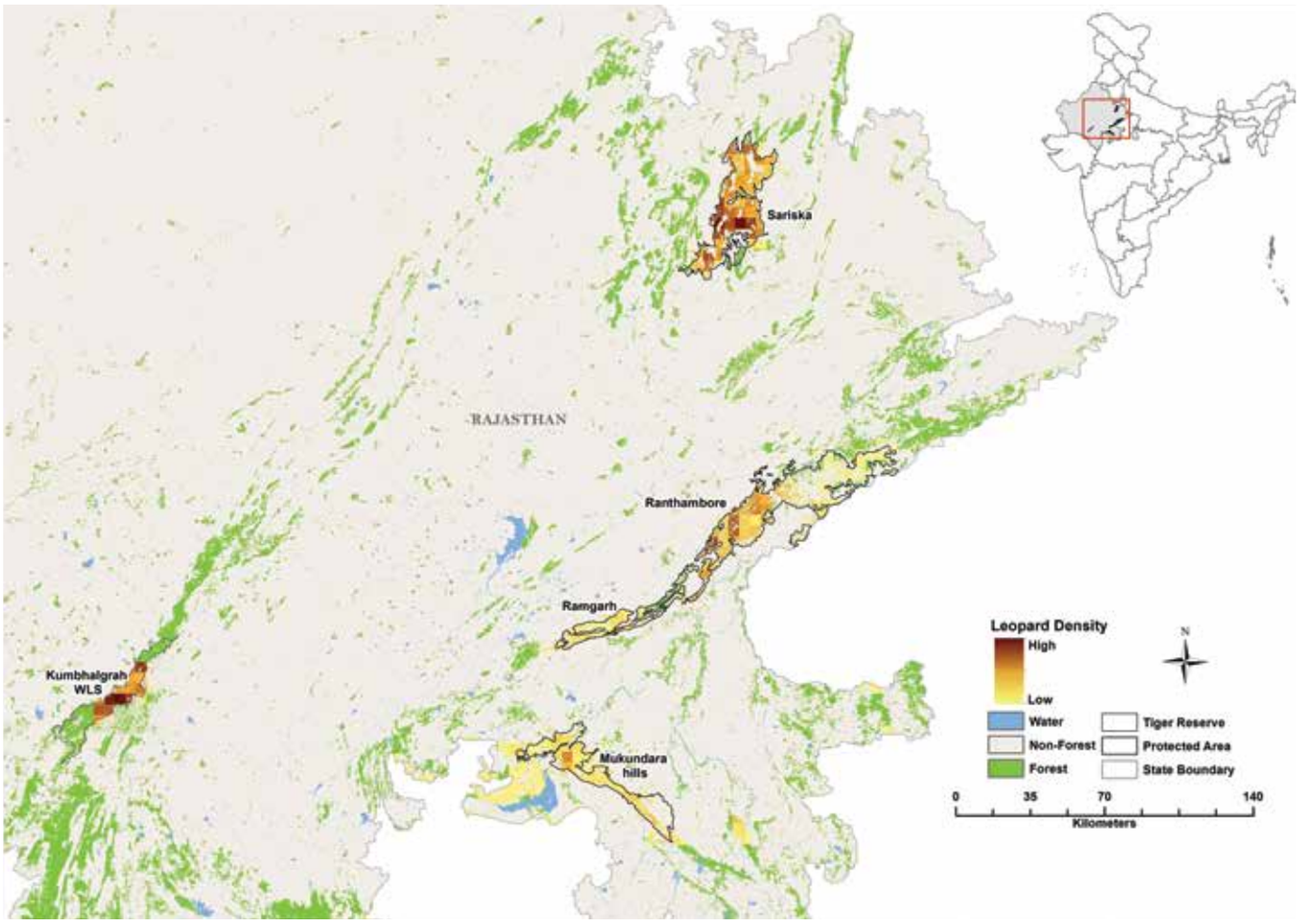

Figure III.9:

Spatially explicit leopard density (individuals/100 km^2) modelled from camera traps-based capture-mark-recapture and covariates; Rajasthan, 2022.

Rajasthan has a forest cover of 16,655 km^2 constituting 4.87 % of the state's total area (Indian State of the Forest Report 2021). The semi-arid zone of Rajasthan marks the westernmost extent of the central Indian landscape. The dry forests in this region are predominantly characterized by *Anogeissus pendula*, accompanied by associated species such as *Acacia, Butea, Lannea,* and others.

This terrain is significant for its distinctive topography and diverse flora, contributing to the ecological richness of the state. The sampling was restricted to Tiger Reserves and three wildlife sanctuaries (Kumbalgarh, Bhainsrodgarh and Shergarh), sanctuaries were sampled first time in this countrywide monitoring exercise. These eight sites yielded 337 individual leopards. Leopard population of the state was estimated at 721 (SE 112). Although leopard population in Rajasthan seems to be stable; however, direct comparisons with previous estimates are not possible due to the inclusion of new sampling areas in this nationwide estimation of 2022 (Figure III.9).

Sariska still has the highest leopard density of 21.43 (SE 1.91) amongst all the camera trapped sites in India. The density of leopard in Ranthambore Tiger Reserve has declined, however population remain stable (Table III.1). The primary issue facing leopards in this landscape is the loss and fragmentation of their habitat, primarily attributed to mining and developmental projects. To mitigate leopard-human conflict in the region, it is crucial to address the expansion of human land use and the escalating anthropogenic activities within leopard habitats.

Telangana

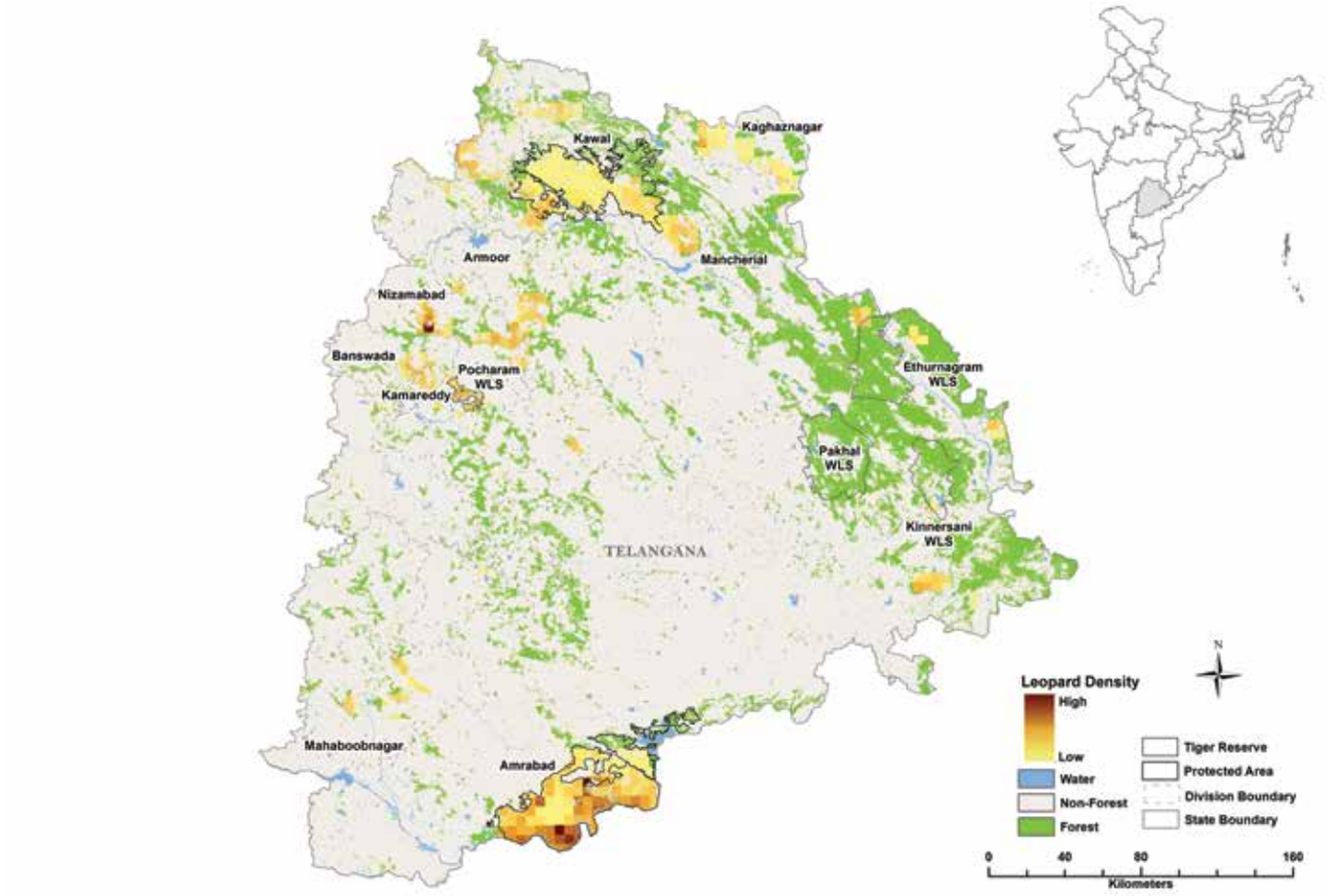

Figure III.10:

Spatially explicit leopard density (individuals/100 km^2) modelled from camera traps-based capture-mark-re-capture and covariates; Telangana, 2022.

Telangana has a forest cover of 21,214 km^2 constituting 18.93 % of the state's total area (Indian State of the Forest Report 2021). Telangana is situated in the Central Plateau biotic province of the Deccan Peninsula bio-geographic zone. The predominant forest types include dry deciduous mixed forests, dry deciduous scrub, and dry teak forests. The occupancy of leopard in Telangana was stable and mainly concentrated in the two Tiger Reserves (Kawal and Amrabad). Leopard has occupied new areas in northern Telangana, however leopard occupancy has declined from Kineersani Wildlife Sanctuary (Fig. III.1).

Six sites were camera trapped in Telangana that yielded 146 individual leopards. Leopard population of the state was estimated at 297 (SE 20), which has declined from the previous countrywide estimate of 334 (SE 16) of 2018. Based on population connectivity leopard distribution can be divided into two population (i) Northern Telangana: This include Kawal Tiger Reserve, Kagaznagar forest division up to Pocharam Wildlife Sanctuary (Figure III.10). The leopard density in the Kawal was reported to be 1.19 (SE 0.29) per 100 km^2 (Table III.1). (ii) Southern Telangana: This includes Amrabad Tiger Reserve where Leopard density was 3.94 (SE 0.37) per 100 km^2 (Table III.1).


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Table III.1 *Sampling details and leopard density parameter estimates using spatially explicit capture mark recapture analysis in a likelihood framework for sites in Central India and Eastern Ghats landscape, 2022*

State	Site	Model space (km^2)	Camera traps	M_{t+1}	Best fit model	$\hat{D}$ secr/ 100 km^2 (SE)	g_0 Female (SE)	g_0 Male (SE)	σ Female (SE) Km	σ Male (SE) Km	Pmix (SE)
Andhra Pradesh	Nagarjunasagar Srisailam TR	6211	783	254	σ ~(sex), Pmix~(sex), g0~(sex)	5.85 (0.38)	0.01 (0.001)	0.02 (0.001)	1.9 (0.05)	3.08 (0.07)	0.75:0.25 (0.03)
Andhra Pradesh	Narsimha WLS	1962	84	23	σ ~(.), Pmix~(sex), g0~(.)	2.02 (0.47)	0.02 (0.004)		2.9 (0.33)		0.47:0.53 (0.13)
Andhra Pradesh	Papikonda	1220	103	20	σ ~(sex), Pmix~(sex), g0~(.)	3.05 (0.8)	0.02 (0.01)		1.34 (0.18)	2.31 (0.31)	0.88:0.12 (0.07)
Andhra Pradesh	Venkateshwara NP	929	19	13	σ ~(.), g0~(.)	2.6 (0.09)	0.02 (0.011)		2.59 (0.48)		NA
Chhattisgarh	Achanakmar TR	1517	317	70	σ ~(sex), Pmix~(sex), g0~(sex)	7.19 (0.89)	0.02 (0.003)	0.028 (0.003)	1.52 (0.07)	2.83 (0.12)	0.79:0.21 (0.05)
Chhattisgarh	Udanti-Sitanadi TR	2684	142	26	σ ~(sex), Pmix~(sex), g0~(.)	1.97 (0.44)	0.024 (0.005)		2.24 (0.28)	3.5 (0.4)	0.7:0.3 (0.11)
Jharkhand	Palamau TR	1664	323	23	σ ~(.), g0~(.)	3.06 (0.76)	0.003 (0.001)		3.18 (0.43)		NA
Madhya Pradesh	Balaghat	3278	495	134	σ ~(sex), Pmix~(sex), g0~(.)	7.15 (0.66)	0.01 (0.001)		1.31 (0.05)	2.94 (0.1)	0.7:0.3 (0.04)
Madhya Pradesh	Bandhavgarh TR	2038	697	133	σ ~(.), Pmix~(sex), g0~(.)	8.65 (0.76)	0.01 (0.001)		1.93 (0.06)		0.59:0.41 (0.05)
Madhya Pradesh	Barghat	1013	69	20	σ ~(.), Pmix~(sex), g0~(.)	5.85 (2.1)	0.02 (0.01)		2.41 (0.56)		0.5:0.5 (0.14)
Madhya Pradesh	North Betul	710	107	22	σ ~(sex), Pmix~(sex), g0~(sex)	8.94 (3.15)	0.003 (0.003)	0.02 (0.004)	2.26 (1.25)	5.53 (0.49)	0.84:0.16 (0.08)
Madhya Pradesh	Bhopal (Samardha)	258	43	8	σ ~(.), g0~(.)	6.46 (2.71)	0.01 (0.003)		1.32 (0.27)		NA
Madhya Pradesh	Dewas	741	120	21	σ ~(.), Pmix~(sex), g0~(.)	3.81 (0.87)	0.01 (0.003)		3.32 (0.34)		0.46:0.54 (0.14)
Madhya Pradesh	Kanha TR	2430	664	153	σ ~(sex), Pmix~(sex), g0~(.)	8.63 (0.71)	0.02 (0.002)		1.7 (0.04)	2.88 (0.07)	0.72:0.28 (0.04)
Madhya Pradesh	Kuno WLD	1007	146	111	σ ~(.), Pmix~(sex), g0~(.)	16.38 (1.59)	0.04 (0.003)		1.27 (0.04)		0.54:0.46 (0.05)
Madhya Pradesh	Lamta	1573	221	84	σ ~(sex), Pmix~(sex), g0~(sex)	9.29 (1.11)	0.02 (0.003)	0.03 (0.003)	1.33 (0.09)	2.86 (0.11)	0.67:0.33 (0.05)
Madhya Pradesh	Mandla	942	107	28	σ ~(sex), Pmix~(sex), g0~(sex)	5.26 (1.13)	0.02 (0.004)	0.03 (0.005)	1.63 (0.21)	3.1 (0.23)	0.73:0.27 (0.08)
Madhya Pradesh	Narmadapuram	1857	267	29	σ ~(.), Pmix~(sex), g0~(.)	3.49 (0.8)	0.002 (0.001)		2.97 (0.41)		0.67:0.33 (0.1)
Madhya Pradesh	Nauradehi WLS	NA	114	1	NA	NA	NA	NA	NA	NA	NA
Madhya Pradesh	North Panna	457	112	40	σ ~(.), Pmix~(sex), g0~(.)	11.8 (1.91)	0.06 (0.01)		1.07 (0.06)		0.54:0.46 (0.1)
Madhya Pradesh	Obedullaganj -Ratapani WLS	2515	666	134	σ ~(.), Pmix~(sex), g0~(.)	6.64 (0.58)	0.01 (0.001)		2.1 (0.06)		0.42:0.58 (0.05)
Madhya Pradesh	Panna TR	1977	574	240	σ ~(sex), Pmix~(sex), g0~(.)	16.09 (1.05)	0.01 (0.001)		1.41 (0.04)	2.19 (0.05)	0.56:0.44 (0.03)

State	Site	Model space (km^2)	Camera traps	M_{t+1}	Best fit model	$\hat{D}$ secr/ 100 km^2 (SE)	g_0 Female (SE)	g_0 Male (SE)	σ Female (SE) Km	σ Male (SE) Km	Pmix (SE)
Madhya Pradesh	Pench TR	1440	426	125	σ ~(sex), Pmix~(sex), g0~(.)	12.27 (1.11)	0.02 (0.001)		1.37 (0.04)	2.54 (0.08)	0.74:0.26 (0.04)
Madhya Pradesh	Rampur Bhatodi	608	39	11	σ ~(.), Pmix~(sex), g0~(.)	3 (1.12)	0.01 (0.004)		3.59 (0.67)		0.44:0.56 (0.17)
Madhya Pradesh	Sanjay Dubari TR	2504	573	104	σ ~(sex), Pmix~(sex), g0~(sex)	6.17 (0.62)	0.013 (0.002)	0.009 (0.001)	1.88 (0.09)	3.67 (0.15)	0.70:0.30 (0.05)
Madhya Pradesh	Satna	504	88	25	σ ~(sex), Pmix~(sex), g0~(.)	10.35 (2.54)	0.02 (0.005)		0.97 (0.14)	2.65 (0.26)	0.71:0.29 (0.1)
Madhya Pradesh	Satpura TR	2510	830	210	σ ~(sex), Pmix~(sex), g0~(.)	10.23 (0.71)	0.03 (0.001)		1.49 (0.03)	2.27 (0.04)	0.65:0.35 (0.03)
Madhya Pradesh	Sehore	455	48	10	σ ~(.), Pmix~(sex), g0~(.)	3.53 (1.21)	0.04 (0.01)		1.75 (0.24)		0.33:0.67 (0.16)
Madhya Pradesh	Shahdol	1456	95	17	σ ~(sex), Pmix~(sex), g0~(.)	4.82 (1.86)	0.01 (0.003)		1.83 (0.45)	4.1 (0.79)	0.81:0.19 (0.11)
Madhya Pradesh	South Panna	1141	94	36	σ ~(.), Pmix~(sex), g0~(.)	6.09 (1.16)	0.03 (0.01)		1.63 (0.15)		0.39:0.61 (0.11)
Madhya Pradesh	South Seoni	937	96	18	σ ~(sex), Pmix~(sex), g0~(.)	6.4 (1.97)	0.01 (0.003)		1.77 (0.31)	3.9 (0.77)	0.87:0.13 (0.08)
Madhya Pradesh	Umaria	669	102	19	σ ~(sex), Pmix~(sex), g0~(.)	6.42 (1.66)	0.02 (0.004)		1.33 (0.17)	2.43 (0.33)	0.81:0.19 (0.09)
Madhya Pradesh	West Betul	751	100	16	σ ~(.), Pmix~(sex), g0~(sex)	5.5 (2.14)	0.001 (0.001)	0.03 (0.01)	3.37 (0.34)		0.79:0.21 (0.1)
Maharash-tra	Bor TR	880	206	34	σ ~(sex), Pmix~(sex), g0~(.)	5.14 (0.9)	0.03 (0.003)		1.5 (0.1)	2.36 (0.15)	0.53:0.47 (0.09)
Maharash-tra	Bramhapuri	1931	417	106	σ ~(sex), Pmix~(sex), g0~(sex)	8.16 (0.82)	0.015 (0.002)	0.023 (0.002)	1.47 (0.07)	3.43 (0.1)	0.73:0.27 (0.04)
Maharash-tra	Central Chanda	1515	308	50	σ ~(sex), Pmix~(sex), g0~(sex)	4.43 (0.64)	0.01 (0.001)	0.03 (0.002)	2.88 (0.16)	3.71 (0.13)	0.65:0.35 (0.07)
Maharash-tra	Chandrapur	1223	223	69	σ ~(sex), Pmix~(sex), g0~(sex)	8.01 (0.99)	0.03 (0.003)	0.04 (0.004)	1.51 (0.08)	2.8 (0.16)	0.75:0.25 (0.05)
Maharash-tra	Dnyanganga	NA	82	44	NA	NA	NA	NA	NA	NA	NA
Maharash-tra	Gadchiroli	4215	541	47	σ ~(.), Pmix~(sex), g0~(sex)	1.8 (0.27)	0.005 (0.001)	0.015 (0.001)	5.07 (0.2)		0.62:0.38 (0.07)
Maharash-tra	Karanja Sohol WLS	NA	8	2	NA	NA	NA	NA	NA	NA	NA
Maharash-tra	Katepurna WLS	59	15	7	σ ~(.), g0~(.)	13.33 (5.33)	0.02 (0.01)		2.54 (0.78)		NA
Maharash-tra	Melghat TR	3300	885	171	σ ~(sex), Pmix~(sex), g0~(sex)	7.11 (0.55)	0.02 (0.002)	0.02 (0.001)	1.57 (0.06)	2.57 (0.06)	0.67:0.33 (0.04)
Maharash-tra	Navegaon-Nagzira TR	1758	526	110	σ ~(sex), Pmix~(sex), g0~(sex)	8.03 (0.77)	0.009 (0.001)	0.012 (0.001)	1.61 (0.06)	2.9 (0.1)	0.75:0.25 (0.04)
Maharash-tra	Painganga WLS	430	42	11	σ ~(.), Pmix~(sex), g0~(.)	3.89 (1.3)	0.02 (0.005)		2.27 (0.4)		0.25:0.75 (0.15)
Maharash-tra	Pandharkawada	1099	106	10	σ ~(.), Pmix~(sex), g0~(.)	1.15 (0.38)	0.01 (0.002)		7.68 (1.13)		0.43:0.57 (0.19)
Maharash-tra	Pench TR	1172	302	64	σ ~(sex), Pmix~(sex), g0~(.)	8.79 (1.14)	0.02 (0.002)		1.45 (0.08)	2.74 (0.13)	0.7:0.3 (0.06)
Maharash-tra	Sahyadri TR	2648	435	83	σ ~(.), g0~(.)	5.09 (0.59)	0.003 (0.0003)		3.25 (0.15)		NA

State	Site	Model space (km^2)	Camera traps	M_{t+1}	Best fit model	$\hat{D}$ secr/ 100 km^2 (SE)	g_0 Female (SE)	g_0 Male (SE)	σ Female (SE) Km	σ Male (SE) Km	Pmix (SE)
Maharash-tra	Tadoba Andhari TR	1848	630	129	σ ~(sex), Pmix~(sex), g0~(.)	8.86 (0.78)	0.02 (0.001)		1.68 (0.04)	3.32 (0.07)	0.7:0.3 (0.04)
Maharash-tra	Tipeswar WLS	NA	62	5	NA	NA	NA	NA	NA	NA	NA
Maharash-tra	Umred Pauni Karhan-dla WLS	225	85	7	σ ~(.), Pmix~(sex), g0~(.)	3.38 (1.33)	0.03 (0.005)		3.43 (0.66)		0.4:0.6 (0.22)
Odisha	Kuldiha WLS	NA	16	0	NA	NA	NA	NA	NA	NA	NA
Odisha	Satkosia TR	1493	258	77	σ ~(.), Pmix~(sex), g0~(.)	7.41 (0.86)	0.02 (0.016)		2.02 (0.07)		0.5:0.5 (0.07)
Odisha	Similipal TR	2330	459	85	σ ~(sex), Pmix~(sex), g0~(sex)	5.67 (0.64)	0.01 (0.001)	0.03 (0.002)	1.81 (0.08)	3.31 (0.12)	0.8:0.2 (0.04)
Rajasthan	Bhainsrodgarh WLS	365	29	10	σ ~(.), Pmix~(sex), g0~(.)	8.93 (3.82)	0.035 (0.015)		1.03 (0.21)		0.6:0.4 (0.22)
Rajasthan	Kailadevi WLS (RTR II)	NA	14	5	NA	NA	NA	NA	NA	NA	NA
Rajasthan	Kumbhalgarh WLS	533	52	55	σ ~(sex), Pmix~(sex), g0~(.)	19.20 (2.68)	0.12 (0.012)		0.82(0.04)	1.75(0.098)	0.72:0.28(0.06)
Rajasthan	Mukundara Hills TR	2661	169	41	σ ~(sex), Pmix~(sex), g0~(.)	4.87(0.088)	0.016(0.003)		1.55(0.016)	2.83(0.33)	0.73:0.27(0.09)
Rajasthan	Ramgarh Visdhari TR	811	74	19	σ ~(.), Pmix~(sex), g0~(.)	3.11 (0.75)	0.032 (0.006)		2.58 (0.19)		0.33:0.67 (0.16)
Rajasthan	Ranthambore TR I	2034	158	66	σ ~(sex), Pmix~(sex), g0~(.)	12.97 (1.72)	0.02(0.003)		0.79(0.057)	1.51(0.078)	0.62:0.38 (0.07)
Rajasthan	Sariska TR	1262	158	138	σ ~(sex), Pmix~(sex), g0~(sex)	21.43 (1.91)	0.09(0.008)	0.002(0.001)	0.91(0.029)	6.57(1.95)	0.95:0.05(0.04)
Rajasthan	Shergarh WLS	NA	31	3	NA	NA	NA	NA	NA	NA	NA
Telangana	Amrabad TR	4405	812	117	σ ~(sex), Pmix~(sex), g0~(sex)	3.94 (0.37)	0.008 (0.001)	0.006 (0.001)	2.85 (0.1)	6.32 (0.22)	0.73:0.27 (0.04)
Telangana	Chennur	NA	151	0	NA	NA	NA	NA	NA	NA	NA
Telangana	Eturnagaram WLS	NA	96	0	NA	NA	NA	NA	NA	NA	NA
Telangana	Kagaznagar	1891	147	8	σ ~(.), Pmix~(sex), g0~(.)	0.52 (0.19)	0.02 (0.004)		7.36 (0.91)		0.33:0.67 (0.19)
Telangana	Kawal TR	2079	316	19	σ ~(.), Pmix~(sex), g0~(.)	1.19 (0.29)	0.01 (0.001)		5.81 (0.57)		0.69:0.31 (0.13)
Telangana	Kothagudem	NA	56	2	NA	NA	NA	NA	NA	NA	NA

SE: *Standard error, D^SECR: Density estimate from Maximum Likelihood based spatially explicit capture recapture, σ : Spatial scale of detection function, g0: Magnitude (intercept) of detection function, Pmix: Detection corrected estimate of proportion of female and male*

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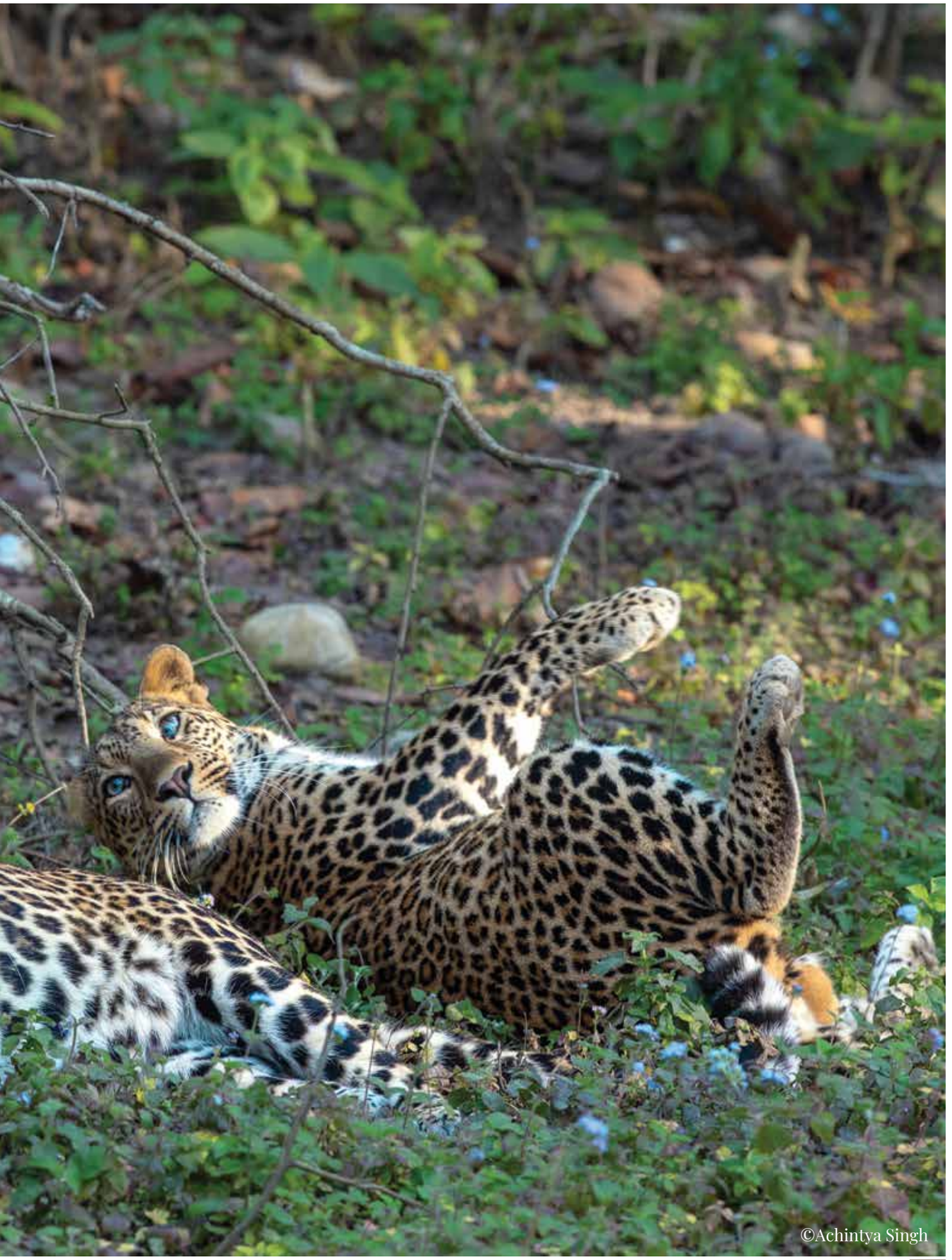
Conservation Implications

Leopards possess a broad dietary niche and has remarkable adaptability to a varying habitat condition, even in human dominated areas. A large (68%) population of leopard reside outside the Protected Areas in multiple use forests (Jhala *et al.*, 2021). This proximity to human habitation makes them more vulnerable to poaching and human leopard conflict. Among the large carnivores found in India, leopards are the most poached species (Mondol *et al.*, 2015). The Central Indian landscape stands out as a hotspot for leopard poaching, with a bias towards the poaching of males (Mondol *et al.,* 2015). Poaching of large carnivores may alter demography, behaviour of the target species also leaves cascading impact on the native biodiversity.

Beyond poaching, habitat fragmentation due to developmental activities such as the development of linear infrastructure and mining poses significant threats to leopards in this landscape. Rich in coal and mineral reserves, this region serves as a crucial link connecting major economic hubs through a network of roads and railways that intersect its biodiverse forest habitats. Over the last century, leopards in India have experienced a substantial human-induced population decline (Bhatt *et al.,* 2020).

Interestingly, this landscape experiences relatively fewer conflicts compared to hilly regions like Uttarakhand and Himachal Pradesh (Shivakumar *et al.,* 2023). The diverse habitat and abundant prey base in this landscape could be the reason of low conflict (Jhala *et al.,* 2015). However, as human populations encroach further into leopard habitats, incidents of human-leopard conflict are on the rise. In some instances, these conflicts escalate into violence, with communities retaliating against leopards that have preyed on their livestock or injures human. Maharashtra has emerged as the worst affected state, reporting 113 fatal attacks in the last seven years (Kulkarni, 2023).

While recent studies have accumulated substantial knowledge about leopard populations, habitat use, food habits, and human-leopard conflict, there remains a notable gap in understanding their behaviour in varying natural conditions. With the leopard population expected to increase in the future, a concerted effort toward long-term monitoring, coupled with a deeper understanding of their natural history and behaviour, is imperative to devise effective management strategies.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IV: Western Ghats Landscape

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Western Ghats

Leopards are widely distributed in the southern states of Goa, Karnataka, Kerala and Tamil Nadu, from the semi-evergreen patches of Western Ghats to semi-arid landscapes of central and parts of northern Karnataka. Unlike tigers, leopards are often found in the human-dominated land uses in Western Ghats, having adjusted themselves in the mosaics of coffee estates, plantations, and forests (Athreya *et al.,* 2013, Gubbi *et al.,* 2017).

While in the forested landscapes, leopards majorly rely on wild prey species (Karanth and Sunquist 1995, Ramesh *et al.,* 2009), in the semi-urban set up, they can sustain themselves by consuming livestock, domestic dogs, and human subsidized food sources (Athreya *et al.,* 2014, Sidhu *et al.,* 2015). Such interfaces often result in conflicts with human (attack on human, livestock depredation) (Sidhu *et al.,* 2017). In recent years, numerous developmental projects, linear infrastructure and human encroachment caused habitat loss and fragmentation in the leopard distribution range (Gubbi *et al.,* 2017).

The leopard population in the landscape is almost continuous apart from a few natural breaks. The population in the northern part of Western Ghats (Kali-Sahyadri-Shimoga-Mollem cluster) is connected to Bhadra-Bhadravathi-Chikmagalur-Kudremukh cluster through the hill forests of Sharavathi-Someswara Wildlife Sanctuary (WLS). This landscape population further extends to Nilgiri cluster (Nagarhole, Wayanad, Bandipur, Mudumalai, BRT Hills, Sathyamangalam) through Brahmagiri-Pushpagiri-Talakaveri Sanctuaries. Similar to tiger and elephant, the Nilgiri cluster harbors the single largest leopard population in India distributed amongst the states of Karnataka, Tamil Nadu, and Kerala, and serves as a link between Western Ghats and Eastern Ghats. In the north, the Nilgiri population further extends into the patchy forest-scrubland mosaics of Ramanagara, Bengaluru Urban, Bengaluru Rural, and Tumkur divisions through MM Hills, Cauvery Wildlife Sanctuary.

The central Karnataka leopard population is sparsely distributed into the forest-scrubland-agriculture mosaics of Ballari, Davangere divisions and connected through the stepping stone forest/refuge patches to Haveri, Dharwad and adjoining Divisions. Below the Silent Valley-Mukurthi forests (southern part of the Nilgiri cluster), the Palghat gap remains a geographical barrier and separates the Nilgiri cluster from the Anamalai-Parambikulam cluster. Further south, the semi-evergreen forests of Periyar-Srivilliputhur-Meghamalai (below Shencottah gap), Anamalai-Parambikulam in the north and the Kalakad Mun-

danthurai-Kanyakumari in the south forms important clusters of reasonable leopard population. The Kalakad Mundanthurai-Kanyakumari cluster forms the southern-most leopard population in India, distributed in the states of Tamil Nadu and Kerala. These two blocks south of the Palghat gap are connected through narrow linkages which are conducive to leopard movement between these two populations.

Leopard Occupancy, Population Extent and Abundance

Leopards are one of the most versatile large carnivores in the world, known to occur in high densities in the prey rich undisturbed forests as well as managed to survive in the urban landscapes at the edge of forest patches. The forests of Western Ghats are some of the most productive forests in the country and harbor rich assemblages of predator and their prey (Jhala *et al.,* 2021).

As a part of the All India Leopard Estimation exercise (2022), a total of 1,558 cells (100 km^2) were sampled using camera traps and foot sampling, out of which leopard was found to be present in 64% (1,001) cells. The camera trapping exercise resulted into 18,712 leopard photographs from which 2,052 individual leopards were identified. The spatially-explicit capture recapture estimate of leopard population in the Western Ghats was estimated at 3,596 (SE 482) leopards in the Western Ghats. Leopard presence in the landscape remains almost the same compared to 2018 (Fig. IV.1 & IV.2). Leopards occur in much lower densities in the scrubland-open forest mosaics of central Karnataka or the evergreen patches of southern Western Ghats (<1 leopard/100 km^2) (Table IV.1). The latest All India Leopard Estimate exercise depicted, the Kali-Shimoga-Mollem cluster harbours a low to medium density leopard populations, with moderately high leopard density observed at the Kali Tiger Reserve (Fig. IV.2). Similar pattern can be observed in the Bhadra-Bhadravathi-Kudremukh cluster, where leopards mostly have a sporadic distribution in the landscape, and occur in high densities only within Bhadra TR (Fig. IV.2). In the more human-dominated areas of central Karnataka, leopards occur mostly at low densities. Leopards have been found in very high (12-13 leopards/100 km^2) to moderately high densities in the Nilgiri cluster (Nagarhole-Wayanad-Bandipur-Mudumalai-BRT-Sathyamangalam TRs) (Fig. IV.2). The remaining forested habitats of the Nilgiri block also have moderate to high leopard densities, making this cluster a stronghold of leopard population. Its noteworthy to mention that the Nilgiri cluster also harbours the world's largest tiger population. The Anamalai-Parambikulam cluster (south to Palghat gap) harbors moderate density leopard population, with leopards occurring at moderately high densities mostly in Parambikulam Tiger Reserve. Leopards occur at lower densities in the evergreen and semi-evergreen forests of Periyar-Srivilliputhur-Meghamalai landscape and KMTR-Kanyakumari landscape (Fig. IV.2).

The population estimate of the previous cycle (2018) estimated 3,387 (SE 142) leopards in the landscape (Jhala *et al.,* 2021). Within the consistently sampled area (sampled in 2018 and 2022), there is a marginal increase in the leopard population (133 leopards). Approximately 65% of this leopard population occurs outside the Protected Areas of the landscape.


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Figure IV.1:

Change in leopard distribution from 2018 to 2022 in the Western Ghats Landscape.

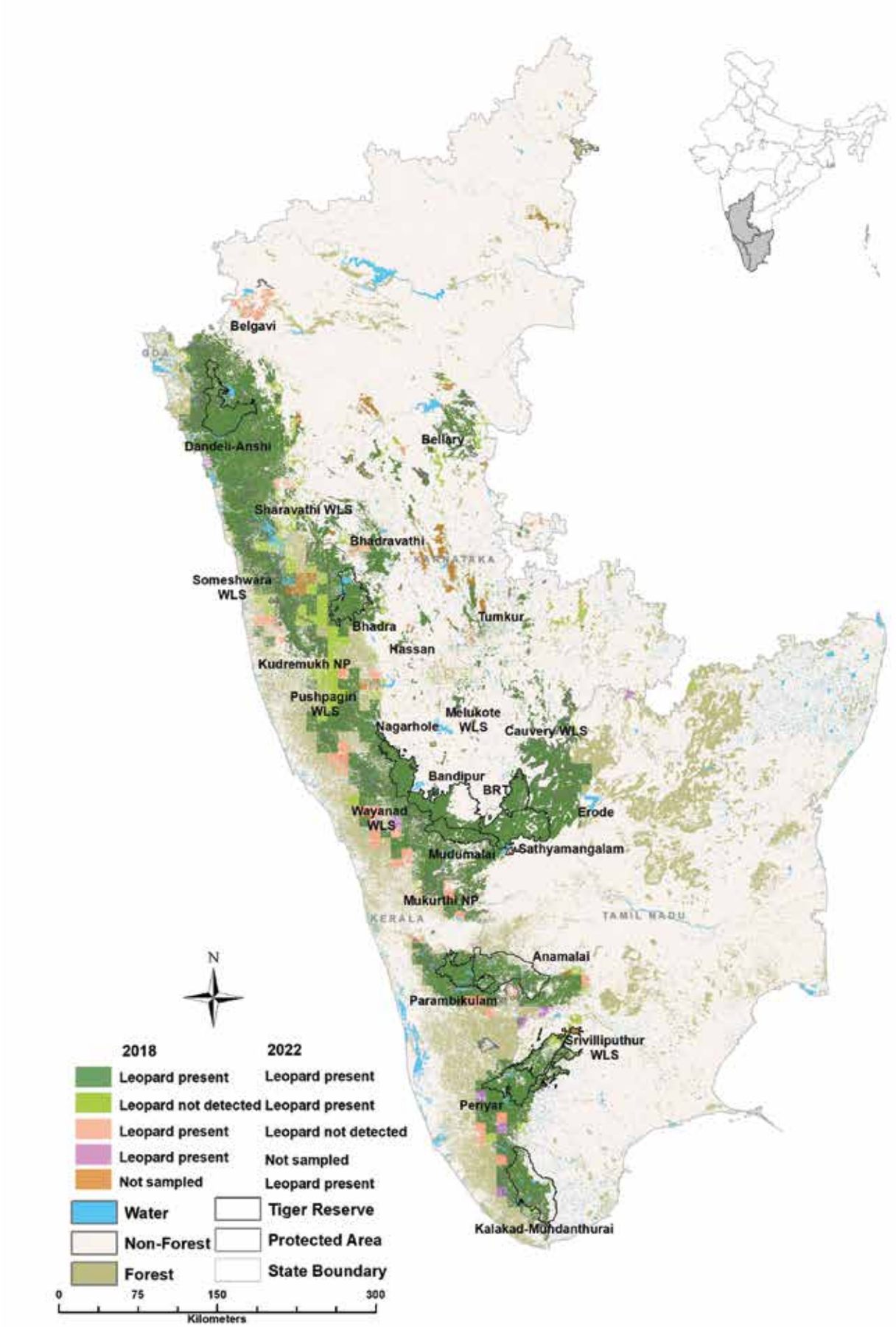
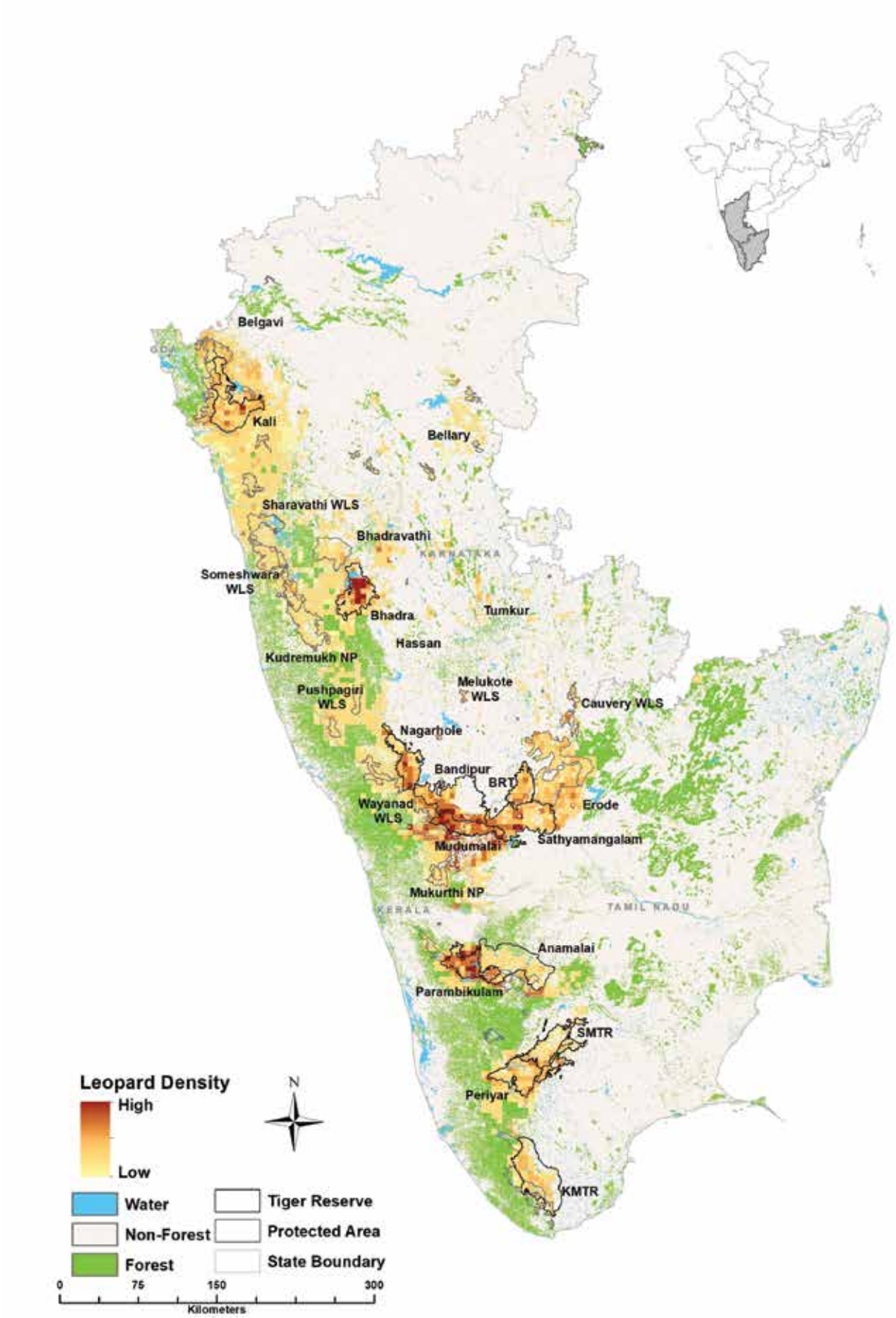


Figure IV.2:

Spatially explicit leopard density (individuals /100 km^2) modelled from camera traps-based capture-mark-recapture and covariates of leopard sign, prey and human disturbance for Western Ghats Landscape, 2022.



Goa

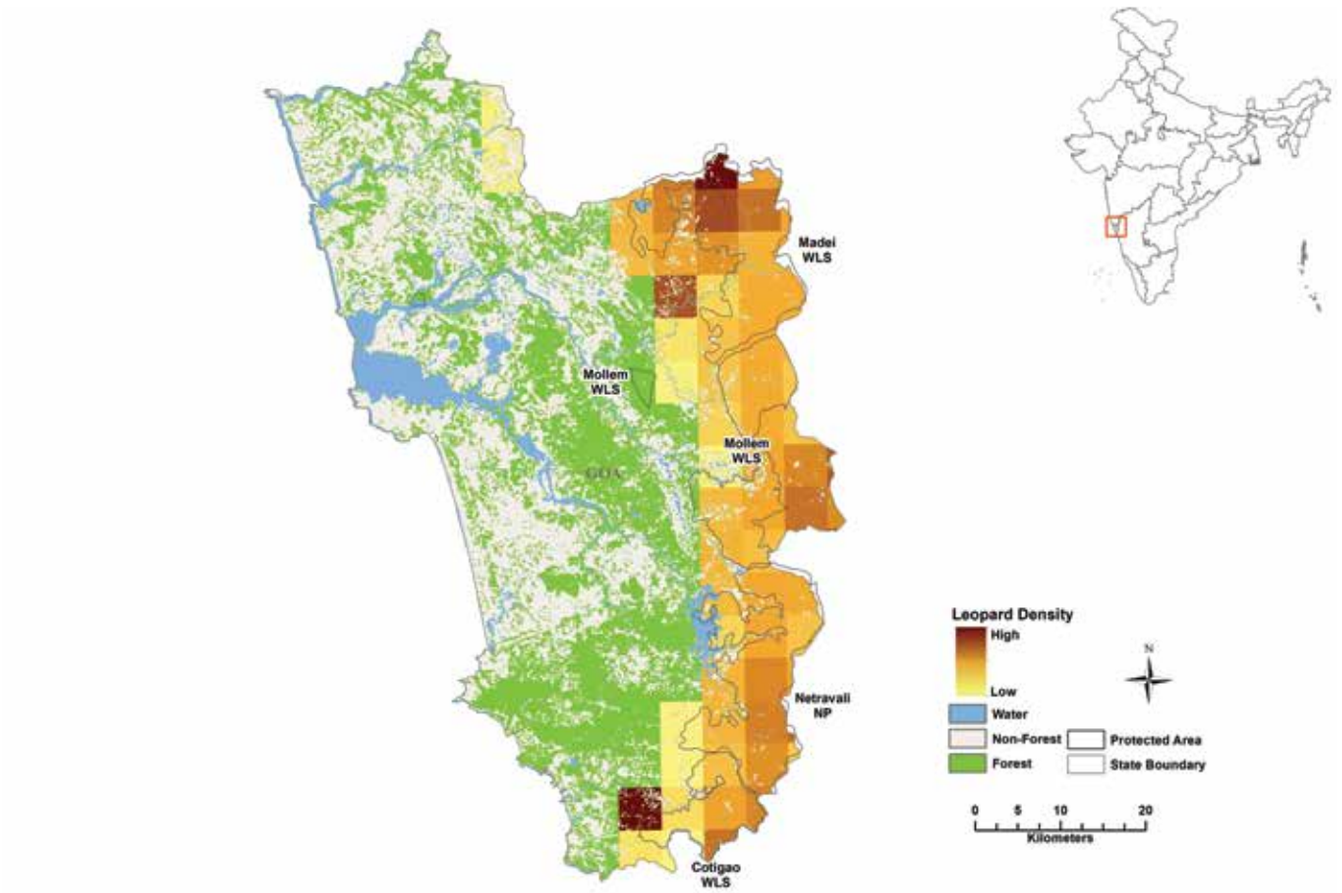


Figure IV.3:

Spatially explicit leopard density (individuals /100 km²) modelled from camera traps-based capture-mark-recapture and covariates; Goa, 2022.

Goa has a forest cover of approximately 1,800 km² which is contiguous with Kali Tiger Reserve in Karnataka. The state forms a linkage between the forests of the northern and central Western Ghats. For the first time as a part of the All India Tiger Estimation exercise the Goa Forest Department sampled 5 sites using camera traps that yielded 219 photo-captures of 30 individual leopards (Fig. IV.3). The leopard population of the state was estimated to be 77 (SE 13), from camera trap and covariate model, with approximately 26% of the population residing outside the Protected Areas of Goa. The continuous forest patches of Mhadei-Mollem harbor higher density of leopards compared to other parts of the state (Table IV.1, Fig. IV.3).

In Goa, there has been an increase in the cases of leopards straying into human habitations around the villages on the fringe of Cotigao Wildlife Sanctuary, that is, Loliem, Poinguinim, Cotigao, Gaondogrem, Sristhal, Agonda and Cola. Leopard mortalities or injuries due to snaring is not uncommon as locals often put snares to capture wild pigs. Leopards also got killed by speeding trains and vehicles, an emerging threat to the wildlife of the state due to rapid development of unmitigated linear infrastructure. Leopards, sloth bears and gaurs often venture into cashew plantations which are in proximity to the forested landscapes, leading to increased instances of negative human-animal confrontations in residential areas. The recent increase in leopards straying into human habitations has raised concerns amongst the locals. It's important to investigate the state of the Goa's forests in terms of prey, habitat conditions, protection to gain insight into the situation. The Forest Department should initiate regular camera trapping for carnivores and monitoring of prey and their habitat in the forested landscapes of Goa apart from the All India Tiger Estimation. With appropriate management and conservation measures, the forests of Goa have immense potential for harboring sizeable large carnivore population.

Karnataka

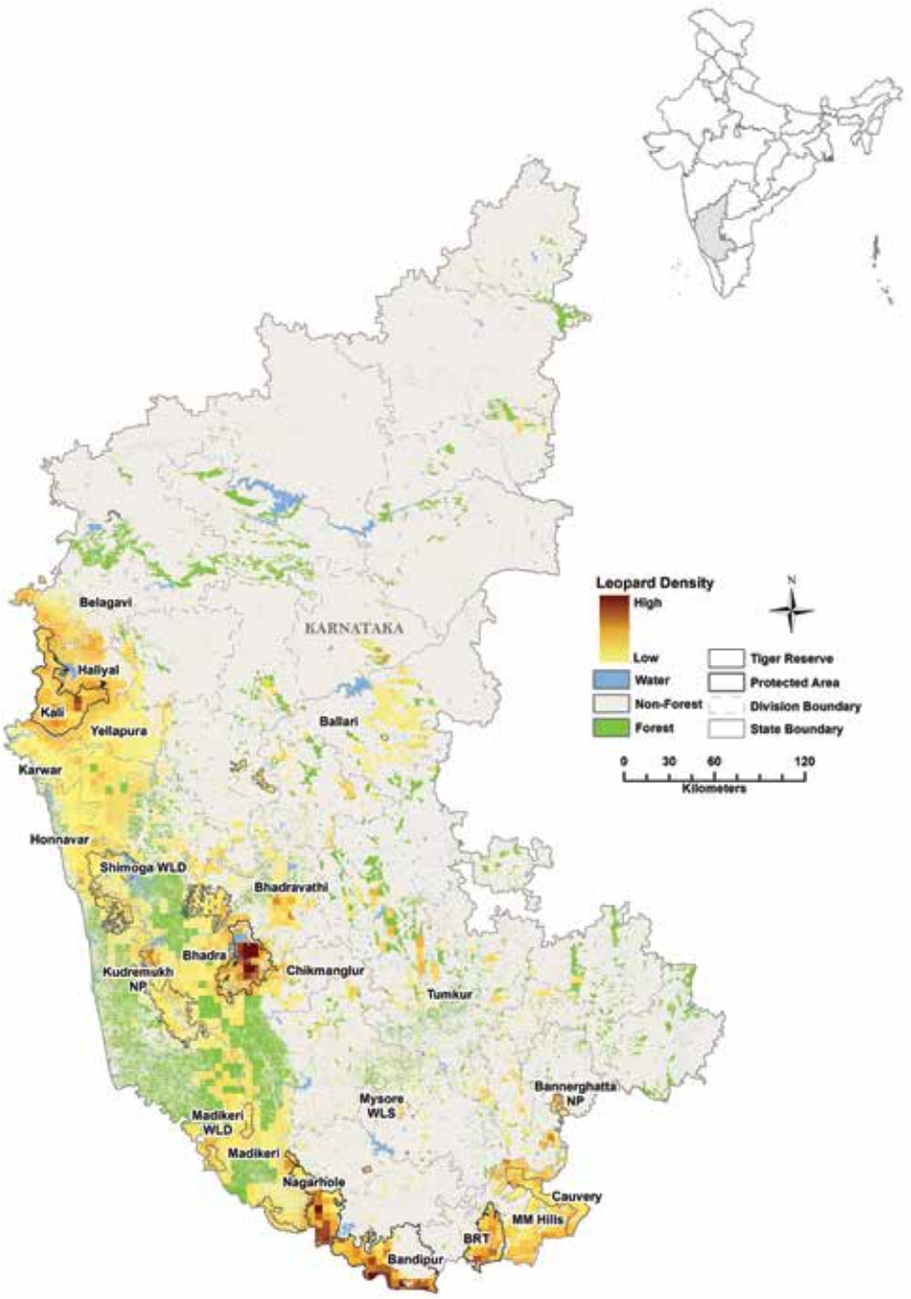


Figure IV.4:

Spatially explicit leopard density (individuals /100 km^2) modelled from camera traps-based capture-mark-recapture and covariates; Karnataka, 2022.

The forests of Karnataka span over an area of 33,931 km^2 (Forest Survey of India 2017), encompassing a diverse landscape that features dry deciduous, moist deciduous, evergreen, semi-evergreen forests, scrub forests and rocky outcrops (Gubbi *et al.,* 2020). The state consists of three biogeographic zones, namely, the Coasts, Western Ghats and Eastern Plains (Deccan south) (Jhala *et al.,* 2021). The Karnataka Forest Department, under the ambit of All India Tiger Estimation, put enormous effort to sample 37 sites using camera traps yielded 9,351 photo-captures of 1,062 individual leopards (Fig. IV.4). The leopard population of the state remain stable with a population estimate of 1,879 leopards (SE 261) in 2022 compared to 2018 estimates of 1,783 leopards (SE range 71) (Jhala *et al.,* 2021). The Nagarahole-Bandipur-BRT Hills Tiger Reserves harbor the largest leopard population in the state, while Bhadra Tiger Reserve holds the highest density of leopards (Table IV.1). Approximately 59% of the leopard population of Karnataka resides outside the Protected Areas, sporadically distributed in the territorial divisions of Tiger Reserves and the human-dominated areas of state, like Bengaluru rural, Dharwad, Davanagere, Hassan, Haveri, Koppa, Mangaluru, Ramanagara, Tumkur, Sagara, Sirsi and Virajpet. From 2018 to 2022, majority

Karnataka

of the sampled sites in Karnataka showed stable population trends for leopards. Leopard densities remain stable in Bandipur, Belagavi, Bhadra, Bhadravathi, Cauvery, Kali, Nagarahole (Table IV.1). A significant increase in leopard population was observed in Bannerghatta National Park, where there has been a considerable increase in the spatial coverage of camera trapping. In BRT Hills, the leopard population had increased compared to 2018. In Bhadra Tiger Reserve and Kudremukh National Park, the number of individual leopard photo-captured increased to a great extent, over the cycles, but the densities have remained stable. The sampling area and spatial coverage of camera trapping increased significantly (Table IV.1). A sizable population of leopards in Karnataka inhabit areas in the proximity to human settlements, resulted in high numbers of negative interactions between human and leopards throughout the state (Gubbi *et al.,* 2017).

The conflict between humans and leopards, initially confined to mostly Ramanagara, Tumkuru, Mandya, Mysuru, and Hassan, however, gradually spread across to Ballari, Koppala, and Kolara. This escalation is attributed to extensive mining and widespread granite quarrying activities, leading to a significant reduction in the natural habitats of leopards (Reddy *et al.,* 2019). The adverse effects of dam constructions, the establishment of major roads through Protected Areas, soil erosion, mining operations, agricultural encroachment along forest boundaries, grazing of domestic animals, reduced rainfall, and climate change are likely to contribute to the diminishing wild spaces in the state.

In recent years, leopards have increasingly preyed on domestic animals within human habitats due to the decline in herbivore populations (Sidhu *et al.,* 2017), which has resulted in key species such as leopards and tigers finding themselves in conflicts with humans in the peripheral regions surrounding Protected Areas as well as territorial areas (Chauhan *et al.,* 2021). During the period from 2009 to 2016, the majority of conflict cases (~80%) were concentrated in the districts of Mysuru, Udupi, Hassan, Tumkuru, Ramanagara, Ballari, Koppala, and Mandya (Manjunatha *et al.,* 2023). Karnataka accounted for almost half of the reported wildlife conflict related deaths in the country during 2012-13 (Karanth *et al.,* 2013). From 2018 to 2023 there has been a gradual rise in the leopard conflict cases recorded in the state of Karnataka. In this time frame over 100 cases of human-leopard encounters were recorded in the state, with the highest number of incidents documented between November 2022 and January 2023 (Manjunatha *et al.,* 2023). Leopards were responsible for the death of around 516 domestic animals in Mandya district alone from 2019 to 2022 (Manjunatha *et al.,* 2023). There has been a recent surge in human fatalities and domestic animal killings attributed to leopard attacks, particularly in the taluks of Mysuru, Nanjangud, HD Kote, Sargur, T. Narsipur, Mandya, Pandavapura, Nagamangala, and the surrounding areas. Effective and timely management actions and mitigating the human-leopard conflict is the need of the hour in Karnataka in order to safeguard the leopard populations in the state.

Tamil Nadu

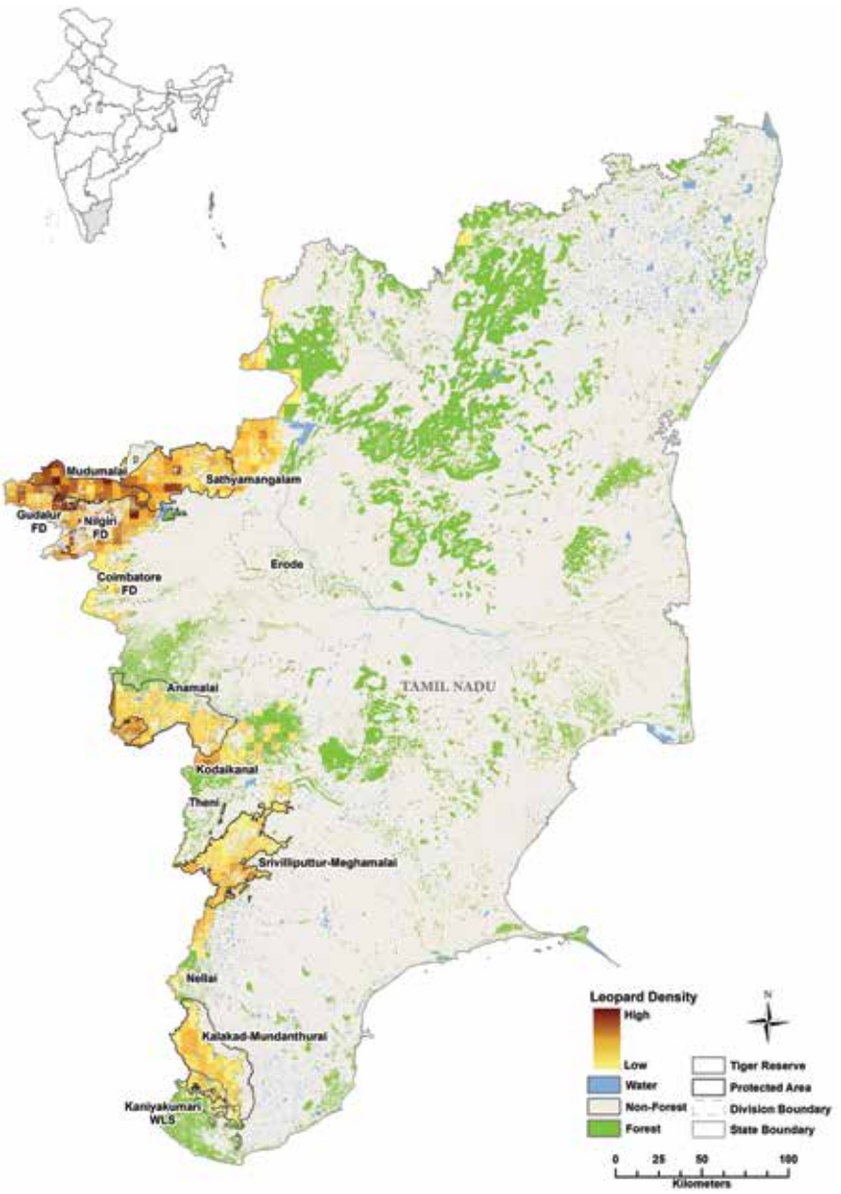


Figure IV.6:

Spatially explicit leopard density (individuals /100 km^2) modelled from camera traps-based capture-mark-recapture and covariates; Tamil Nadu, 2022.

Tamil Nadu comprises three biogeographic zones, namely, Western Ghats, Deccan peninsula and Coastal zone. The state extends over both Western Ghats and Eastern Ghats, comprising the forested area of 21,509 km^2. Nine out of 16 major forest types and 48 sub types of forest recognized by Champion and Seth (1968) occur in Tamil Nadu. A total of 14 sites were sampled using camera traps in Tamil Nadu that yielded 5,433 photo-captures of 736 individual leopards (Fig. IV.6). The leopard population of the state has significantly increased with an estimated 1,070 (SE 132) leopards in 2022, as compared to 868 (SE 40) leopards in 2018 (Jhala *et al.,* 2021) and 815 (SE 228) leopards in 2014 (Jhala *et al.,* 2015). A majority of the leopard population of Tamil Nadu, that is approximately 80%, reside outside the Protected Areas of the state, with high density leopard populations mostly concentrated near the Nilgiri region (including Coimbatore, Erode, Gudalur and Nilgiri divisions) and in the Valparai area. Mukurthy, Kanyakumari and Kodaikanal exhibit consistently low densities of leopards.

From 2018 to 2022, the leopard populations of Erode, Gudalur, Mudumalai TR, Kanyakumari Wildlife Sanctuary, Kodaikanal Wildlife Sanctuary, Mukurthy National Park, Nellai Wildlife Sanctuary, Sathyamangalam and Srivilliputhur-Meghamalai Tiger Reserves have remained stable (Table IV.1). In case of Nilgiri and Meghamalai, there has been a significant increase in the sampling area and number of individual leopard photo-captured, however, the densities have remained stable. There has been a considerable increase in leopard density of Anamalai. On the other hand, KMTR

Tamil Nadu

experienced a significant decline which may be a result of a decrease in spatial coverage of camera traps.

In Tamil Nadu, the coffee-tea estates and other commercial plantations surrounded by forests are frequently occupied by leopards and are major hubs for human-leopard conflicts (Sidhu *et al.,* 2017; Deivanayaki & Ezhilarasi 2019, Jhala *et al.,* 2021). Several cases have been reported from the forest fragments of Valparai plateau and Anamalai Tiger Reserve. Since land is cheaper near the edges of forests, plantation workers buy these land for building houses. High human population densities in these tea and coffee plantations have led to increasing negative interactions with leopards involving livestock depredation and human injury (Sidhu *et al.,* 2017).

Kerala

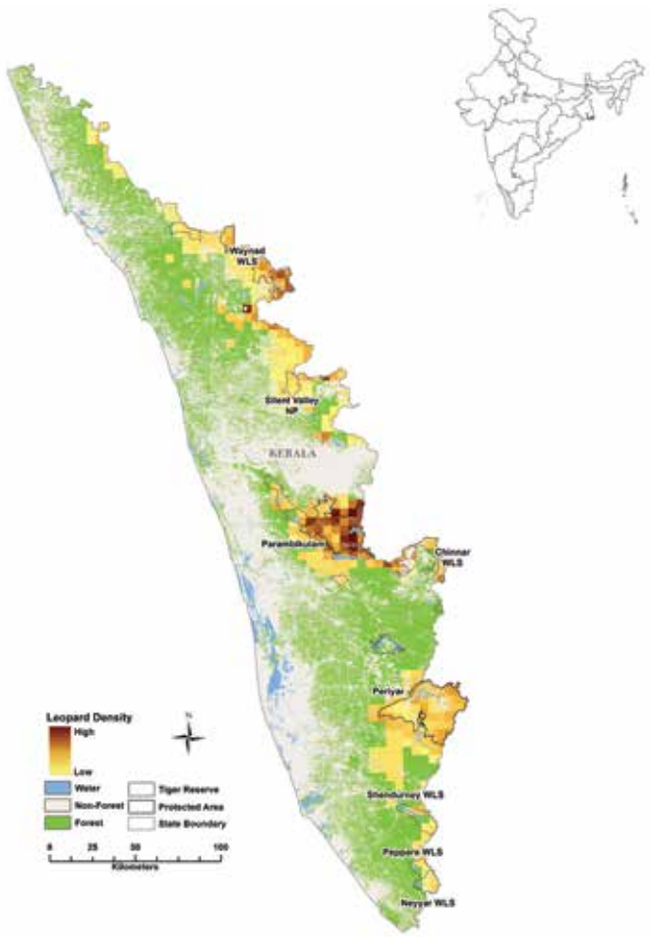


Figure IV.5:

Spatially explicit leopard density (individuals /100 km^2) modelled from camera traps-based capture-mark-recapture and covariates; Kerala, 2022.

Kerala is situated at the south-western part of India with a total forest cover of 16,267 km^2 (Forest Survey of India 2017). A total of 10 sites were sampled using camera traps in Kerala that yielded 3,709 photo-captures of 270 individual leopards (Fig. IV.5). The leopard population of the state was estimated at 570 (SE 76), depicting a decline in the leopard population as compared to 650 (SE 28) in 2018 (Jhala *et al.,* 2021). Approximately 63% of the leopard population of Kerala occur outside the Protected Areas of the state.

From 2018 to 2022, Periyar Tiger Reserves showed an increase in leopard population, while the Wayanad and Malayattoor regions experienced a significant decline in leopard population (Table IV.1). Further, Eravikulam National Park, Konni, Ranni and Vazhachal divisions exhibited consistently low leopard densities.

In Kerala, there is a surge in number of human-wildlife conflict cases from 6,022 in 2015-16 to 10,036 in 2021-22 (Issac *et al.,* 2022). There is a rise in incidents of cattle loss and human injury/death caused by leopards (Issac, *et al.,* 2022; Karthik, 2020). From 2013-14 to 2018-19, there were a total 547 reported incidents of human-leopard conflict. Total 173 incidents of livestock deaths or injuries (93 cattle, 2 buffalo, 78 goats) were caused by leopards (Kerala State Planning Board, 2022). Most conflict-prone areas were identified as Wayanad, Palakkad, Kannur, Calicut, Thrissur and Malappuram (Jhala *et al.,* 2021). From 2019-20 to 2021-22, most number of human-wildlife conflict incidents were from Wayanad North division, followed by Kannur division and Wayanad South division and the least number of incidents were from the Parambikulam division, followed by Periyar East division and Munnar Wildlife division (Issac *et al.,* 2022).

Table IV.1: *Sampling details and leopard density parameter estimates using spatially explicit capture mark recapture analysis in a likelihood framework for sites in Western Ghats 2022.*

State	Site	Model space (Km^2)	Camera points	M_{t+1}	Best fit model	$\hat{D}$ secr/ 100 km^2 (SE)	g0 Male (SE)	g0 Female (SE)	σ Male (SE) (km)	σ Female (SE) (km)	Pmix (M:F) (SE)
Goa	Bondla	NA	5	1	NA	NA	NA	NA	NA	NA	NA
Goa	Cotigao	NA	7	2	NA	NA	NA	NA	NA	NA	NA
Goa	Mhadei	418	32	14	σ ~(.), Pmix~(sex), g0~(.)	7.3 (2.31)	0.055 (0.016)		1.49 (0.21)		0.58:0.42 (0.18)
Goa	Mollem	NA	28	8	NA	NA	NA	NA	NA	NA	NA
Goa	Netravalli	NA	23	5	NA	NA	NA	NA	NA	NA	NA
Karnataka	Ballari	1581	46	30	σ ~(.), Pmix~(sex), g0~(.)	3.11 (0.64)	0.09 (0.02)		2.67 (0.28)		0.54:0.46 (0.1)
Karnataka	Bandipur TR	1928	612	131	σ ~(sex), Pmix~(sex), g0~(sex)	9.59 (0.85)	0.03 (0.001)	0.02 (0.001)	1.84 (0.05)	1.27 (0.07)	0.49:0.51 (0.05)
Karnataka	Bengaluru Rural	NA	48	8	NA	NA	NA	NA	NA	NA	NA
Karnataka	Banner-ghatta	513	83	30	σ ~(.), Pmix~(sex), g0~(.)	8.41 (1.56)	0.074 (0.008)		1.75 (0.09)		0.60:0.40 (0.10)
Karnataka	Belagavi	1860	107	41	σ ~(.), Pmix~(sex), g0~(.)	6.41 (1.44)	0.013 (0.004)		2.17 (0.27)		0.60:0.40 (0.12)
Karnataka	Bhadhravati	1786	120	46	σ ~(sex), Pmix~(sex), g0~(.)	5.0 (0.78)	0.05 (0.01)		2.92 (0.21)	1.61 (0.13)	0.35:0.65 (0.08)
Karnataka	Bhadra TR	1577	332	112	σ ~(sex), Pmix~(sex), g0~(sex)	11.31 (1.08)	0.036 (0.003)	0.015 (0.001)	2.03 (0.06)	1.77 (0.06)	0.31:0.69 (0.04)
Karnataka	BRT TR	1076	260	58	σ ~(sex), Pmix~(sex), g0~(sex)	8.47 (1.14)	0.02 (0.002)	0.011 (0.002)	2.34 (0.12)	1.6 (0.11)	0.29:0.71 (0.06)
Karnataka	Cauvery WLS	2344	448	65	σ ~(sex), Pmix~(sex), g0~(sex)	5.01 (0.68)	0.02 (0)	0.01 (0)	3.67 (0.19)	1.84 (0.15)	0.23:0.77 (0.05)
Karnataka	Chikmag-alur	793	44	12	σ ~(.), Pmix~(sex), g0~(.)	4.45 (1.98)	0.04 (0.02)		1.39 (0.35)		0.67:0.33 (0.27)
Karnataka	Davanagere	NA	19	1	NA	NA	NA	NA	NA	NA	NA
Karnataka	Dharwad	NA	26	9	NA	NA	NA	NA	NA	NA	NA
Karnataka	Haliyal	2487	104	27	σ ~(sex), Pmix~(sex), g0~(.)	4.08 (1.26)	0.03 (0.01)		2.97 (0.37)	1.14 (0.21)	0.16:0.84 (0.07)
Karnataka	Hassan	NA	11	1	NA	NA	NA	NA	NA	NA	NA
Karnataka	Haveri	NA	18	4	NA	NA	NA	NA	NA	NA	NA
Karnataka	Honnavar	1839	125	25	σ ~(.), Pmix~(sex), g0~(.)	2.77 (0.64)	0.035 (0.009)		1.67 (0.19)		0.73:0.27 (0.11)
Karnataka	Hunsur	NA	36	12	NA	NA	NA	NA	NA	NA	NA

State	Site	Model space (Km^2)	Camera points	M_{t+1}	Best fit model	$\hat{D}$ secr/ 100 km^2 (SE)	g0 Male (SE)	g0 Female (SE)	σ Male (SE) (km)	σ Female (SE) (km)	Pmix (M:F) (SE)
Karnataka	Kalburgi	NA	23	0	NA	NA	NA	NA	NA	NA	NA
Karnataka	Kali TR	3627	399	106	σ ~(sex), Pmix~(sex), g0~(.)	6.79 (0.71)	0.022 (0.002)		3.11 (0.13)	1.38 (0.07)	0.22:0.78 (0.04)
Karnataka	Karwar	1594	126	13	σ ~(.), Pmix~(sex), g0~(.)	1.18 (0.35)	0.13 (0.03)		1.28 (0.12)		0.86:0.14 (0.13)
Karnataka	Koppa	NA	49	6	NA	NA	NA	NA	NA	NA	NA
Karnataka	Kudremukh NP	3089	172	58	σ ~(.), Pmix~(sex), g0~(.)	3.8 (0.57)	0.023 (0.004)		2.35 (0.18)		0.58:0.42 (0.09)
Karnataka	Madikeri Territorial	1394	156	14	σ ~(.), Pmix~(sex), g0~(.)	4.4(1.9)	0.009 (0.005)		1.47(0.36)		0.37:0.63(0.17)
Karnataka	Madikeri WLD	1766	169	13	σ ~(.), Pmix~(sex), g0~(.)	2.58 (1.07)	0.01 (0.005)		1.71 (0.41)		0.57:0.43 (0.18)
Karnataka	Mangaluru	NA	57	4	NA	NA	NA	NA	NA	NA	NA
Karnataka	MM Hills	2340	415	51	σ ~(.), Pmix~(sex), g0~(.)	3.59 (0.51)	0.014 (0.002)		2.58 (0.12)		0.90:0.10 (0.06)
Karnataka	Mysore Territorial	NA	35	13	NA	NA	NA	NA	NA	NA	NA
Karnataka	Mysore WLS	174	30	12	σ ~(.), Pmix~(sex), g0~(.)	9.8 (2.98)	0.034 (0.009)		1.98 (0.34)		0.64:0.36 (0.14)
Karnataka	Nagarhole TR	1580	489	97	σ ~(sex), Pmix~(sex), g0~(.)	8.85 (0.91)	0.03 (0)		1.83 (0.06)	0.96 (0.04)	0.35:0.65 (0.05)
Karnataka	Ramanagara	NA	26	4	NA	NA	NA	NA	NA	NA	NA
Karnataka	Sagara	NA	51	7	NA	NA	NA	NA	NA	NA	NA
Karnataka	Shimoga Territorial	NA	38	4	NA	NA	NA	NA	NA	NA	NA
Karnataka	Shimoga WLD	2647	162	24	σ ~(sex), Pmix~(sex), g0~(.)	2.79 (0.66)	0.02 (0.004)		3.34 (0.46)	1.63 (0.23)	0.25:0.75 (0.11)
Karnataka	Sirsi	NA	101	4	NA	NA	NA	NA	NA	NA	NA
Karnataka	Tumkur	NA	24	13	NA	NA	NA	NA	NA	NA	NA
Karnataka	Virajpete	NA	100	2	NA	NA	NA	NA	NA	NA	NA
Karnataka	Yellapura	2722	95	17	σ ~(.), Pmix~(sex), g0~(.)	1.27 (0.39)	0.04 (0.01)		2.35 (0.41)		0.86:0.14 (0.13)
Kerala	Eravikulam NP	NA	28	1	NA	NA	NA	NA	NA	NA	NA
Kerala	Konni	NA	68	10	NA	NA	NA	NA	NA	NA	NA
Kerala	Malayatoor	NA	100	8	NA	NA	NA	NA	NA	NA	NA
Kerala	Parambiku-lam TR	NA	242	127	σ ~(sex), Pmix~(sex), g0~(sex)	13.33 (1.2)	0.07 (0)	0.02 (0)	1.76 (0.04)	1.39 (0.05)	0.33:0.67 (0.04)
Kerala	Periyar TR	2040	396	62	σ ~(.), Pmix~(sex), g0~(.)	7.19 (1.1)	0.01 (0)		2.05 (0.17)		0.85:0.15 (0.07)

State	Site	Model space (Km^2)	Camera points	M_{t+1}	Best fit model	$\hat{D}$ secr/ 100 km^2 (SE)	g0 Male (SE)	g0 Female (SE)	σ Male (SE) (km)	σ Female (SE) (km)	Pmix (M:F) (SE)
Kerala	Ranni	NA	82	5	NA	NA	NA	NA	NA	NA	NA
Kerala	Silent Valley Landscape	1291	86	12	σ ~(.), Pmix~(sex), g0~(.)	2.56 (0.96)	0.011 (0.005)		2.15 (0.43)		0.50:0.50 (0.25)
Kerala	Thattekad	NA	11	0	NA	NA	NA	NA	NA	NA	NA
Kerala	Vazhachal	NA	19	2	NA	NA	NA	NA	NA	NA	NA
Kerala	Wayanad Landscape	2280	281	43	σ ~(.), Pmix~(sex), g0~(.)	4.02 (0.71)	0.003 (0.001)		2.5 (0.13)		0.50:0.50 (0.09)
Tamil Nadu	Anamalai TR	2401	496	95	σ ~(sex), Pmix~(sex), g0~(sex)	15.32 (2.99)	0.014 (0.002)	0.004 (0.001)	2.01 (0.13)	1.21 (0.16)	0.12:0.88 (0.03)
Tamil Nadu	Coimbatore	1172	111	32	σ ~(.), Pmix~(sex), g0~(.)	4.7 (0.94)	0.035 (0.008)		1.73 (0.16)		0.69:0.29 (0.10)
Tamil Nadu	Erode	1537	368	63	σ ~(sex), Pmix~(sex), g0~(sex)	6.52 (0.84)	0.02 (0.002)	0.01 (0.002)	2.25 (0.11)	1.64 (0.12)	0.38:0.62 (0.07)
Tamil Nadu	Gudalur	720	80	39	σ ~(.), Pmix~(sex), g0~(.)	11.9 (2.32)	0.023 (0.005)		1.22 (0.13)		0.57:0.43 (0.11)
Tamil Nadu	Kalakad Mundan-thurai TR	1558	228	48	σ ~(sex), Pmix~(sex), g0~(.)	5.61 (0.87)	0.012 (0.002)		2.43 (0.17)	1.46 (0.15)	0.37:0.63 (0.08)
Tamil Nadu	Kanyaku-mari	NA	105	5	NA	NA	NA	NA	NA	NA	NA
Tamil Nadu	Kodaikanal	560	97	12	σ ~(.), Pmix~(sex), g0~(.)	5.13 (1.63)	0.012 (0.004)		1.53 (0.22)		0.33:0.67 (0.19)
Tamil Nadu	Mudumalai TR	1903	394	120	σ ~(sex), Pmix~(sex), g0~(sex)	11.56 (1.08)	0.027 (0.002)	0.018 (0.003)	2.11 (0.07)	1.04 (0.06)	0.30:0.70 (0.04)
Tamil Nadu	Mukurthy NP	685	50	9	NA	NA	NA	NA	NA	NA	NA
Tamil Nadu	Nellai	975	80	19	σ ~(.), Pmix~(sex), g0~(sex)	3.35 (0.81)	0.008 (0.002)	0.039 (0.014)	3.12 (0.27)		0.76:0.24 (0.09)
Tamil Nadu	Nilgiri	2133	328	121	σ ~(sex), Pmix~(sex), g0~(sex)	13.14 (1.39)	0.201 (0.43)	0.028 (0.005)	1.88 (0.1)	0.79 (0.06)	0.30:0.70 (0.05)
Tamil Nadu	Sathyaman-galam TR	2700	704	103	σ ~(sex), Pmix~(sex), g0~(.)	7.05 (0.75)	0.011 (0.001)		2.62 (0.11)	1.2 (0.07)	0.30:0.70 (0.04)
Tamil Nadu	Srivil-liputhur	1219	264	44	σ ~(sex), Pmix~(sex), g0~(.)	6.42 (1.03)	0.01 (0)		2.35 (0.19)	1.74 (0.18)	0.45:0.55 (0.11)
Tamil Nadu	Meghamalai	1490	344	39	σ ~(.), Pmix~(sex), g0~(.)	4.63 (0.77)	0.01 (0)		1.97 (0.14)		0.5:0.5 (0.11)

SE: *Standard error, D^SECR: Density estimate from Maximum Likelihood based spatially explicit capture recapture, σ : Spatial scale of detection function, g0: Magnitude (intercept) of detection function, Pmix: Detection corrected estimate of proportion of female and male*

Conservation Implications

The leopard is the most widely distributed large carnivore in the Western Ghats landscape, and involved in the most of the large carnivore-human conflict cases. The leopard populations in the Western Ghats landscape are facing the wrath of rapid development, habitat loss, and retaliatory killing by humans. Although the latest figures of the leopard population estimates depicted slight increase in the landscape, local declines were observed in some of the strongholds (e.g., Wayanad). It is crucial to investigate the population status and collate further information on poaching, human-leopard conflict, and status of co-predators to understand population dynamics of leopards and make appropriate and timely conservation interventions. Studies focused on land-tenure systems of leopards (involving radio-telemetry) and demographic parameters of leopards from different parts of the landscape will provide valuable insights into the lesser known aspects of species ecology, thus help making knowledge-based conservation actions.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V: North East Hills and Brahmaputra Flood Plains

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North East Hills and Brahmaputra Flood Plains

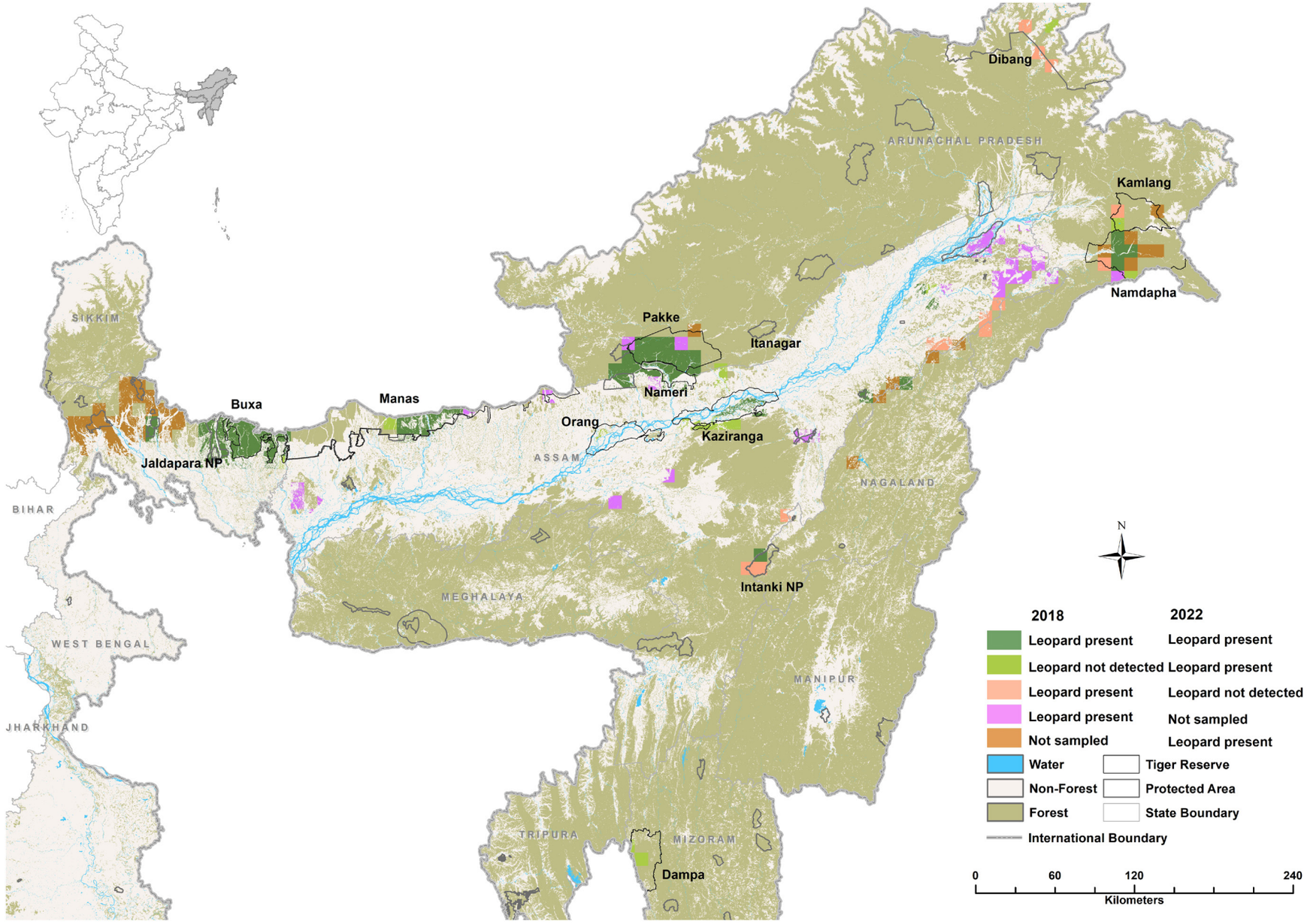
Eastern Himalaya and its foothills including the north Bengal *Dooars*, and fertile floodplains of Brahmaputra and Barak along with north east Hills act as Indo-Malayan biodiversity hotspot and home to several endangered and endemic faunas. However, due to geo-political and developmental reasons, this landscape undergone several land-use changes which led to sever loss of natural habitats across the landscape (Jhala *et al.,* 2020).

Leopards are present across the entire landscape, however, in this report estimate of leopard is limited to the sampled forested area only. Spread of phase I sampling was sparse in Arunachal Pradesh, Assam and Mizoram and restricted mostly in the Tiger Reserve. The entire landscape is mosaic of forested habitat, agriculture and plantations, and several other human land use features thus provide excellent cover for leopards which are quite adaptable with regards to their habitat preference and dietary need (Jhala *et al.,* 2021) and often found in areas bordering human dominated habitats. This causes significant human leopard conflict in this landscape (Marker and Sivamani 2009, Bhattacharjee and Parthasarathy 2013, Kshettry *et al.,* 2017, Naha *et al.,* 2018). Despite being present all across the landscape, leopards are least studied species in the landscape and there are very few studies available on population estimates of leopards since last decade (Jhala *et al.,* 2021). Jhala *et al.,* 2021 published the baseline population estimates of leopard at landscape and individual site level, however, this too was a snapshot of the population of leopard in this landscape.

Leopard occupancy, population extent and abundance

Leopard signs are recorded from north Bengal *Dooars*, Assam, Arunachal Pradesh, Mizoram and Nagaland. However, except north Bengal *Dooars* where Phase I sampling was carried out outside Protected Areas as well, leopard signs obtained are very sporadic in other states owing to the poor Phase I sampling. In Assam, especially in upper Assam and areas like Karbi-Anglong and western Assam where

Fig V.1: *Change in leopard distribution in North East Hills and Brahmaputra Flood Plains landscape from 2018 to 2022.*



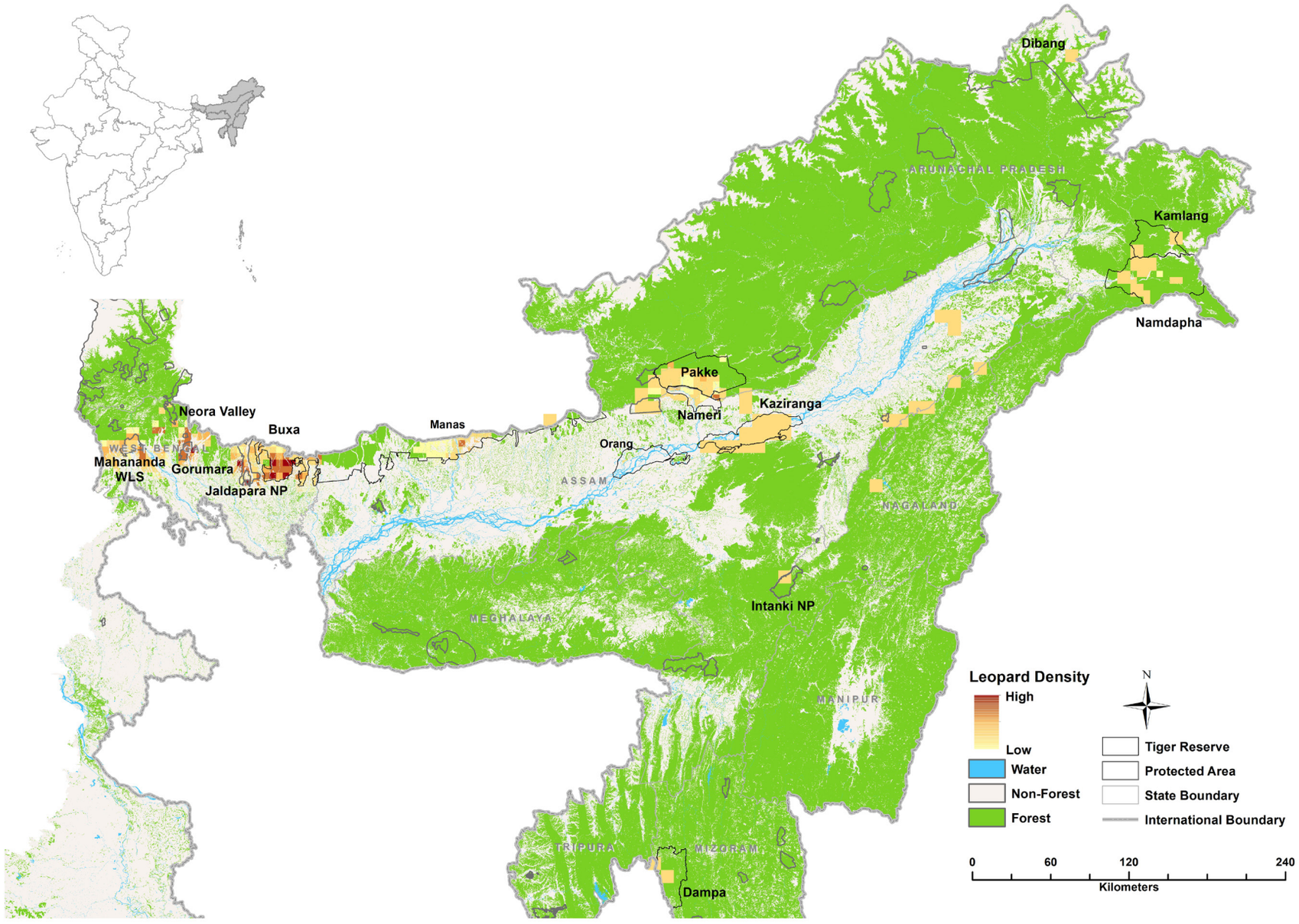


Figure V.2: *Leopard distribution and density for North East Hills and Brahmaputra Flood Plains landscape, 2022.*

leopards were detected in 2018 had not been sampled in 2022 (Fig. V.1).There is an increase in sampling effort in north Bengal *Dooars*, Arunachal Pradesh and Nagaland.

A total of 250 cells (100 km^2) were sampled in 2022 in this landscape, out of which leopard presence were recorded from 53%(133) cells. Almost one third of the total cells in 2022 were not sampled in 2018 and have recorded leopard presence in 2022 (Fig. V.1).

A total of 15 sites in this landscape were sampled using camera trap based mark- recapture method, and leopard images were obtained from 11 sites. Due to inadequate spatial and temporal photo-captures, density estimates could not be assessed for Namdapha Tiger Reserve of Arunachal Pradesh, Neora valley National Park and Mahananda Wildlife Sanctuary of West Bengal. Phase I sampling in Arunachal Pradesh was restricted mainly to Tiger Reserves, thus leopard density could not be extrapolated outside Tiger Reserves in the states (Table V.1). In addition, we could not estimate leopard population for Nagaland and Mizoram as no leopard positive scat and/ or leopard images were obtained from these two states.

The leopard population of this landscape was estimated to be 349 (SE 42) as compared to 141 (SE 26) in 2018. 228 individual leopards were identified from 4614 photo-captures. The increase in the population estimate is mainly because of sampling artefact, as Phase I and III sampling effort increased significantly in north Bengal *Dooars* in 2022. The figure V.2 depicts leopard density in the landscape, however, in Nagaland, Mizoram and parts of Arunachal Pradesh and Assam the low density represents only the presence of leopard signs in sampled forested areas.

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Arunachal Pradesh

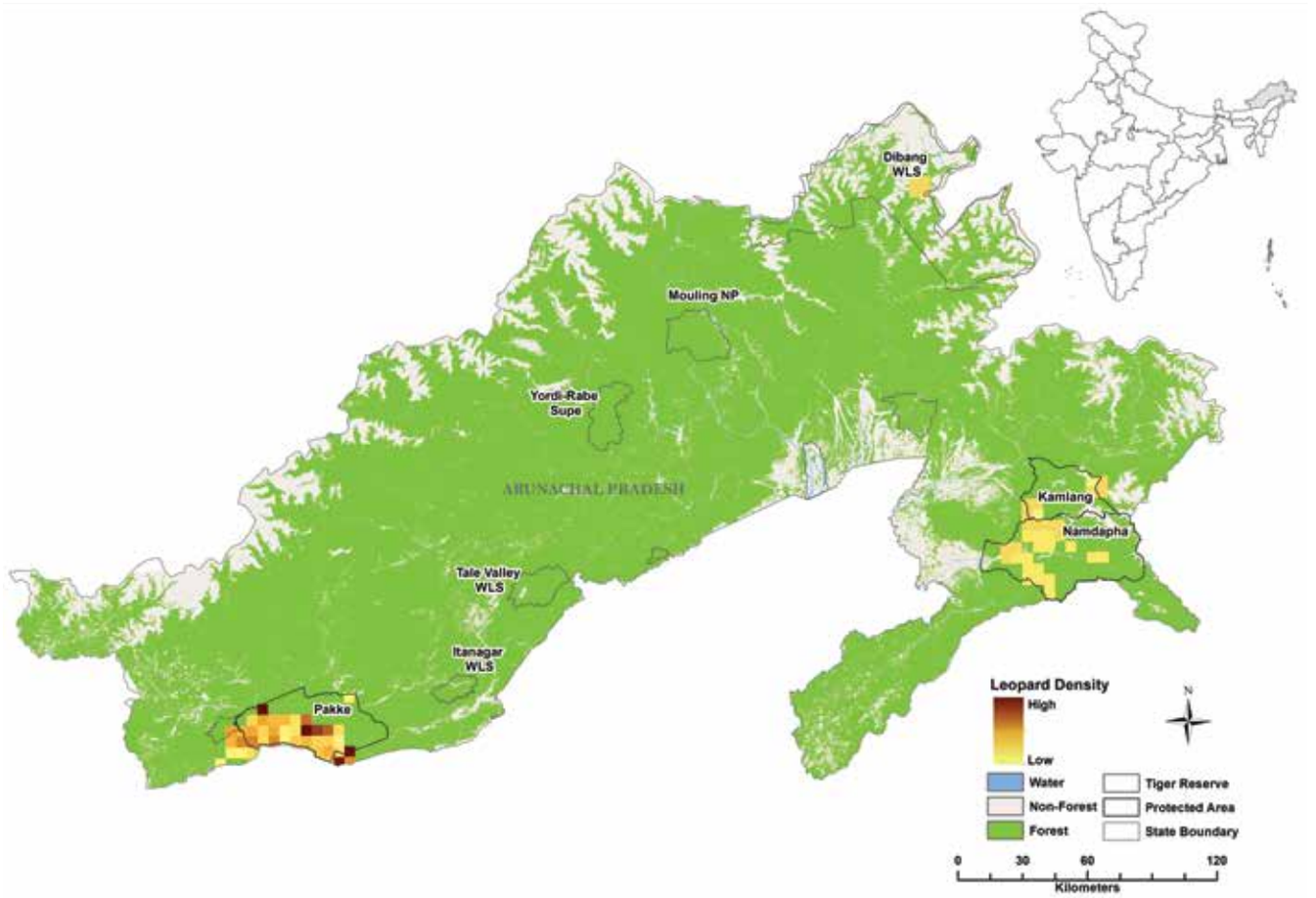

Fig V.3:
Leopard distribution and density for Arunachal Pradesh, 2022.

Camera trap based mark recapture sampling was done in four sites in the state namely Kamlang, Namdapha and Pakke Tiger Reserves and Dibang Wildlife Sanctuary. However, leopard images were obtained only from Namdapha and Pakke Tiger Reserves. Leopard presence was not confirmed from Kamlang and Dibang, either from camera trap or through scat DNA.

News report of a straying leopard being rescued from Wakro town in Lohit district adjacent to Kamlang Tiger Reserve in 2022 (The Arunachal Times, 2022) suggests the presence of the leopard around Kamlang Tiger Reserve.

A total of 41 individual leopards were identified from 796 photo-captures in Arunachal Pradesh of which four leopards were common between Arunachal Pradesh (Pakke Tiger Reserve) and Assam (Nameri Tiger Reserve). Estimated leopard population of Arunachal Pradesh was 42 (SE 10) which is an underestimation as leopard population was estimated only from the camera-trapped sites. There is a substantial increase in the population density of leopards in Pakke since 2018 (Jhala *et al.,* 2021) (Table V.1).

Moderate to high density of leopards can be observed in Pakke Tiger Reserve. As several developmental projects are coming up in Arunachal Pradesh (Qureshi *et al.,* 2013), there is an urgent need of sampling outside Tiger Reserves in the state to understand the spatial extent and abundance of leopards and other wildlife.

Assam

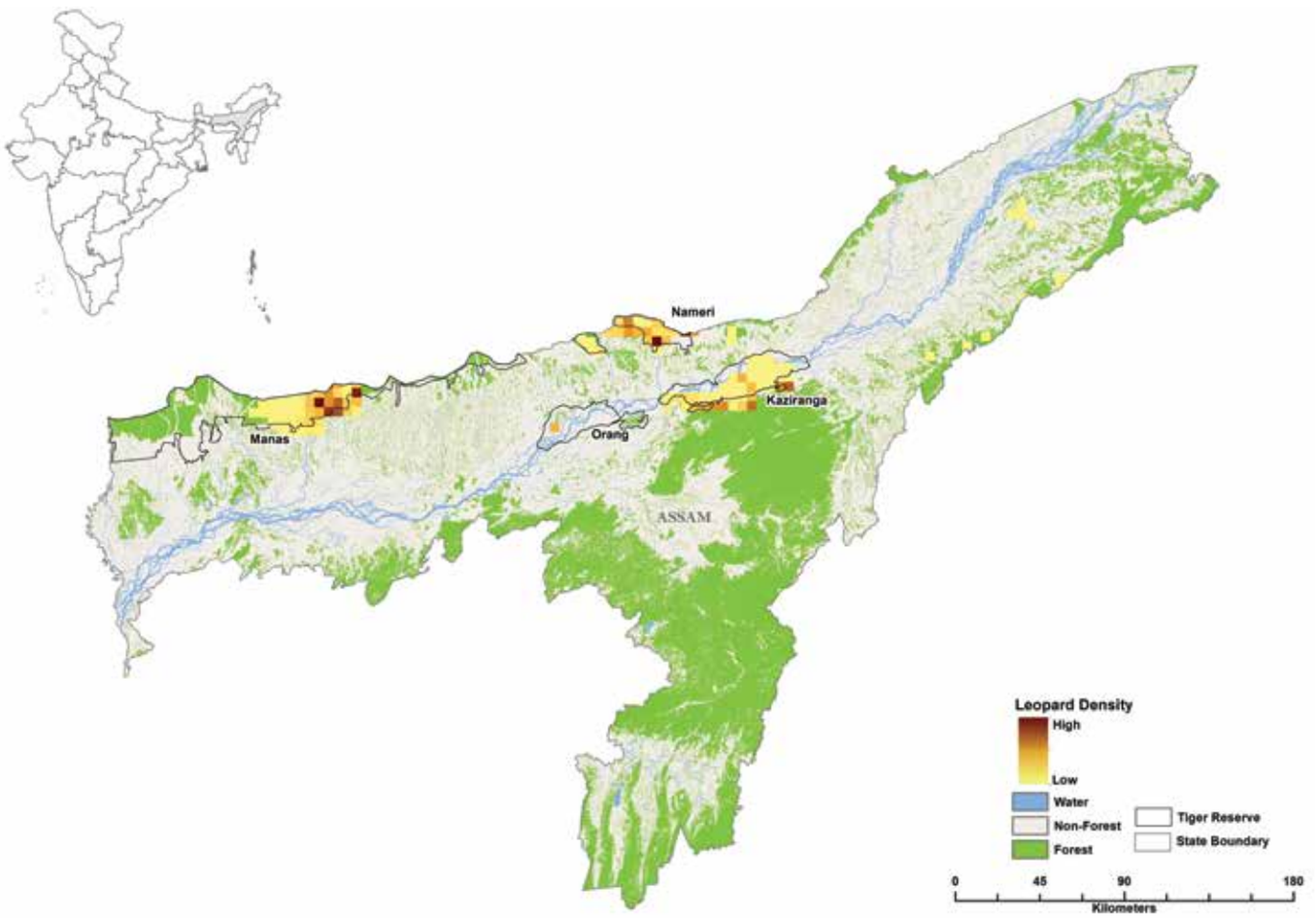

Figure V.4:
Leopard distribution and density for Assam, 2022.

Five sites were camera trapped in using mark-recapture framework in the state (Table V.1) and only one site (Nagaon Wildlife Division) had no leopard photo-capture. A total of 726 photo-captures yielded 62 individual leopards and leopard population was estimated at 74 (SE 11). Four leopards of Nameri Tiger Reserve were common with neighbouring Pakke Tiger Reserve in Arunachal Pradesh. An individual leopard was photo-captured from Orang Tiger Reserve for the very first time (Table V.1). Population estimate of leopards is certainly an underestimation, as being an adaptable feline, leopards are reported from almost every corner of the state. In addition, studies have reported presence of leopard from Raimona National Park and Ripu Reserve Forest of western Assam (Nath *et al.,* 2021, Nath *et al.,* 2023) where Phase I and III sampling was not carried out. The entire Manas- Buxa-Royal Manas complex acts as a single population block thus maintaining habitat integrity in this complex is crucial. Low to moderate density of leopards can be observed in sampled forests of Assam, with few parts of Manas and Kaziranga having high density. Population estimate of leopards is limited to the Tiger Reserves, and leopard density could not be extrapolated in the state owing to the extremely poor sampling spread of Phase I. Many of the forest divisions in upper Assam, western Assam and areas of Karbi Anglong where leopard presence was recorded earlier in 2018, were not sampled in 2022. Although, leopards are recorded from most parts of the state, only a few studies have been carried out to assess the status and spatial extent of leopard (Bora *et al.,* 2013, Harihar *et al.,* 2020, Jhala *et al.,* 2021). Density of leopard in Kaziranga, Manas and Nameri remain stable in comparison to 2018 (Jhala *et al.,* 2021) (Table V.1).

Due to the habitat being a mosaic of forests, tea plantations and agricultural lands which serve as excellent cover for leopards, growing human leopard conflict is a major concern towards conservation of leopard in the state. In addition, increased traffic in several state and national highways also causes mortality of leopards in the state. However, a thorough Phase I sampling in the forested habitat of the state along with camera trapping exercise in Protected Areas are essential to identify the spatial extent and status of the leopard in the state. This would also help wildlife managers and policy makers to plan and mitigate negative human leopard interaction in the state.

West Bengal (North Bengal *Dooars*)

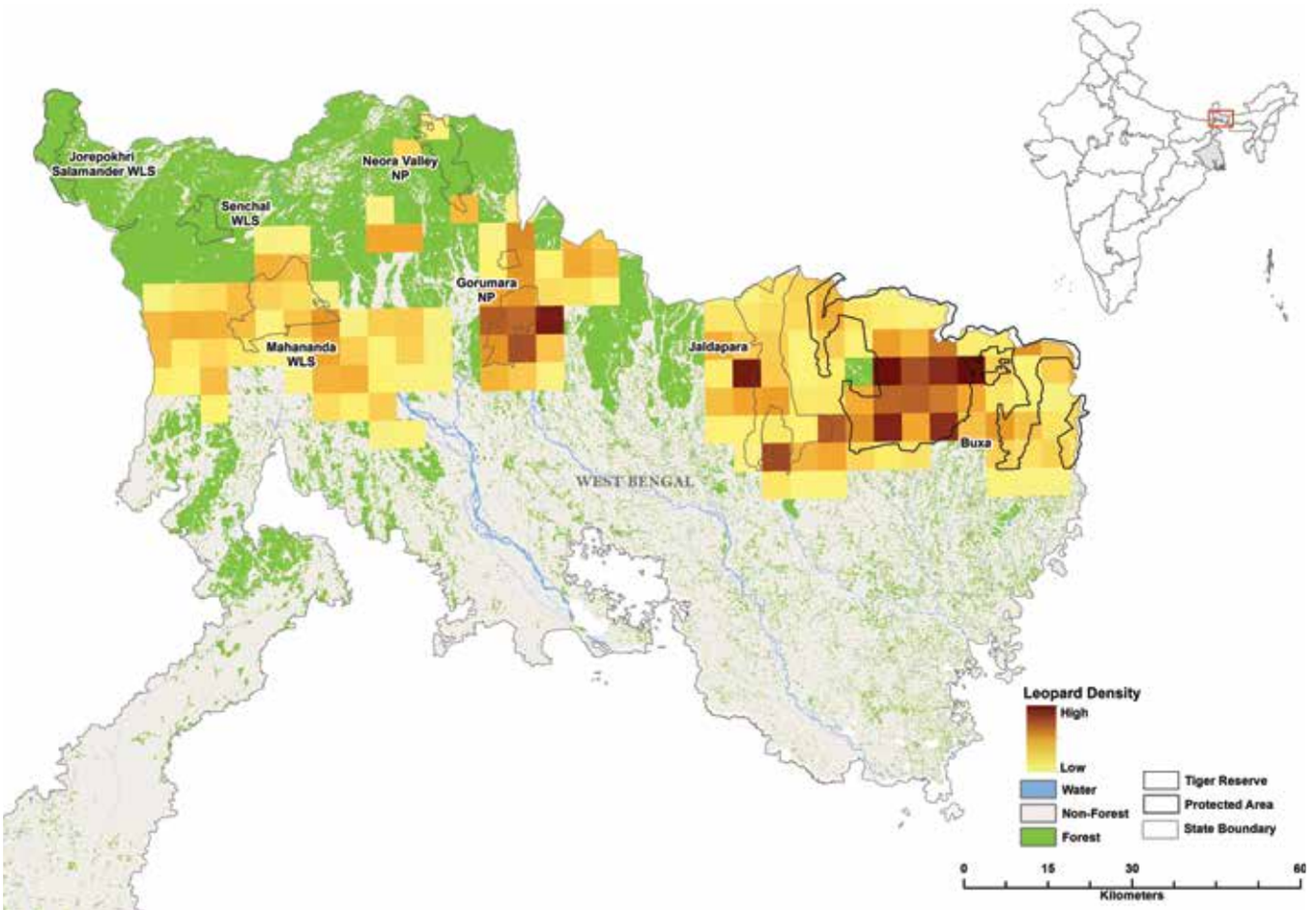

Fig V.5:

Leopard distribution and density for West Bengal (North Bengal Dooars), 2022.

North Bengal *Dooars* is an extension of Indo-Gangetic alluvial floodplains and situated along the foothills of eastern Himalayas. For the very first time, an extensive area including forested habitats outside Protected Areas in this landscape have been systematically sampled to collect Phase I data. In addition, a total of five sites were sampled in camera trap based mark- recapture framework and leopard photo-captures were recorded in all the sites (Table V.1). A total of 3,092 photo-captures of leopard yielded 129 individuals. However, due to low detection and inadequate spatial and temporal photo-captures of individual leopards in Neora valley National Park and Mahananda Wildlife Sanctuary, Spatially Explicit Capture Recapture (SECR) based density estimates was not possible.

Despite leopard being present across north Bengal *Dooars*, there are only two studies (Borthakur *et al.,* 2021, Jhala *et al.,*2021) available, which have reported the status of leopard population in north Bengal *Dooars*. As per Borthakur *et al.,* 2021, population of leopard was estimated at 111 obtained from scat based DNA sampling in north Bengal *Dooars*, whereas Jhala *et al.,* 2021 provided a snapshot of baseline data from mark-recapture based camera trap data obtained from three Protected Areas namely Buxa Tiger Reserve, Gorumara and Jaldapara National Parks. Leopard population of north Bengal *Dooars* estimated at 233 (SE 21) which is more than two fold as compared to 2018 (Jhala *et al.,* 2021) (Table I.3) . However, this could be an artefact of sampling, as the sampling effort has increased and Phase I data was collected outside the camera trap sites as well, which was not the case in earlier cycles. Leopard signs have been obtained from areas which were not sampled in 2018. Density estimates of leopard remained stable for Jaldapara National Park (Table V.1), however, there was a substantial increase in leopard population and density estimates of Buxa Tiger Reserve and Gorumara National Park as compared to 2018 (Jhala *et al.,* 2021) (Fig V.1).

Like Assam, large forested tracks of north Bengal *Dooars* had been exploited during colonial era for cultivation tea and revenue generation by timber extraction. Majority of the human population living in tea estates are marginal workers brought from Chotanagpur plateau region during colonial period and rear livestock for livelihood. This has resulted in fragmentation of natural habitats situated in the mosaic of tea gardens and several other human land use features. Leopards, however, with a flexible and broader niche and dietary preference have adapted in this fragmented landscape as the mosaic habitat characteristics provide ample cover for leopards. With increasing human

West Bengal (North Bengal *Dooars*)

population, human leopard conflict in the landscape has escalated and acts as major challenge for conservation of leopard in north Bengal *Dooars* (Vyas and Sengupta 2014). A study by Naha *et al.,* 2018 reported that 97% of human injuries are resulted by leopard attack in North Bengal as compared to 60% in Pauri Garhwal district of Uttarakhand. Much of the literature from north Bengal *Dooars* addressed human leopard conflict, dietary preference, and niche preference (Kshettry *et al.,* 2017, Kshettry *et al.,* 2018, Naha *et al.,* 2018, Naha *et al.,* 2020, Naha *et al.,* 2021, Borthakur *et al.,* 2021). Major portion of the diet (~65%) of leopards in north Bengal *Dooars* comprised of livestock which complement wild prey species (Borthakur *et al.,* 2021, Kshettry 2023) and have higher livestock depredation risk (Naha *et al.,* 2020).

North Bengal *Dooars* are connecting link to the peninsular India (Qureshi *et al.,* 2023) and hence numerous linear infrastructures traverse north Bengal *Dooars* to maintain geo-political integrity with neighbouring countries, which further complicates the scenario of leopard conservation in this landscape. Especially, National Highway NH31 and railway line between Siliguri- Alipurduar junctions cuts across many forested areas and at least three Protected Areas (Mukherjee *et al.,* 2019) and leads to accidents with many wild animals and which need appropriate mitigation measures. An active management plan with community perspectives should be prepared to minimize human-leopard conflict in north Bengal *Dooars.*

Conservation Implications

Although there is an increase in leopard population in this landscape as compared to earlier cycles. Majority of leopard population is recorded from north Bengal *Dooars,* which was due to increased sampling effort. Due to extremely low abundance of tiger (Qureshi *et al.,* 2023), leopard serve as apex predator in the Protected Areas of north Bengal *Dooars*. Leopard density in North East Hills and Brahmaputra Flood Plains landscape varies from 1.94 (SE 0.53) leopards/ 100 km^2 in Kaziranga Tiger Reserve of Assam to 15.12 (SE 2.75) leopards/ 100 km^2 in Gorumara National Park of West Bengal (Table V.1). Also, for the very first time a leopard was photo-captured in Orang Tiger Reserve. Arunachal Pradesh also has recorded increase in leopard population in sampled area (Jhala *et al.,* 2021). Kamlang Tiger Reserve has not recorded any leopard in current cycle of All India Tiger Estimation 2022. Leopard presence was also not confirmed from Dampa Tiger Reserve (Mizoram) from either camera trap image or scat. A thorough sampling throughout these Tiger Reserves is crucial to understand the status and spatial extent of large carnivores. North Bengal *Dooars* is situated amidst mosaic of human land-use patterns and forested patches, managerial efforts are needed to carefully execute the process to minimize human- leopard conflict.

Buxa Tiger Reserve is preparing for ambitious tiger re-introduction program, and with its growing population of leopards this should be taken up with caution. Since Buxa harbours low abundance of wild prey species (Jhala *et al.,* 2020), stocking of wild prey and prey augmentation procedures should take into account other large carnivores of this area.

This report, however, provides an extended baseline information of status of leopards in this landscape. In addition, systematic and thorough sampling for covariates through Phase I survey in the floodplains and foothills of eastern Himalayas and camera trapping and/ or scat collection in the North Eastern hills are crucial to identify conservation priority areas and to mitigate negative human leopard interactions.

Table V.1: *Sampling details and leopard density parameter estimates using spatially explicit capture mark recapture analysis in a likelihood framework for sites in the North East Hills and Brahmaputra Flood Plains landscape, 2022.*

State	Site	Model Space (km^2)	Camera traps	M_{t+1}	Best Fit Model	$\hat{D}$ secr/ 100 km^2 (SE)	g0 Female (SE)	g0 Male(SE)	σ Female (SE) (km)	σ Male (SE)(km)	Pmix (SE)
Arunachal Pradesh	Namdapha TR	NA	117	5	NA	NA	NA	NA	NA	NA	NA
Arunachal Pradesh	Pakke TR	1040	135	36	σ ~(.), Pmix~(sex), g0~(.)	4.2 (0.7)	0.03 (0.003)		2.55 (0.11)		0.40:0.60 (0.1)
Assam	Nameri TR	579	73	12	σ ~(.), Pmix~(sex), g0~(.)	2.66 (0.8)	0.03 (0.003)		2.55 (0.11)		0.20:0.80 (0.1)
Assam	Orang TR	NA	39	1	NA	NA	NA	NA	NA	NA	NA
Assam	Kaziranga TR	747	230	14	σ ~(.), Pmix~(sex), g0~(.)	1.94 (0.5)	0.005 (0.001)		4.53 (0.34)		0.70: 0.30 (0.1)
Assam	Manas TR	1052	267	35	σ ~(sex), Pmix~ (sex), g0~(sex)	4.19 (0.7)	0.006 (0.001)	0.02 (0.002)	2.21 (0.19)	2.87 (0.18)	0.70:0.30 (0.1)
West Bengal	Buxa TR	802	162	61	σ ~(.), Pmix~(sex), g0~(.)	9.17 (1.2)	0.03 (0.002)		2.01 (0.06)		0.60:0.40 (0.1)
West Bengal	Jaldapara NP	345	75	30	σ ~(.), Pmix~(sex), g0~(.)	13.84 (2.8)	0.02 (0.005)		1.13 (0.12)		0.50:0.50 (0.1)
West Bengal	Gorumara NP	217	49	31	σ ~(.), Pmix~(sex), g0~(.)	15.12 (2.8)	0.04 (0.004)		1.96 (0.1)		0.40: 0.60 (0.1)
West Bengal	Neora Valley NP	NA	21	1	NA	NA	NA	NA	NA	NA	NA
West Bengal	Mahananda WLS	NA	22	6	NA	NA	NA	NA	NA	NA	NA

SE: *Standard error, D`SECR: Density estimate from Maximum Likelihood based spatially explicit capture recapture,: Spatial scale of detection function, g0: Magnitude (intercept) of detection function, Pmix: Detection corrected estimate of proportion of female and male*

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Annexure I

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10	Madhya Pradesh	Sh. Alok Kumar, Sh. J.S. Chouhan
11	Maharashtra	Sh Mahip Gupta, Sh. Sunil Limaye
12	Mizoram	Sh. PI Lalrammawii Sailo
13	Nagaland	Sh. Ved Pal, Sh. Satya Prakash Tripathi
14	Odisha	Sh. S. K. Popli, Sh. Shashi Paul
15	Rajasthan	Sh. Arindam Tomar, Sh. M.L Meena
16	Tamil Nadu	Sh. Syed Muzammil Abbas, Sh. Shekhar Kumar Niraj, Sh. Srinivas R Reddy
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Annexure II

Across the country, five major workshops were held, while an additional 70 workshops were conducted online. Moreover, 35 training sessions took place in various states. States have further conducted workshops in their Protected Areas and divisions.

List of Training of Trainers Workshops

Date of Workshop	Venue of the Workshop	Participating States	Approximate number of personnel trained
August 06 - 08, 2021	Mudumalai Tiger Reserve, Tamil Nadu	Andhra Pradesh, Goa, Karnataka, Kerala, Tamil Nadu, Telangana	112
August 12 - 14, 2021	Ranthambore Tiger Reserve, Rajasthan	Chhattisgarh, Madhya Pradesh, Maharashtra, Odisha, Rajasthan	105
August 25 -27, 2021	Rajaji Tiger Reserve, Uttarakhand	Bihar, Uttar Pradesh, Uttarakhand, Jharkhand	80
September 02 - 04, 2021	Manas Tiger Reserve, Assam	West Bengal (North), Assam, Mizoram, Meghalaya, Nagaland, Arunachal Pradesh	96
November 02 - 04, 2021	Sundarbans Tiger Reserve, West Bengal	Staff of Sundarbans of India and Bhitarkanika NP (Odisha)	62

Annexure III

Contribution is based on work done for field sampling, data analysis supervision, and writing up; The WII team names are in no particular order; the data presented belongs to the NTCA, WII, and State Forest Departments according to the respective MoU's;

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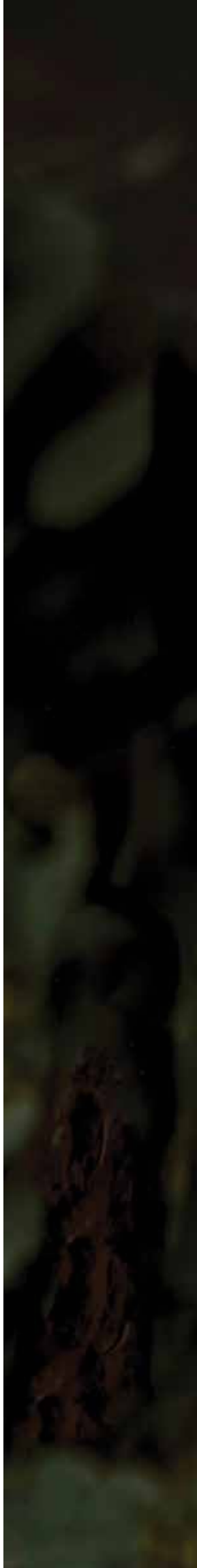

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